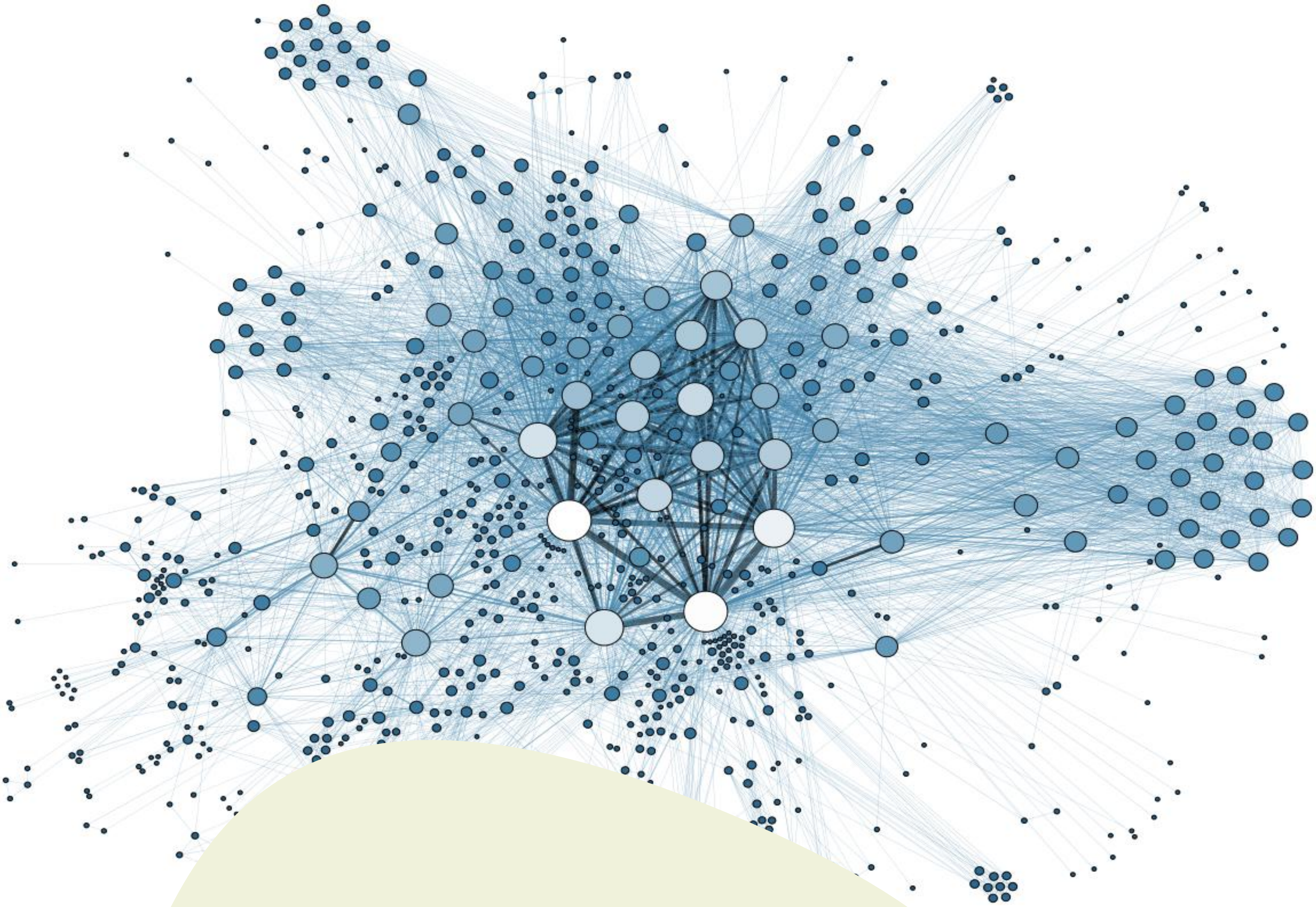

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Tracing Regional Integration into Global Value Chains*

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Abstract

This study examines how European regions are integrated into global value chains by tracing how regional production is realized within a multiregional production system. Using a multiregional input–output framework, the analysis moves beyond participation intensity and upstream–downstream position to characterize integration through distinct production roles, linkage structures, and propagation mechanisms in a multistage economy. Based on MRIO data for European NUTS2 regions over the period 2000–2017, the study shows why participation and functional position alone fail to identify the structural configuration of production linkages, the depth of indirect propagation, or scale-dependent system significance. A two-dimensional activity space is introduced to describe regions' forward and backward production linkages, while indirect propagation depth captures how regional value added is transmitted through successive production stages. Economic scale is reintroduced through propagation mass, allowing identification of system-significant regions whose production generates disproportionately large indirect effects. The results show that regional integration has increased across Europe without convergence in regional roles. Instead, deeper integration has reinforced a differentiated regional allocation of economic activities, implying that regional exposure and system significance cannot be inferred from participation or positional indicators alone.

Keywords: Europe, Global value chains, Regional integration, Multiregional input–output analysis, FIGARO-REG
JEL classification: F14, R12, C67, O52

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1. Introduction

Global value chains (GVCs) have fundamentally reorganized production on a global scale, fragmenting value creation across multiple countries, regions, and production stages (Baldwin 2006; Mudambi 2007; 2008). This unbundling of production has brought significant gains in efficiency, specialization, and knowledge diffusion by allowing each stage of production to be located where it can be performed most productively. At the same time, the increasing fragmentation of production has made regional economies more interdependent and exposed to distant disruptions. Recent shocks – notably the COVID-19 pandemic and rising geopolitical tensions – have starkly illustrated how vulnerabilities and risks propagate through GVC networks, and how unevenly the gains and pains of globalization can be distributed (OECD 2013; Timmer et al. 2014; Baldwin et al. 2022; Baldwin & Evenett 2020; Gereffi 2023). These developments underscore that it is no longer sufficient to ask whether a region is integrated into GVCs, but rather how it is integrated. In other words, the form and depth of a region's integration into global value chains have become as consequential as the fact of integration itself.

Empirical research on global value chains has predominantly adopted a national perspective, developing measures of participation and functional position – such as upstreamness and downstreamness – based on trade in value added and input–output techniques (Koopman et al. 2014; Los et al. 2015a, 2015b; Aslam et al. 2017; Wang et al. 2017). While this literature has substantially advanced the understanding of international production fragmentation, it relies on an abstraction that is analytically consequential. The production relationships that constitute global value chains are organized through firm- and region-level linkages: production stages, supplier–buyer relationships, and intermediate input flows are anchored in specific locations, and regions within the same country often occupy distinct and persistent roles within the production system (Ivanova et al. 2019; Bolea et al. 2022; Baldwin et al. 2025). Treating regions as production units in their own right is therefore necessary for understanding how production is structured and how shocks and policy interventions propagate through the production system.

This heterogeneity matters because production in a multistage economy is realized through sequences of interdependent activities rather than through isolated regional or national units. Economic outcomes, therefore, depend not only on participation in global value chains but also on how regional production is embedded in interregional input–output relationships and how production impulses propagate through the system. Regions that appear similar when assessed at the national level may differ fundamentally in their role within system-wide production interdependence, in their exposure to disruptions, and in their economic significance once scale is taken into account. Without an explicit focus on these regional production relationships, such differences remain hidden, limiting our ability to understand the transmission of shocks and the effects of policy interventions. This study addresses this gap by shifting the analytical focus from aggregate participation and position toward the structural mechanisms through which regