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Functional diversification and GVC exposure: Evidence and implications

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ABSTRACT

This work examines the links between the diversification of economies across value chain functions and their exposure to disruptions in global value chains (GVCs). We empirically model this relationship by combining new indicators of GVC exposure with an FDI-based measure of functional diversification for a wide range of countries and industries in 2003–2018. Our results show that greater functional diversification lowers GVC exposure on average, at both the country and industry levels. However, this negative relationship holds for Scale-intensive and Supplier-dominated industries, not for Science-based and Specialized supplier industries. This seems consistent with the greater need for the latter types of industries to rely on global sourcing of specific components and knowledge assets located abroad. Our findings are robust to the inclusion of several control factors and confirmed by System-GMM model estimates accounting for potential endogeneity concerns. Accordingly, industrial policies aimed at expanding the array of value chain functions should be complemented by a careful selection of global partners for the supply of key inputs and tailored to the specific needs of different industries.

1. Introduction

The international fragmentation of production has led to the geographical dispersion of value chain activities on a global scale for the realization of goods and services (Feenstra, 1998; Timmer et al., 2014). While this process has reshaped the international division of labor and opened up new industrialization opportunities (UNCTAD, 2013; Landesmann and Stöllinger, 2019), it has also led to greater inter-dependencies across world economies. As a result, countries and regions have become increasingly exposed to the risks of global interruptions in access to critical intermediate inputs, components, as well as know-how (Van Cauwenberge et al., 2019; Schwellnus et al., 2023).

The increasing reliance on Chinese and Southeast Asian economies for an ever-widening range of components and materials has become a growing source of concern in advanced economies since the turn of the century. This has sparked a lively discussion on dependencies in global value chains (GVCs) and on the potential advantages associated with reshoring strategies (see, e.g., Panwar, 2010; Shih, 2014; Bontadini et al., 2023). More recent disruptive events like the outbreak of the COVID-19 pandemic (Coveri et al., 2020; Giammetti et al., 2020; Villani and Fana, 2021), the Russian invasion of Ukraine (Astrov et al., 2022; Sturm, 2022), the ongoing US-China trade war (Fajgelbaum et al., 2024; Baldwin, 2025), recurring conflicts in the Middle East, as well as the emerging tensions in the US-EU trade relations, have definitively placed the evolving configuration and vulnerability of GVCs at the center of academic and political debate (see, e.g., Javorcik, 2020; Miroudot, 2020).

Several recent studies have highlighted the dual role of GVCs in both transmitting economic shocks from specific regions where key suppliers are concentrated and mitigating supply shortages when domestic value chains are disrupted (Boehm et al., 2019; Van Cauwenberge et al., 2019; Bonadio et al., 2021; Carvalho et al., 2021;

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Espitia et al., 2022; Yu et al., 2023). Consistently, Borin et al. (2021) found that the involvement in GVCs reduces exposure to domestic shocks while increasing vulnerability to global shocks.[1]

In response to these challenges, there has been growing interest in policies aimed at increasing “strategic autonomy” in Europe and other regions. This strategy involves promoting self-reliance and control over key industries and technologies at the macro-regional level while selectively internationalizing through friend-shoring and regionalization of value chains (European Commission, 2022; Amighini et al., 2023). This policy approach emphasizes a combination of enhanced production capacity in critical sectors with the development of less risky, and more resilient supply chains (CSC, 2023; Giovannetti et al., 2023). What remains underexplored is whether and how a strong and diversified production capacity can translate into a lower fragility of GVCs. In this regard, previous research has focused mainly on how economies can improve their capacity to respond to adverse shocks by diversifying either the industry structure or the geographical sources of input supply (e.g., Brown and Greenbaum, 2017; Todo et al., 2023). However, extant literature has largely disregarded the conceptual and empirical analysis of the links between the *functional diversification* of economies and their exposure to disruptive events that might undermine their involvement in global production networks. This paper aims to fill this research gap. Our contribution in this respect is twofold.

First, we argue that the emergence and evolution of GVCs induces a deep reconsideration of the nature itself of diversification. Indeed, the issue at stake is not only, and not so much, the degree of diversification of economies at the product or industry level, namely sectoral diversification. It is rather a matter of diversifying into a broader set of *value chain functions* within individual industries (Kruse et al., 2023), namely functional diversification. This shifts the focus toward the strategic importance of value-adding functions – such as R&D, production, and logistics – within GVCs.

Second, we suggest that functional diversification is likely to affect the reliance of economies on foreign inputs and their exposure to supply chain disruptions. As we shall argue, there are important partially countervailing effects that functional diversification may have on GVC exposure. On the one hand, functionally diversified economies are likely to exhibit a greater bundle of domestic capabilities, as well as a higher capacity to select foreign suppliers and innovatively respond to disruptive events, hence reducing the need for foreign inputs. On the other hand, they may be better at managing the risk associated with sudden changes in supply chains, hence enabling them to cope with – and even benefit from – high foreign input reliance. These effects may be hard to disentangle, and an exploratory effort is needed. Hence, this paper will focus on the following research question: *How does functional diversification of economies affect their exposure to GVC disruptions?*

We empirically model this link by combining new indicators on the GVC exposure for a large array of countries and industries with high-quality data on Foreign Direct Investment (FDI) indicating the value chain activities they are intended to perform over the 2003–2018 period.

Our findings show a robust negative relationship between our indicator of functional diversification in FDI and GVC exposure – the latter measured by the Foreign Input Reliance (FIR) indicator – consistent with the idea that maintaining and expanding the capabilities for performing a broader set of value-adding activities help reduce the overall exposure to GVC disruptions.

At the industry level, using Pavitt classes to group sectors according to their structure and innovation propensity, we observe some heterogeneity in the association between functional diversification in FDI and GVC exposure. In fact, while the negative relationship does hold for Scale-intensive (SI) and Supplier-dominated (SD) industries, which constitute the industrial base for many middle-as well as high-income countries, our findings are more nuanced in the case of other sectors. For instance, Science-based (SB) industries exhibit a rigid demand for global knowledge sources and intangible assets which can hardly be substituted for, even in the presence of high functional diversification efforts undertaken by individual countries. In the case of Specialized supplier (SS) industries, which focus on capital goods and specialized equipment, a key competitive asset consists in the ability to creatively combine commodity-like components that can be accessed in international markets. Accordingly, FIR can hardly be reduced by additional capacities in R&D, logistics or marketing in these industries.

The remainder of this work is organized as follows. Section 2 discusses the distinction between sectoral and functional diversification, develops our conceptual framework and derives the main research question addressed in this paper. Section 3 describes the data used in this work, while Section 4 offers descriptive evidence on the main variables under investigation. Section 5 outlines our empirical modelling strategy and Section 6 shows the results of the empirical analysis. The last section concludes by drawing policy implications and discussing the limitations to be addressed in future research.

2. Background literature and research question

Our key argument is that the degree of diversification of economies is likely to affect their exposure to GVC disruptions. Despite the growing concern about the economic consequences of countries’ exposure to disruptive events,[2] reflections on how economies can reduce their vulnerability to such shocks are still limited.

In this regard, the current debate has been largely centred on how sectoral diversification can reduce the exposure of economies to domestic and foreign shocks (Caselli et al., 2020). Specifically, the need to increase production capacity has been highlighted as a means to reduce foreign dependence in critical sectors (Giovannetti et al., 2023), especially when few large and geographically concentrated firms control the supplies of rare inputs (Ilankoon et al., 2022; Salim et al., 2022; Hamed et al., 2024).

We add to existing literature by combining two lines of reflection: on the nature of diversification and on how functional diversification affects GVC exposure to disruptive events. We will suggest that economies’ resilience to GVC disruptions does not depend only nor primarily on their ability to diversify across a large variety of sectors to compensate for interruptions in foreign supplies of goods. It rather hinges upon strategic investments in critical functions at national and regional levels and the selective establishment of global linkages to access essential resources and knowledge (Coveri and Zanfei, 2023a). In our view, functional diversification should thus be considered as a proactive strategy, enabling economies to manage GVC exposure more effectively by reducing dependence on foreign supply sources while enhancing the

[1] Borin et al. (2021) introduced new indicators based on international input-output tables aimed at measuring the exposure of countries and industries to GVC shocks, namely to the risks faced by countries and industries due to demand and supply bottlenecks in GVCs. In particular, they computed GVC measures based on the overall country-industries’ output that directly or indirectly crosses more than one border, thereby providing more comprehensive measures of exposure to GVC disruptions than indicators based on export flows only.

[2] Several works have highlighted the consequences of GVC disruptions associated with COVID-19 (e.g., Villani and Fana, 2021; Schwellnus et al., 2023) and other shocks, e.g. due to the Ukraine war (Astrov et al., 2022; Sturm, 2022) and the great financial crisis (Accetturo and Giunta, 2018). While examining the differential impacts of distinct shocks is beyond the scope of this paper, it is worth observing that the three crises mentioned here exhibit significant heterogeneity in terms of the sectors, countries, transmission mechanisms and geopolitical tensions involved, entailing different levels of countries’ exposure to the resulting trade disruptions as well as a variety of response patterns to them.

capabilities of domestic industries to respond to sudden changes in trade conditions.

2.1. From sectoral to functional diversification

Standard models have long relied on the argument that specialization is the key engine of gains from trade. However, the economic advantages of specialization are not as straightforward as they might appear at first glance. To start with, pioneers of economic development – such as Rosenstein-Rodan (1943), Prebisch (1950), Singer (1950), Myrdal (1957), Hirschman (1958) and Kaldor (1967) – have pointed out that not all sectors share the same growth potential. Countries that succeed in specializing in industries yielding larger learning effects and higher returns to scale are likely to undertake a more sustained economic development path (Amsden, 1989; Dosi et al., 1990). Moreover, a growing stream of literature adopting an "economic complexity" approach has stressed that productive diversification of countries (especially into products that are incrementally more complex) is a key driver for development (Hausmann et al., 2007; Hidalgo et al., 2007; Hidalgo and Hausmann, 2009).

While these frameworks have highlighted the developmental benefits of diversification, they primarily focus on products and sectors. The emergence of GVCs has necessitated a shift in focus from sectoral diversification to functional diversification. This change in perspective is rooted in the recognition that the value captured by economies depends not only on the sectors in which they operate, but rather on the specific *functions* they perform within GVCs of individual industries (Mudambi, 2008; Shin et al., 2012; Durand and Milberg, 2020).

What should be made more explicit is that sectoral diversification may coexist with a narrow functional specialization within sectors. In this respect, entering new, more dynamic sectors (or increasing specialization therein) may yield limited economic benefits if the economy only performs low value-adding activities within those sectors. To exemplify, while it may be true that an economy will derive greater advantages from entry into a high-tech industry like microchips than from specializing in potato chips (Dosi et al., 2021), it is also likely that pure assembly of microchips does not contribute to fostering skills and capabilities as much as specializing in R&D, design and testing of microchips (Coveri and Zanfei, 2023b). Conversely, functional diversification reflects a wider array of tasks carried out by local actors, implying a greater breadth and depth of domestic technological and organizational capabilities. From this viewpoint, the ability to perform a wider range of value-adding activities – from more knowledge-intensive functions such as R&D to fabrication and commercialization activities – may also offer greater opportunities to enter new and more innovative industries (Coveri et al., 2022; Hernandez-Rodríguez et al., 2025).

While the distinction between sectoral and functional diversification is worthy of consideration, measuring functions is not an easy task. Input-output based measures of the international fragmentation of production (Johnson and Noguera, 2012; Koopman et al., 2014; Timmer et al., 2014) cannot *per se* capture what value-adding activities are being carried out in a given sector. In other words, no relevant information can be provided on the tasks undertaken in the production process, hence allowing little or no inference on its functional specialization and related value capture opportunities (de Vries et al., 2021).

Two distinct strands of contributions have recently addressed this measurement issue more directly. One stream of research, initiated by Timmer et al. (2019), has developed a methodology to identify the 'functional specialization in trade' of countries by tracing the value added embodied in exports according to the occupational categories of workers employed along the value chain of exporting industries (see also Buckley et al., 2020). Another strand of contributions has relied on foreign direct investments (FDIs) data detailed by value chain activities (including R&D, manufacturing operations, and commercialization activities) to assess how GVC functions are geographically distributed within multinational networks. In doing so, these studies have developed different measures of 'functional specialization in FDI' and employed them to explore the positioning patterns of economies along GVCs by adopting a cross-sectional perspective at the country-industry level (Stöllinger, 2021) and a longitudinal perspective at both country and subnational region levels (Coveri et al., 2022; Coveri and Zanfei, 2023b).

Using different indicators of functional specialization, these studies have investigated the development opportunities due to a shift towards functions at the upper ends of the value chain (such as R&D and branding, as well as marketing and after-sales activities), namely those relying largely on intangible assets (Durand and Milberg, 2020; Buckley et al., 2022; Bontadini et al., 2024). However, while growing attention has been paid to the role of functional specialization in the most intangible-intensive activities as a driver of value capture in GVCs, relatively less attention has been dedicated to its counterpart – i.e., functional diversification – and particularly to how the latter can moderate countries' vulnerability to GVC disruptions.

Indeed, previous research in the GVC literature (Gereffi et al., 2021), international economics (Grossman et al., 2021; Todo and Inoue, 2021; Todo et al., 2023) and supply chain risk management (Christopher and Peck, 2004; Sheffi, 2005) has long recognized the challenges associated with a lack of geographical diversification in sourcing strategies. These contributions have advanced our understanding of how supply chain configurations can be optimized for robustness and adaptability. Nevertheless, they have largely overlooked how diversifying across value chain functions *within industries* can enhance resilience by reducing reliance on selected locations and suppliers. This study aims to fill this gap by positioning functional diversification as a critical yet underappreciated dimension, as well as a strategic policy tool, to mitigate countries' exposure to GVC fragilities.

2.2. Functional diversification and exposure to GVC disruptions

Functional diversification can affect the exposure of economies to unexpected changes in trade flows in different ways. One key channel is *innovation*. Diversified economies can be better placed to generate valuable knowledge and capabilities. This argument connects to a reflection on the importance of jointly carrying out manufacturing and other higher value-added activities, that dates back to Cohen and Zysman (1987) and has been revived more recently by Pisano and Shih (2012, Shih, 2020). The view advocated by these authors is that while manufacturing offshoring strategies may be rational from the viewpoint of the individual firm, they can be detrimental at the macro level. As suggested by Pisano and Shih (2012), such strategies can undermine to the point of eroding what they call "industrial commons", which consist of "webs of technological know-how, operational capabilities, and specialized skills that are embedded in the workforce, competitors, suppliers, customers, cooperative R&D ventures, and universities and often support multiple industrial sectors" (Pisano and Shih, 2012, p. 13). In addition, specializing in an increasingly narrow set of core functions due to cost-reduction objectives jeopardizes their capabilities to exploit external agglomeration economies (Feldman and Kogler, 2010). This is especially true in industries where the innovation process largely relies on the geographical proximity between lead firms and supply chain suppliers to effectively transmit and exchange tacit knowledge (Dankbaar, 2007; Castellani and Lavoratori, 2020).

These research lines contribute to a reflection on the downsides to the long-term competitiveness of economies due to strategies based on the dismantling of manufacturing activities and the concurrent concentration on higher value-adding functions. In fact, specializing "only" in a limited range of intangible-intensive activities (such as R&D and design functions) without any presence in lower-end functions (such as fabrication or assembly) may not allow growth opportunities to be fully exploited. This low diversification (or hyper-specialization) risks inflating economies' exposure to international shocks, thus increasing their vulnerability to events undermining trade relations. Furthermore, these streams of literature provide additional conceptual insights for the analysis of the structural determinants of the international performance of economies (see Castellani et al., 2022 for a review). On the one hand, by enhancing innovation capabilities, functional diversification increases the capacity of economies to creatively react to supply chain interruptions, thus reducing the damage associated with sudden foreign sales contractions. On the other hand, functional diversification augments the absorptive capacity of firms and enables them to better select and utilize foreign inputs, hence reducing their need to rely on foreign sources.

The second key channel has to do with *risk diversification*. Especially in the field of economic geography, several contributions have highlighted that a larger number of (partially uncorrelated) economic activities alleviates the negative consequences of disruptive events affecting selected industries, technologies or occupations (Brown and Greenbaum, 2017; Tóth et al., 2022). Most importantly, countries' diversification can be expected to reflect a larger mix of technological and organizational capabilities, which in turn can be more easily and flexibly recombined to soften the consequences of adverse phenomena, to adapt to changes in the economic environment and to develop new growth paths (Pike et al., 2010; Neffke et al., 2011; Martin and Sunley, 2015).

However, this line of reasoning needs to more explicitly account for a functional perspective. Greater sectoral diversification might not be enough to ensure a more robust production matrix to the extent that it is accompanied by a narrow set of productive and knowledge capabilities. In other words, domestic actors' capacity to absorb adverse shocks does not only depend on the variety of products they can actually produce. It largely depends on the array of assets, skills and knowledge they are able to mobilize to rapidly recover. We thus suggest that functionally diversified economies are likely to be better placed to respond to disruptive events for two reasons. On the one hand, they are more likely to find alternative domestic capacities that can replace external resources when necessary. On the other hand, they can rely on more domestic capabilities to combine with external inputs that might be accessed from alternative foreign sources.

It is worth highlighting two diverging consequences of this risk-management argument. One possible implication is that, by enhancing risk management capacity, functional diversification may prompt economies to increase their reliance on foreign supplies. Under such circumstances, functional diversification would increase the risk propensity of economies, thus resulting associated with *higher* foreign input reliance. A different, quite opposite implication is that, by augmenting the capacity of economies to respond to disruptive events, functional diversification could reduce the incentives to take on the risks associated with foreign input sourcing. Under such circumstances, functional diversification would increase risk aversion, thus resulting associated with *lower* foreign input reliance.[3] Accordingly, it is worth empirically exploring *how functional diversification of economies actually affects their exposure to GVC disruptions.*

3. Data

3.1. Foreign input reliance as an indicator of exposure in GVCs

Different indicators of GVC exposure have been developed in the literature, each with its own strengths and limitations (for a review, see Baldwin et al., 2022). As explained below, measures based on gross trade flows, rather than trade in value added (Johnson and Noguera, 2012; Giammetti et al., 2022), should be preferred for assessing exposure to supply shocks, since the latter usually disrupt the entire (cumulative) value of trade flows rather than only the value added in the disrupted country. Consistently, in this work, we use the Foreign Input Reliance (FIR) indicator as a measure for assessing a country's exposure to potential GVC disruptions.

This indicator, based on recent contributions by Baldwin and Freeman (2022) and Baldwin et al. (2022, 2023), quantifies the dependency on directly and indirectly foreign-sourced inputs for domestic production, with the explicit aim of assessing countries' and industries' vulnerabilities to external shocks affecting upstream (foreign) suppliers.[4] Notably, recent studies have emphasized that FIR is a valuable indicator for analyzing GVC risks. For example, Schwellnus et al. (2023) used this indicator to investigate whether a higher exposure of industries to GVC disruptions is associated with weaker economic performance *after* a shock occurs. In particular, these authors estimate the transmission of foreign disruptions associated with COVID-19 on domestic output through global supply chains. They find that GVC exposure is an accurate predictor of the impact of shocks to foreign suppliers and buyers on domestic production. Additionally, Baldwin and Freeman (2022) highlight that economies with more diversified supply bases face lower vulnerability to GVC interruptions, as they can substitute suppliers if one source is disrupted. FIR has also been recently used to assess critical trade dependencies among countries, as well as the risks and opportunities arising from different GVC-reshaping policy strategies induced by geopolitical tensions (Crowe and Rawdanowicz, 2023; Arriola et al., 2024).

FIR is calculated based on Inter-Country Input-Output (ICIO) tables, which map production linkages across borders by tracing both direct and indirect dependencies within global production networks. Specifically, FIR utilizes the Leontief inverse matrix to capture immediate (direct) foreign inputs as well as multi-tiered (indirect) dependencies within the supply chain. Formally, FIR is expressed as:

$FIR_{r,j,s} = \sum_i^I b_{i,j}^{r,s}$ for all $r \neq s$ where $b_{i,j}^{r,s}$ represents the elements of the Leontief inverse, reflecting total foreign input requirements (direct and indirect) from the country and industry of origin of the gross output (r,i) for the production of one unit of output by the country and industry of destination (s,j), tracing dependencies across borders and sectors.

To compute the FIR indicator, we use the 2023 release of the OECD Inter-Country Input-Output (ICIO) tables, which provide data for 76 economies and 45 industries from 1995 to 2020. This extensive dataset allows for a detailed analysis of FIR across a wide array of countries and sectors over time.

The calculation method implies that FIR is a "gross trade" measure, meaning that foreign inputs are counted multiple times if they cross borders repeatedly before reaching final production stages. As a result, FIR values can exceed 1 in highly integrated GVCs due to cumulative dependencies on foreign inputs, capturing the complex interdependence within global supply networks.

The deliberate inclusion of double counting, that distinguishes FIR from other exposure measures previously proposed in the GVC literature, makes this indicator very effective in identifying structural

[3] A summary comparison of sectoral and functional diversification, as well as their different expected links to the exposure of economies to GVC disruptions, is provided by Table A.6 in the Online Appendix.

[4] Together with FIR, Baldwin and Freeman (2022) and Baldwin et al. (2022, 2023) also proposed another indicator of foreign reliance, called Foreign Market Reliance (FMR). The latter captures the demand-side exposure to GVC disruptions by focusing on countries' and industries' dependence on downstream (foreign) buyers. While FIR is particularly well suited for assessing supply-side vulnerabilities, therefore aligning with the objective of this study, exploring whether and how functional diversification interacts with demand-side GVC exposure would require a distinct conceptual framework. Accordingly, future research could provide a complementary perspective to ours by leveraging FMR for this purpose.

vulnerabilities to various types of shocks by providing a baseline measure of foreign reliance. For instance, high FIR values in health-related sectors highlighted exposure during the COVID-19 pandemic when supply chain disruptions underscored the risks of concentrated foreign input reliance (Baldwin and Freeman, 2022). By signalling where GVC exposure is greatest, FIR can pre-emptively indicate risk areas across industries and guide resilience-building strategies (Schwellnus et al., 2023). Therefore, FIR should be conceived as an exposure indicator rather than a measure of direct economic harm, as it aims to highlight the changing level and geographical composition of foreign dependencies. As such, this metric measures the vulnerability of economies to potential disruptions in international trade flows of intermediate inputs (Baldwin et al., 2022, 2023).

While FIR offers significant insights into GVC dependencies, it is important to acknowledge its limitations, which are mainly due to the nature of the data underlying this indicator, i.e. multi-regional Input-Output (I-O) tables. A key caveat of I-O models is the assumption of fixed coefficients at the industry level, which implies that production inputs are supposed to be homogenous across firms within a given sector and remain constant across different output levels, thereby potentially oversimplifying the adaptive capacity of firms during disruptions. This assumption may limit FIR's accuracy in highly dynamic sectors or in response to sudden, large-scale disruptions, where production structures adapt quickly. Moreover, FIR does not inform about potential alternative sources of (domestic or foreign) supply, nor about the costs of switching supplies, if not implicitly: for example, a greater FIR is likely to signal a shortage of viable and cost-effective alternative supplies (Baldwin and Freeman, 2022). Hence, while it successfully captures the overall GVC exposure of countries and industries, this indicator does not account for all dimensions concerning the adaptability and resilience of GVCs to disruptions.

These limitations are at least partially addressed in our empirical analysis, which includes additional control variables aimed at capturing aspects that FIR alone may overlook (see Section 5). For instance, we check the robustness of our results by controlling for the trade 'breadth' of economies, which accounts for the geographic scope of trade flows in which countries are involved; and, along with other controls, we include Pavitt-time fixed effects to capture all time-varying factors that might influence the range of viable sourcing options commonly available to industries belonging to a certain Pavitt class. In this way, we strive to account for all those factors that might affect the relationship between the GVC exposure (as measured by FIR) and the functional diversification of economies.

3.2. Measuring functional diversification

We combine trade-based indicators on GVC exposure with a measure on the functional diversification of economies, that we build by leveraging the richness of information on cross-border investments provided by the fDi Markets database. The latter is a proprietary data source maintained by the Financial Times, covering all greenfield FDIs from 2003 onwards and reporting, *inter alia*, information on the destination country-industry of each FDI together with the business function undertaken in the host economy.

To compute our measure of functional diversification, we follow Paglialunga et al. (2022) and focus on information concerning the value chain functions each inward FDI is aimed at performing. The fDi Markets database classifies cross-border investments in several functions, ranging from headquarter activities, R&D and design, to production operations, up to logistics, marketing and further post-production activities. Accordingly, we use the above classification of FDIs to compute an index of *functional diversification in FDI* (FD) based on the normalized Herfindahl–Hirschman index (HHI). For each country c and year t, and considering each GVC function k, the FD index is computed as follows:

$$FD_{c,t} = 1 - HHI^{K}_{c,t} = 1 - \left[\left(\sum_{k=1}^{M} \left(\frac{FDI^{k}_{c,t}}{FDI_{c,t}} \right)^2 - \frac{1}{M} \right) \Big/ \left(1 - \frac{1}{M} \right) \right] \quad (1)$$

where $HHI^{K}_{c,t}$ is the normalized HHI based on GVC functions and the ratio in the round brackets represents the share of FDIs related to the k-th of the M functions over the total inward FDIs for country c in year t.[5] This measure of functional diversification will be used as focal explanatory variable in the analysis of the determinants of the economies' exposure to GVC disruptions.

Like all databases, fDi Markets has pros and cons. It is thus worth acknowledging and discussing some limitations of our FDI-based indicator of functional diversification to validate its usage.

First, fDi Markets includes information on greenfield investment projects only (i.e., new wholly-owned subsidiaries, including joint ventures leading to a new physical operation), while it does not account for mergers and acquisitions (M&A). However, no data are available on the functional nature of brownfield investments, which is why previous contributions focusing on the value chain functions pursued by cross-border investments also limited their attention to greenfield FDIs only (Castellani and Pieri, 2013; Castellani et al., 2013; Crescenzi et al., 2014; Stöllinger, 2021; Coveri and Zanfei, 2023b). Moreover, the absence of data on brownfield investments limits the coverage of international operation modes, but also reduces the noise associated with the purely financial motivations that often underlie M&A strategies (Castellani et al., 2016). Accordingly, data on greenfield FDIs are likely to be more suitable to proxy the actual capabilities of industries to carry out different value-adding functions.

Second, granular data on FDI flows included in fDi Markets do not report information on disinvestment decisions, which would be required to fully reconstruct the stock of FDI in each country-industry pair. However, data on disinvestments are generally not available at a highly detailed level, reason why also previous contributions which applied panel methodologies to fDi Markets data have largely focused on annual FDI flows (see, *inter alia*, Castellani et al., 2013; Crescenzi et al., 2014; Crescenzi et al., 2022).

Third, and most importantly, our FDI-based indicator provides a significant, though not exhaustive, proxy of the diversification of countries and industries across GVC activities, as it disregards the value chain functions performed by domestic firms. Consequently, our indicator mainly captures the involvement of countries and sectors in GVCs characterized by a hierarchical type of governance (Gereffi et al., 2005). Nonetheless, multinational corporations are key actors in GVCs and FDI flows have been a fundamental driver of GVC expansion, playing a significant role in shaping domestic capabilities and promoting knowledge flows across local firms (Branstetter, 2006; Castellani and Zanfei, 2006; Cadestin et al., 2019; Li and Tanna, 2019). Hence, although FDI data may not capture the whole picture, they provide valuable insights into the available technologies and the bundle of productive capabilities countries and industries are equipped with.

As we shall explain in more detail in Section 5, we will first explore the association between functional diversification in FDI and GVC exposure at the country level, focusing on a sample of 45 economies. Next, concentrating on a subset of 22 countries, we will deepen the empirical investigation at the macro-industry level by aggregating sectors according to the revised Pavitt taxonomy (Pavitt, 1984; Bogliacino

[5] The formula in squared brackets reported in equation (1) is the normalized version of the HHI, also known as the Berry-Herfindahl index (Berry, 1971). The normalization procedure ensures that the HHI ranges between 0 and 1. Applied to this context, the HHI measures the degree of concentration of inward FDIs across the different functions of the value chain. It follows that the complement to one of the (normalized) HHI provides an indicator of diversification, as it assumes higher values (i.e., closer to one) when inward FDI flows are more evenly distributed across value chain functions.

and Pianta, 2010).[6]

4. Descriptive evidence

This section lays the groundwork for our empirical analysis by outlining trends in risk exposure within GVCs as captured by FIR and examining functional diversification in FDI (FD) across both countries and industries.

Country-level FIR data reveal a clear divide in GVC reliance based on economic size and development. Smaller economies, including *inter alia* Vietnam, Thailand, Slovakia and Hungary, exhibit higher FIR, indicating substantial dependence on foreign inputs for production and domestic demand fulfilment. Conversely, larger and richer economies – like the United States and Japan – show lower FIR, reflecting robust domestic supply structures. Notable exceptions are China and Germany, which maintain relatively high levels of FIR, reflecting their deeply integrated industrial structures into global supply chains and high reliance on imported components (see Figures A.1-A.2 in the Online Appendix for details).

In terms of FD, advanced economies such as Canada, France, the UK, and the USA display high and stable FD, indicating diversified economic functions and potential resilience to GVC disruptions (see Figure A.3 in the Online Appendix). Emerging economies with a high FIR, like Hungary, Slovakia, Vietnam and Thailand, show lower FD, aligning with the hypothesis of a negative relationship between these indicators.

At the industry level, differences emerge when analyzing FIR and FD across Pavitt classes. For instance, Scale-intensive (SI) in advanced economies generally exhibit lower FIR and higher FD, suggesting that these sectors benefit from diversified domestic production capabilities, which reduce dependency on foreign inputs. Conversely, Supplier-dominated (SD) industries in emerging economies, such as Vietnam and Thailand, often display high FIR and low FD, signalling structural vulnerabilities in labor-intensive industries that rely heavily on imported inputs. This contrast is particularly visible in countries actively participating in GVCs but with limited functional diversification (see Figures A.4-A.5 in the Online Appendix).

A clearer representation of the inverse relationship between FIR and FD is provided by Figs. 1 and 2, which illustrate the association between these metrics across countries and Pavitt industries, respectively. Fig. 1 shows that countries with high FD tend to have lower FIR, indicating a diversified industrial base that might mitigate foreign input reliance.

Fig. 2 further highlights this relationship within Pavitt classes. In Supplier-dominated industries, a clear negative correlation emerges: Vietnam, with high FIR and low FD, contrasts sharply with advanced economies like the USA, Japan, and Germany, which show lower FIR and higher FD, suggesting that a diversified economic structure is associated with lower reliance on foreign inputs.

In Scale-intensive industries, the trend persists, with countries such as Hungary, the Czech Republic and Vietnam showing high FIR and relatively low FD, indicative of deep integration in GVCs, particularly in sectors like automotive. Advanced economies, including the USA and Japan, maintain a lower FIR and higher FD, underscoring the role of a broad economic base in limiting foreign dependency.

The picture is more nuanced in the case of industries wherein technology and intangibles play a greater role. In the Science-based sector, a negative relationship between FIR and FD is evident, but this association is apparently driven by countries that are not major players in these industries. On the one side, advanced economies display a blurred pattern, suggesting that the FIR–FD relationship may require further analysis in these highly globally integrated, knowledge-intensive

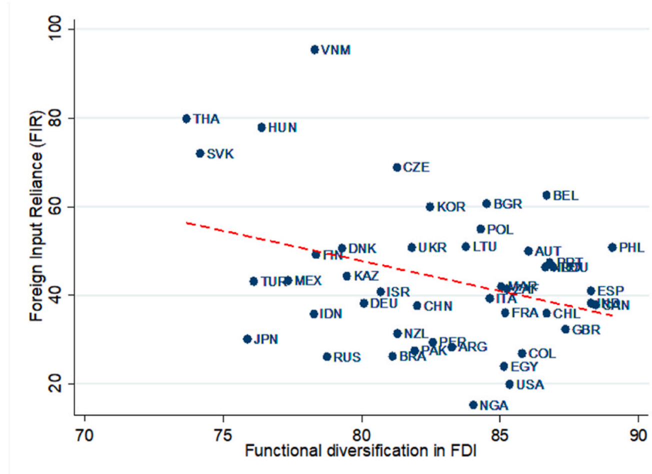

Fig. 1. The association between Functional diversification in FDI and the FIR indicator, average values over the period 2003–2018.
Source: authors' elaborations based on OECD ICIO and fDi Markets data.

industries. On the other side, countries such as Thailand, Vietnam, Hungary and Mexico exhibit high FIR and relatively lower FD. In particular, Thailand and Vietnam emerge as outliers in the FD–FIR relationship, reporting extremely low levels of functional diversification coupled with very high levels of foreign dependence. This is consistent with the pathway to industrialization undertaken by these economies, which joined SB-related (especially electronics) GVCs by specializing in a relatively narrow set of (mostly low) value-adding functions (Jaax and Miroudot, 2021; Durongkaveroj, 2023). Although this strategy has fostered industrial development in these countries, challenges related to domestic capability upgrading have limited their ability to functionally diversify, leaving them highly dependent on imported inputs.

In Specialized supplier industries, where innovation and the exploitation of niche markets play significant roles, the relationship is less distinct. Advanced economies exhibit both low FIR and high FD, while countries like Thailand, Vietnam, Hungary and Mexico are characterized by high FIR and variable FD levels. Notably, Thailand and Vietnam appear as outliers in the case of these industries as well, essentially because of their exceptionally high level of FIR. This is likely due to their growing involvement in GVCs related to electrical and machinery equipment industries matched with their high need to source technology-intensive inputs and knowledge assets from abroad for these productions.

In summary, the descriptive evidence shown in this section is consistent with the line of argument developed in Section 2, suggesting that enhancing functional diversification may mitigate the exposure to disruptions in GVCs. This motivates further exploration of the functional diversification-GVC exposure nexus, which we carry out in Section 5.

5. Empirical modelling strategy

In this section we further explore the extent to which diversification in terms of value chain activities is associated with the reliance of economies on foreign partners. In particular, we investigate the association between functional diversification in FDI of countries and industries and their risk exposure to GVC disruptions by means of panel methodologies, which allow us to also control for a number of other potential drivers of economies' vulnerability to GVC-disrupting events.

To this aim, we compute the functional diversification in FDI at both country and industry levels. In the latter case, data limitations concerning the number of inward FDIs yearly targeting country-industry pairs prompt us to aggregate sectors in macro-industries. We opted for aggregating sectors according to the revised Pavitt taxonomy (Pavitt, 1984; Bogliacino and Pianta, 2010), which classifies both manufacturing and service

[6] The revised Pavitt taxonomy extends the original Pavitt classification of manufacturing industries to also include service industries (Bogliacino and Pianta, 2010). The full description is provided by Table A.7 in the Online Appendix.

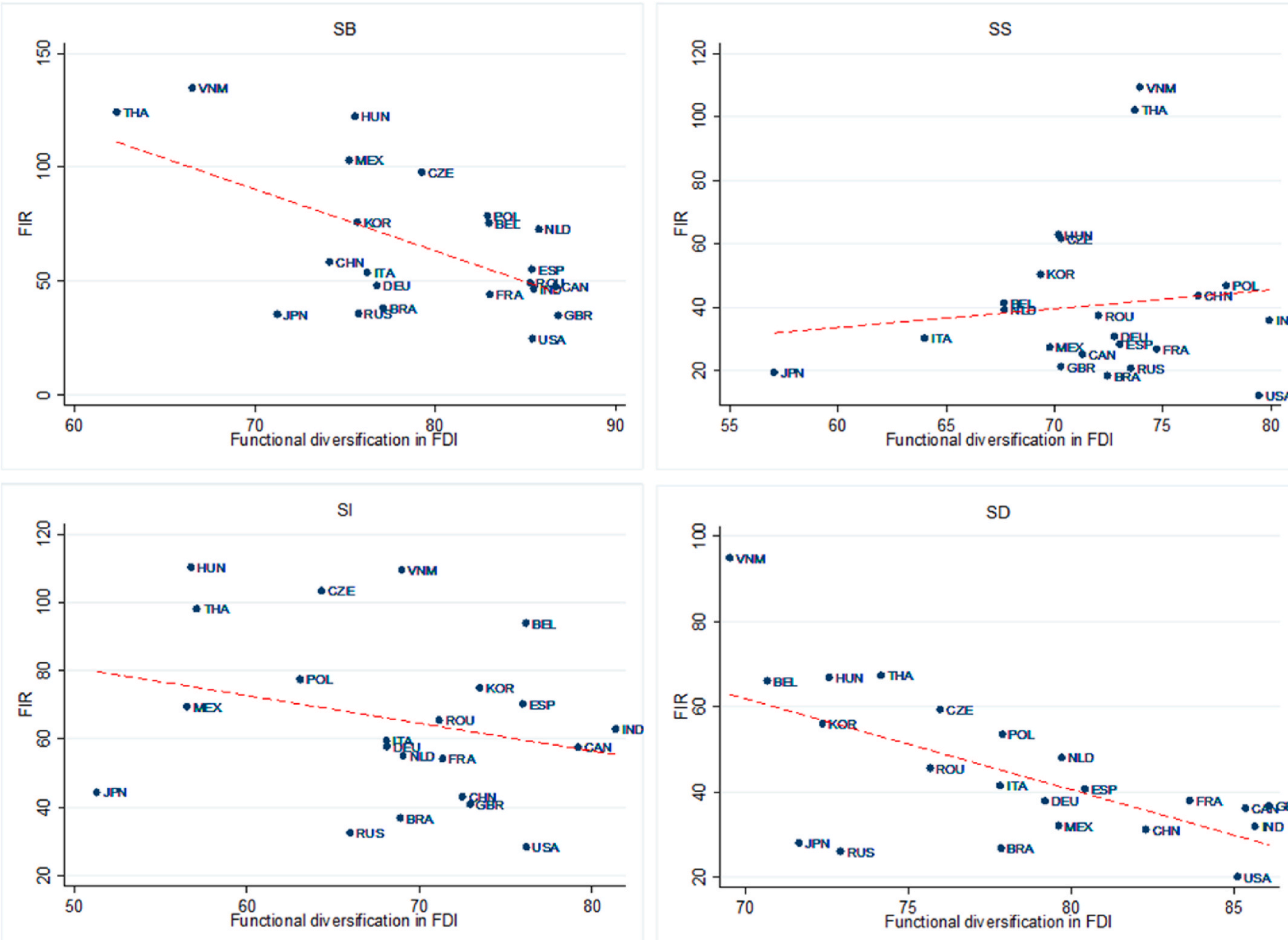

Fig. 2. The association between Functional diversification in FDI and the FIR indicator by country-Pavitt pairs, average values over the period 2003–2018. Source: authors' elaborations based on OECD ICIO and fDi Markets data.

industries in four classes, namely Science-based (SB), Scale-intensive (SI), Specialized suppliers (SS) and Supplier-dominated (SD). This classification allows us to explore the heterogeneity in the association between FD and FIR according to the innovation propensity of industries, which is especially important from an industrial policy perspective. Moreover, by classifying industries according to market structure and the nature, sources and appropriability of innovation, the Pavitt taxonomy provides more insight into the technological and organizational characteristics and market potential of industries than classifications based only on R&D intensity (Galindo-Rueda and Verger, 2016).

Formally, the empirical analysis at the country level is carried out by estimating the following regression equation:

$$FIR_{c,t} = \beta_0 + \beta_1 (FD_{c,t}) + \beta_2 (total\ inward\ FDI)_{c,t} + \beta_3 X_{c,t} + \gamma_c + \delta_t + \varepsilon_{c,t} \quad (2)$$

where $FIR_{c,t}$ is the Foreign Input Reliance index and represents our measure of risk exposure to GVC disruptions for country *c,* at time *t*. $FD_{c,t}$ stands for our FDI-based measure of functional diversification, while *total inward FDI* captures the overall number of cross-border investments received by country *c* at time *t,* allowing us to account for the overall attractiveness of economies to FDI flows.[7] The term $X_{c,t}$ includes an array of time-varying control variables at country level (see below). The terms γ_c and δ_t stand for country and time fixed effects, accounting respectively for unobserved time-invariant country-specific characteristics (e.g., geographical location) and year-specific events that may have an impact on both dependent and explanatory variables. Finally, β_0 stands for the intercept and $\varepsilon_{c,t}$ is the error term.

Along with fixed effects, the inclusion of control variables is crucial for reducing the potential omitted variable bias, which would lead our dependent variable to be correlated with the error term, giving rise to endogeneity concerns. In particular, we include control variables to account for the country size (population and GDP in constant 2017 international PPP dollars), level of economic development (GDP per capita), industrial structure (manufacturing value added as percentage share of GDP). We also account for two measures of technological change, i.e., R&D expenditure as a percentage share of GDP; and gross fixed capital formation (GFCF) as percentage share of GDP, the latter representing an indicator of embodied technical change. Finally, we also include variables that capture the strength of countries' international linkages with foreign economies, namely the standard trade openness index (i.e., the sum of exports and imports as a percentage share of GDP); and the KOF financial globalization index (*de facto*), the latter capturing short-term portfolio investments along with other stocks of financial assets and liabilities. Data on all these variables are retrieved from the World Bank's World Development Indicators (WDI) database, except for data on the financial globalization index which are drawn from the KOF Swiss Economic Institute database of the ETH Zurich (Dreher, 2006;

[7] The inclusion of total inward FDI is important to correctly identify the coefficient of $FD_{c,t}$: otherwise, the latter would end up conflating the functional diversification of inward FDIs with the total number of inward FDIs drawn by countries.

Gygli et al., 2019).

While variables capturing the country size are expected to be negatively associated with FIR, as larger countries are typically less reliant on foreign supply (Timmer et al., 2014), the relationship between the level of economic development, industrial structure and technological progress of countries and their GVC exposure is likely more ambiguous. On the one hand, higher incomes and faster technological pace could stimulate the provision of domestic capabilities and knowledge assets, leading to lower foreign input reliance; while lower incomes and rates of technical progress could induce economies to rely more extensively on not-domestically available inputs. On the other hand, higher-income and faster technological pace are likely to foster GVC involvement and accentuate the propensity to specialize in core activities while sourcing cheap supplies from abroad (Fana and Villani, 2022), which could lead to higher foreign dependency. Accordingly, it is important to account for these factors to distinguish their role from that played by functional diversification in FDI. Moreover, both trade openness and the financial globalization index are expected to be positively associated with FIR, as higher values for these variables reflect the absence of trade and capital flow restrictions in a country and, more in general, the strength of its linkages with foreign actors.

As a robustness check, we also control for further indicators measuring international trade and capital flows, namely the KOF trade globalization index (*de facto*), gauging the trade openness along with the trade partner diversity of economies; and four variables quantifying the "depth" and "breadth" of both trade and capital flows.[8] Additional controls include upstreamness and downstreamness indicators, measuring countries' positioning along GVCs (Antràs et al., 2012; Fally, 2012). In particular, these distance-oriented indicators gauge the absolute value of the (average) number of production steps that "separate" a country's output from final demand (upstreamness) and primary inputs (downstreamness), i.e. from the two ends of global chains of production. Greater upstreamness (downstreamness) is expected to be negatively (positively) associated with FIR, as countries that are positioned more upstream (downstream) along GVCs should result predominantly suppliers (buyers) of production inputs. Also, controlling for these variables gives us the opportunity to at least partially "isolate" the component of the FIR that depends on the length of GVCs in which countries are involved (Antràs and Chor, 2013).[9]

Lastly, adopting the same methodology used for computing the functional diversification in FDI, we calculate an index of *sectoral diversification in FDI* based on the industry each FDI has targeted. The inclusion of this control variable allows us to compare the role played by the functional and the sectoral diversification of economies in affecting the GVC exposure of countries. From a formal point of view, for each country c and year t, the index is computed as follows:

$$\textit{Sectoral diversification in FDI}_{c,t} = 1 - HHI^J_{c,t} = 1 - \left[\left(\sum_{j=1}^{N} \left(\frac{FDI^j_{c,t}}{FDI_{c,t}} \right)^2 - \frac{1}{N} \right) \bigg/ \left(1 - \frac{1}{N} \right) \right] \tag{3}$$

where $HHI^J_{c,t}$ is the normalized HHI based on the one-digit NACE Rev. 2 sectoral classification, with the ratio in the round brackets representing the share of FDIs related to the j-th of the N sectors over the total inward FDIs for country c in year t. Consistently with the conceptual framework provided in Section 2, we expect this regressor not to be statistically significant, supporting our view that it is the diversification along the functional dimension that matters most.

The estimated regression equation for the model at the country-Pavitt level is as follows:

$$FIR_{c,j,t} = \beta_0 + \beta_1 (FD_{c,j,t}) + \beta_2 (\textit{total inward FDI})_{c,j,t} + \beta_3 \ln(\textit{gross output})_{c,j,t} + \gamma_{c,j} + \delta_{j,t} + \varepsilon_{c,j,t} \tag{4}$$

where $FIR_{c,j,t}$ is the Foreign Input Reliance index for country c, Pavitt class j at time t. $FD_{C,j,t}$ measures the functional diversification in FDI at the country-Pavitt level, while the natural logarithm of gross output is introduced to account for the industry size. Notably, the terms $\gamma_{c,j}$ and $\delta_{j,t}$ stand for country-industry and industry-time fixed effects, accounting respectively for unobserved time-invariant specific characteristics of country-industries and unobserved time-varying factors affecting all industries belonging to a given Pavitt class over the period. This set of fixed effects is crucial to control for a large number of unobserved factors that may have an impact on both dependent and explanatory variables, hence softening endogeneity concerns due to omitted variable bias.

We have access to fDi Markets data from 2003 to 2018, which is thus the time span covered by our empirical investigation. As for the country sample, the *country-level analysis* is conducted on 45 countries out of the 76 economies included in the ICIO tables provided by the OECD. Specifically, we selected all countries that attracted at least 15 FDIs *each* year, *all* years, where this threshold corresponds to the 10th percentile of the distribution of the number of inward FDI projects at the country-year level.[10] This selection procedure is needed to increase the reliability of our FDI-based functional diversification indicator, as it avoids computing the latter for countries which received few FDIs over the period. The sample on which the *country-Pavitt level analysis* is conducted includes 22 countries (out of the 45 countries included in the country level analysis), i.e., all economies that attracted more than 5 FDIs in *each* Pavitt class *each* year, *all* years. This lower bound corresponds to the 25th percentile of the distribution of the number of inward FDI projects at the country-Pavitt-year level. Once again, adopting this selection criterion is essential for increasing the reliability of our measure of functional diversification in FDI of countries and industries.[11] Following this procedure, we ended up with two relatively large and strongly balanced panel datasets

[8] Indicators on "depth" measure the size of international trade and capital flows relative to domestic activity and are expected to be positively associated with FIR; while variables on "breadth" captures how closely each country's distribution of international flows across its partner countries matches the global distribution of partners for those flows. Accordingly, breadth captures whether a country's international flows are spread out globally or more narrowly focused, allowing us to control for countries' geographic diversification of trade partners. Data on these indicators are drawn from Altman and Bastian (2024), to which we refer for further details.

[9] For consistency with the FIR indicator, these variables are based on OECD ICIO data and are drawn from the dataset recently compiled by Mancini et al. (2024). A discussion on the pros and cons of these indicators can be found in de Vries et al. (2021) and Coveri et al. (2024).

[10] Five countries were excluded from the analysis because they were classified as tax havens (Hong Kong, Ireland, Singapore and Switzerland) (Hines, 2010) or because data on several control variables (e.g., GDP, population, etc.) were not available (Taiwan).

[11] In selecting these thresholds, we had to balance the reliability of our indicator of functional diversification of economies with the need to include as many countries as possible in the sample (to avoid shrinking the number of observations). As for the reliability of the indicator, it is worth noting that – following this procedure – the average number of inward FDIs received by economies included in the country-level sample is relatively high and equal to 217 per year, while the median value is 111 per year; the corresponding magnitudes for country-industry pairs included in the country-Pavitt level sample are 87 and 52, respectively. Nonetheless, we also selected higher thresholds (e.g., including countries which received at least 20 or 30 FDIs each year, all years) and performed our empirical analysis on restricted country samples as a robustness check. The results are qualitatively unchanged and are available upon request.

at the country and country-Pavitt level, comprising 720 and 1408 observations, respectively.[12]

Descriptive statistics for all the variables considered in our empirical models are reported in Table A.2 in the Online Appendix.

6. Results

6.1. Country-level estimates: baseline model

Table 1 provides the empirical results deriving from the estimation of the fixed effects model at the country level with FIR as dependent variable, as reported by equation (2). We start from a parsimonious specification and introduce step by step a number of control variables in order to assess the robustness of our findings. Notably, the coefficient of functional diversification in FDI is negative and significant across all the estimated specifications. As for the other variables, the coefficient of total inward FDIs always reports a negative but not statistically significant coefficient, except in columns 9 and 10 where it turns out significant.[13] While the coefficient of the GDP per capita is not significant (column 2), the negative and significant coefficients of the population size and absolute value of the GDP of economies are in line with the descriptive evidence provided above, confirming that larger countries are typically less reliant on foreign inputs for production (columns 3 and 4). Moreover, when we account for both these variables simultaneously (columns 5 to 10), the coefficient of population remains significant while that of GDP does not, signalling that the former better captures the negative association between countries' size and FIR.

In column 6 we include trade openness as a control variable to account for the overall involvement of countries in international flows of exported and imported goods and services. As expected, this regressor shows a positive and strongly significant association with countries' reliance on foreign inputs (trade openness also seems to capture the role played by country size better than GDP and population, which are found to be not significant when this regressor is included). The next two columns of Table 1 report estimate results when controlling for our proxy of sectoral diversification in FDI, the financial globalization index, and GFCF (% of GDP), both without and together with trade openness (see columns 7 and 8, respectively). While the coefficient related to GFCF is never significant, the variable concerning financial globalization (i.e., the KOF financial globalization index) turns out significant in the specification shown in column 7 as well as in subsequent ones (columns 8 to 10), suggesting that countries with more liberalized capital accounts tend also to show a higher reliance on foreign inputs.

Most importantly, the coefficient of our FDI-based indicator of sectoral diversification in FDI turns out negative and statistically significant in column 7 only, while it is not in columns 8 to 10. This result allows us to distinguish the role played by functional from sectoral diversification. While one might argue that diversification across industries could help reduce GVC exposure in some circumstances, it is functional diversification that matters. As discussed in Section 2, a country could be widely diversified across sectors while being highly specialized in few value-adding functions within sectors, which can lead to over-reliance (and increased exposure to GVC disruptions) on foreign partners for an ever-widening range of inputs.

As for columns 9 and 10, these reports estimation results for model specifications controlling also manufacturing value added and R&D expenditure as percentage shares of GDP. While all previous results are confirmed, the coefficient related to manufacturing value added (proxying the industrial structure of the economies) is found to be positive and significant in column 9 only (which could be consistent with the typically higher levels of international fragmentation of production of manufacturing industries compared to primary and service sectors); while R&D expenditure reports a negative but not significant coefficient in both specifications.

6.2. Robustness checks at the country level

As a robustness check, Table A.3 in the Online Appendix shows results from model specifications including additional control variables on the involvement of economies in trade and capital flows. Also in this case, all our previous findings are confirmed, reassuring us about the robustness of our results.

In particular, the coefficient of functional diversification in FDI always reports a negative significant coefficient, while coefficients for the different proxies of trade openness (i.e., the KOF trade globalization index and the trade depth indicator) emerge, as expected, positive and significant (columns 1 to 3). Other variables capturing if a country's trade and capital flows are relatively more spread globally or narrowly focused, as well as capital depth, do not report significant coefficients (columns 3 to 5). Lastly, when accounting for the upstreamness and downstreamness of countries, we find that the former shows a negative and significant coefficient, while the latter a positive and significant one (column 6). Given that FIR captures the "import-side" of GVC exposure and increases as value chains lengthen, this result is perfectly consistent with our expectations. In fact, countries located more upstream along production chains are supposed to be mainly suppliers of intermediate inputs (thereby featuring lower reliance on foreign productions), while the opposite is true for economies located more downstream along production chains (as they typically rely more on global sourcing of intermediate goods and services). It is also worth reminding that these indicators assume higher values the longer value chains are, allowing us to control for the production length of GVCs. Accordingly, results in column 6 suggest that functional diversification in FDI is negatively and significantly associated with the "size" of foreign input reliance.

Most importantly, a potential bias in our estimates may be due to the violation of the strict exogeneity assumption due to the persistency of the GVC exposure of countries and industries over time (as shown by Figure A.2). It follows that the level of the FIR indicator is likely to be correlated over time, giving rise to endogeneity concerns due to autocorrelation of residuals. Moreover, our main explanatory variable may be correlated with the error term if a shock affects both GVC exposure and functional diversification in FDI of a given country i, e.g., a local extreme event (such as an earthquake) which negatively affects domestic supply while reducing the FDI attractiveness of the economy. This can induce reverse causality between our dependent variable and our key regressor, giving rise to endogeneity issues.

To deal with this potential source of endogeneity and account for the autocorrelation of FIR, we provide a further robustness check of our country-level estimate results adopting the dynamic panel estimator introduced by Arellano and Bover (1995) and Blundell and Bond (1998), namely the Two-Step System Generalized Method of Moments (GMM). Notably, this estimator jointly accounts for the autoregressive nature of the dependent variable while generating internal (and testable) valid instruments for directly addressing endogeneity concerns. Moreover, it is best suited to panel datasets like ours, namely with a relatively large number of cross-sectional units and a relatively low number of time periods.

Empirical results using this estimator are provided in Table A.4 in the Online Appendix and largely confirm our previous findings, reassuring us about the robustness of our empirical strategy (see the Online Appendix for more detailed comments).

[12] The full list of economies included in the country and country-Pavitt level analyses is reported by Table A.1 in the Online Appendix.

[13] Estimate results in columns 9 and 10 are based on a lower number of observations because data on manufacturing value added (% of GDP) are not available for Bulgaria, and data on R&D expenditure (% of GDP) of some countries are not available in a few years of our time span.

Table 1
Fixed effects model at the country level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable:	FIR	FIR	FIR	FIR	FIR	FIR	FIR	FIR	FIR	FIR
Functional diversification in FDI	−0.084**	−0.070*	−0.065*	−0.103***	−0.092***	−0.082***	−0.063*	−0.071*	−0.071*	−0.096***
	(0.037)	(0.035)	(0.034)	(0.032)	(0.031)	(0.027)	(0.036)	(0.037)	(0.038)	(0.035)
ln(total inward FDI)	−1.264	−1.343	−1.083	−0.172	−0.245	−0.393	−0.031	−0.451	−1.153*	−1.415***
	(1.065)	(0.998)	(0.914)	(0.959)	(0.894)	(0.826)	(0.830)	(0.657)	(0.593)	(0.452)
ln(GDP per capita)		−4.785								
		(5.890)								
ln(GDP)			−8.245*		−3.605	−1.790	−3.128	−2.331	−7.873*	−3.475
			(4.893)		(5.910)	(3.224)	(6.151)	(3.685)	(4.218)	(3.574)
ln(population)				−31.805***	−27.375***	3.017	−17.687**	6.490	−23.002***	−4.304
				(7.616)	(8.832)	(6.891)	(7.746)	(7.035)	(7.687)	(5.291)
Trade (% of GDP)						0.266***		0.246***		0.215***
						(0.054)		(0.057)		(0.062)
Sectoral diversification in FDI							−0.067*	−0.027	−0.048	−0.014
							(0.035)	(0.028)	(0.036)	(0.029)
KOF Financial Glob. index							0.277***	0.151**	0.164***	0.096*
							(0.079)	(0.065)	(0.050)	(0.048)
GFCF over GDP (%)							−0.070	0.053	0.201	0.180
							(0.208)	(0.166)	(0.189)	(0.219)
Manufacturing V.A. (% of GDP)									0.746***	0.215
									(0.266)	(0.332)
R&D exp. (% of GDP)									−1.048	−2.333
									(1.402)	(1.399)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	720	720	720	720	720	720	720	720	614	614
R-squared	0.386	0.393	0.415	0.445	0.449	0.652	0.514	0.669	0.611	0.698
Number of countries	45	45	45	45	45	45	45	45	44	44

Note: the dependent variable is the Foreign Input Reliance (FIR) indicator. A constant is included but not reported. Robust standard errors clustered at country level in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

6.3. Industry-level estimates using Pavitt classes

Table 2 provides the estimate results of an empirical model whereby the unit of observation is scaled down from the country to the country-Pavitt level, as reported by equation (4). This analysis allows us to explore whether the functional diversification within Pavitt's industry classes is associated with a lower exposure of the latter to GVC-disrupting events.

Columns 1 to 3 show estimate results stemming from specifications that account for country-Pavitt and time fixed effects, while in columns 4 to 6 we also control for unobserved time-varying factors affecting Pavitt industries. Our FDI-based indicator of functional diversification reports a negative and statistically significant coefficient in all specifications, confirming that greater diversification in terms of value-adding activities is negatively associated with GVC exposure even at the level of Pavitt industries. Once again, total inward FDIs always reports a non-significant although positive coefficient, while gross output (proxying industry size) turns out, as expected, positive and significant.

Finally, and most importantly, in order to investigate further the association between the functional diversification in FDI of industries and their GVC exposure, we test whether the former shows a heterogenous association with FIR across Pavitt classes. This is accomplished by introducing a variable which measures the functional diversification in FDI of country-Pavitt pairs when they belong to a given Pavitt category (i.e., SB, SS, SI, or SD), and that is zero otherwise.[14] Results are reported in Table 3.

Notably, we find that the coefficients of functional diversification in FDI are negative and significant for the SI and SD industries across all model specifications, while they result never statistically significant for the SB and SS classes. The result obtained for the SI and SD industries is largely consistent with the general pattern observed at the country level and discussed in Section 6.1. It is indeed not surprising that these industries "drive" the general results, since it is these macro-sectors that constitute the bulk of the industrial base of emerging countries as well as most high-income economies.

As for the most innovative industries, i.e. SB and SS industries, our results highlight the need of a closer industry-by-industry examination as well as a more detailed analysis of economic and institutional features of countries and macro-regions under observation. While this is a matter for future research, we may dare to suggest here two possible general explanations underlying the results obtained for these two macro-sectors.

First, SB sectors are by definition characterised by a greater role of science and technology as major sources of innovation and economic performance. While functional diversification in FDI is necessary for the generation and exploitation of innovation in these industries, the key competitive challenge is to gain access to knowledge sources and key components wherever available. Hence, there is no guarantee that a higher functional diversification in FDI reduces the need for foreign inputs in these industries. Conversely, SD and SI industries require resources, components and knowledge inputs that can more easily reproduced domestically – or at least at the macro-regional level – through greater diversification efforts.

Second, SS industries are by and large producers of capital goods specialized in the creative assembling of commodity-like components and in the adaptation of equipment to industrial user needs. A large fraction of innovative activities in these industries occurs at the plant level and does not necessarily require institutionalised R&D nor high investment in logistics or in marketing activities. Consequently, expanding the range of functions by enhancing domestic capacities to carry out these activities would not end up reducing FIR in the case of

[14] This empirical strategy is equivalent to estimating an interaction model, with the two additional advantages that (i) it does not require us to arbitrarily set the base level of the interaction terms (in our case, a given Pavitt industry); and (ii) it allows us to show the estimate coefficients of functional diversification in FDI for each of the four Pavitt classes. Moreover, and differently from performing separate estimate regressions by Pavitt class, this technique allows us to carry out these estimates on the whole number of observations included in our sample, thereby improving the efficiency of the fixed effects estimator.

Table 2
Fixed effects model at the country-Pavitt level.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	FIR	FIR	FIR	FIR	FIR	FIR
Functional diversification in FDI	−0.069**	−0.068**	−0.068**	−0.067**	−0.066**	−0.065**
	(0.030)	(0.030)	(0.029)	(0.027)	(0.027)	(0.027)
ln(total inward FDI)		0.431	0.329		1.089	0.981
		(0.798)	(0.797)		(0.811)	(0.807)
ln(gross output)			0.226***			0.218***
			(0.064)			(0.060)
Country-Pavitt FE	YES	YES	YES	YES	YES	YES
Pavitt-Time FE	–	–	–	YES	YES	YES
Time FE	YES	YES	YES	–	–	–
Observations	1408	1408	1408	1408	1408	1408
R-squared	0.401	0.402	0.406	0.447	0.451	0.455
Number of country-Pavitt	88	88	88	88	88	88

Note: the dependent variable is the Foreign Input Reliance (FIR) indicator. A constant is included but not reported. Robust standard errors clustered at country-Pavitt level in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

these industries.

6.4. *Robustness checks at the country-Pavitt level*

As already acknowledged in Section 6.2, the fixed effects estimator might provide biased results due to endogeneity issues stemming from the persistency of FIR over time and potential reverse causality between our dependent variable and our key regressor.

Accordingly, we used the Two-Step System GMM estimator also to test the robustness of our empirical findings at the country-Pavitt level. Results are reported by Table A.5 in the Online Appendix. In particular, columns 1–3 provide GMM-based estimate coefficients for model specifications including functional diversification in FDI at country-Pavitt level, without distinguishing its association with FIR across Pavitt classes (hence replicating the model specifications shown in Table 2). Furthermore, in columns 4–6 we split the coefficient of our key regressor to account for the heterogeneity which emerged in Table 3, concerning the different relationship between FIR and functional diversification in FDI for SB and SS industries on the one hand, and for SI and SD on the other.

Once again, GMM estimates largely confirm our previous findings, further reassuring us about the robustness of our fixed effects results (see the Online Appendix for more detailed comments).

7. Industrial policy implications and conclusions

This work has contributed to fill a key research gap on the links between diversification of economies and their exposure to GVC fragilities. First, it has highlighted that the diversification that matters in a world increasingly characterised by the international fragmentation of production is the variety of functions that economies can undertake within industries more than the breadth of product lines. Second, we have suggested that functional diversification can be a key strategy to expand the bundle of competencies that countries can combine to reduce their exposure to supply chain disruptions. Consistent with this view, we have found that our FDI-based indicator of functional diversification is negatively associated with the need for economies to resort to foreign inputs. The observed negative relationship is robust across different model specifications and holds for a relatively large array of sectors. Our results thus generally confirm that broadening value chain functions enables economies to cultivate a wider set of technological capabilities and a more robust productive matrix. Beyond merely reducing dependency on specific foreign suppliers, functional diversification enables industries to better adapt to, and recover from, disruptions in supply chains.

It follows that while investing in intangible-intensive activities – such as R&D, commercialization and after-sales functions – represents a key strategy to increase value capture opportunities, this should not be taken as an invitation to abandon (and redeploy) manufacturing and assembly. In fact, there are important complementarities and interdependencies across functions that need to be exploited to enhance the capacity of economies to respond to GVC disruptions (Pisano and Shih, 2012; Coveri and Zanfei, 2023a). By the same token, our results should not be interpreted as straightforward evidence in support of backshoring strategies. Rather, our findings suggest that economies exhibiting greater functional diversification are better placed to seize the opportunities associated with global production networks, as well as to cope with the challenges due to potential supply chain interruptions.

The key policy implication we derive from our analysis is that countries should combine a reshaping of GVCs, to prioritize suppliers based on their value creation and reliability, with the strengthening of national and regional capacities to perform critical activities. This *dual strategy* of GVC restructuring and enhancing functional (and industrial) diversification can bolster economic resilience against disruptive events and facilitate innovative responses. Accordingly, it is suggested that governments should undertake targeted and long-term commitments to expand the array of value chain functions that economies are able to perform while carefully selecting partners involved in GVCs. This effort is more likely to be effective when conducted at the macro-regional level, as this would allow to better exploit economies of scale and scope. However, it would require a coordinated supranational strategy to identify where to concentrate and diversify value-adding activities within integrated regions and to develop targeted international production linkages.

Our research line is broadly consistent with views of industrial policies aimed to enhance domestic capabilities and economic diversification in a context of global interdependencies (Rodrik, 2008; Landesmann and Stöllinger, 2019; Hauge, 2020). Indeed, recent policy initiatives appear to have partially adopted this approach. In the U.S., the 2021 White House report “Building Resilient Supply Chains” emphasized the need to increase domestic control over key industries to enhance economic resilience. Similarly, the EU report published in 2019 on “Strengthening Strategic Value Chains” underscored the importance of reducing critical industrial and technological dependence from third countries, while developing domestic capabilities across strategic industries. What needs to be made more explicit is that public policies should not only aim to increase domestic investment in key industries as a means to reduce foreign dependence. As our research suggests, such policies should be designed to broaden the array of value-adding activities within industries.

Moreover, our findings highlight that policy interventions ought to be tailored to the specific characteristics and needs of different industries. For instance, in the case of Science-based industries, reducing reliance on foreign inputs may not be an objective to pursue as such, as it

Table 3
Fixed effects model at the country-Pavitt level distinguishing by Pavitt class.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	FIR	FIR	FIR	FIR	FIR	FIR
Func. div. in FDI *in SB*	−0.053	−0.050	−0.050	−0.068	−0.064	−0.063
	(0.063)	(0.064)	(0.064)	(0.067)	(0.066)	(0.067)
Func. div. in FDI *in SS*	0.019	0.017	0.013	0.021	0.016	0.012
	(0.035)	(0.036)	(0.035)	(0.028)	(0.029)	(0.028)
Func. div. in FDI *in SI*	−0.147**	−0.144**	−0.141**	−0.140**	−0.133**	−0.129**
	(0.062)	(0.063)	(0.062)	(0.059)	(0.060)	(0.059)
Func. div. in FDI *in SD*	−0.098**	−0.099**	−0.097**	−0.085**	−0.087**	−0.085**
	(0.039)	(0.038)	(0.039)	(0.042)	(0.042)	(0.043)
ln(total inward FDI)		0.329	0.237		0.989	0.891
		(0.811)	(0.810)		(0.819)	(0.814)
ln(gross output)			0.214***			0.207***
			(0.066)			(0.062)
Country-Pavitt FE	YES	YES	YES	YES	YES	YES
Pavitt-Time FE	–	–	–	YES	YES	YES
Time FE	YES	YES	YES	–	–	–
Observations	1408	1408	1408	1408	1408	1408
R-squared	0.406	0.407	0.411	0.452	0.454	0.458
Number of country-Pavitt	88	88	88	88	88	88

Note: the dependent variable is the Foreign Input Reliance (FIR) indicator. SB, SS, SI, and SD stand for Science-based, Specialized suppliers, Scale-intensive, and Supplier-dominated industries, respectively. A constant is included but not reported. Robust standard errors clustered at country-Pavitt level in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

could hinder the international competitiveness of these strategic knowledge-based sectors. Rather, policies should be aimed at facilitating access to global knowledge networks, while increasing functional diversification to enhance the capacity to generate, absorb and utilize technology. By contrast, Scale-intensive sectors may benefit more from investments aimed at strengthening domestic supply chain capabilities, thereby reducing foreign reliance on strategic components and overall exposure to GVC disruptions. By adopting sector-specific policies, countries can thus optimize the benefits of both functional diversification and global networking according to the structure and sourcing needs of industries.

Overall, our results show that a partial regionalization of value chains might create more stable and less risky supply networks in some circumstances, thereby reducing exposure to global disruptions. Nevertheless, policies should keep into account the need for the most innovative industries to source key components and knowledge assets located abroad and engage in international collaborations with selected partners. It follows that reducing overall involvement in global networks is not *per se* a rule of thumb.

Furthermore, an industrial policy strategy based on a mix of functional diversification and selective sourcing of foreign inputs is not only sector-specific, but also constrained by the opportunity costs associated with it. Indeed, such a strategy may result in higher prices, at least in the short run. If one were to adopt a straightforward comparative advantage approach, the allocation of functions should occur according to relative production costs, thus minimizing consumer prices. By contrast, a functional diversification driven strategy may reduce the standard gains from trade for the benefit of greater self-reliance, broader competencies and higher security. Faced with this trade-off, each country would decide what is more important to it: lower prices or greater production capacity and stability.

One might suggest that there is a certain level of international interdependence below which the advantages of domestic diversification are more than offset by higher prices and lower input variety.[15] What needs to be stressed is that the increasing uncertainties in trade relations are likely to imply that countries will necessarily assign greater value to security, stability and dynamic efficiency than used to be the case in relatively recent and less turbulent times.

Despite the robustness of our findings, limitations exist. First, we should improve our understanding of factors favoring functional diversification at the national and macro-regional levels. This calls for a closer analysis of the mechanisms underlying both domestic and foreign investments in different value-adding activities, as well as the role played by the involvement of countries in free trade agreements and macro-regional production networks.

Second, future research should more carefully consider how a country's position along GVCs affects both its exposure and incentives to (functionally) diversify. For example, several emerging economies have long specialized in specific functions that are more consistent with their key competitive advantages, with little or no capacity to diversify into other value-adding activities. This is for instance the case of Thailand and Vietnam, which have mainly developed fabrication and assembly capacities and have used this specialization strategy as a key asset to enter a wide variety of GVCs. While joining GVCs has represented a key pathway to industrialization for low- and middle-income countries, economies that have done so by specializing in relatively few, low value-adding functions are likely more exposed to potential GVC disruptions. Although our empirical analysis does control for the GVC positioning and level of economic development of countries, future research could further investigate how economies differ according to their mix of functional diversification and reliance on foreign inputs, as well as in terms of the geographic and sectoral concentration of foreign reliance. Indeed, these factors are likely to critically shape the adaptive capabilities of economies in the face of GVC shocks.

Third, a further limitation of this study lies in its exclusive focus on FIR, which measures the GVC exposure of economies to upstream (foreign) suppliers (i.e., import dependencies). While this approach aligns with our research focus on supply-side vulnerabilities, it does not account for export dependencies, often referred to as Foreign Market Reliance. Export dependencies reflect an economy's GVC exposure to disruptions stemming from its reliance on specific downstream (foreign) buyers. This is the case, for instance, with contractions in foreign markets that can result from tariff wars (Freund et al., 2024; Grossman et al., 2024). Accordingly, future research could explore the relationship between functional diversification and export dependencies, investigating whether economies that perform a wider range of value-adding functions are better positioned to mitigate the risks associated with concentrated demand-side dependencies. Such an analysis would require a distinct conceptual framework to identify the theoretical channels through which functional diversification might affect exposure

[15] We are grateful to an anonymous reviewer for bringing this point to our attention.

to downstream bottlenecks. By jointly considering both upstream and downstream dependencies, future studies could thus provide a more comprehensive understanding of the role played by functional diversification in shaping the overall GVC exposure of countries and industries.

Finally, future research could empirically explore how functional diversification affects the actual responsiveness of economies to sudden events. Indeed, there is ample room for work on the capacity of economies to react to shocks and improve their subsequent performance, also considering the complex interplay with sector- and firm-specific factors. This contribution could not address this issue due to the limited time-span of available data. For instance, the data cut-off to 2018 makes it impossible to analyze the actual outcomes of recent disruptions, such as the COVID-19 pandemic or the more recent tariff war initiated by the US administration (Baldwin, 2025; Gensler et al., 2025). These events have further highlighted the importance of stability in value chains and how shocks can undermine international interdependence. The availability of more up-to-date data could enable future studies to investigate how GVC shocks actually translate into different economic performances according to countries' functional diversification profiles. From this perspective, more granular and recent data would be invaluable to improve our understanding of the relationship between diversification and resilience, as well as to tailor industrial policy interventions accordingly.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.econmod.2025.107303.

Data availability

The authors do not have permission to share data.

Research Data on 'The links between diversification and GVC exposure' (Original data) (Mendeley Data)

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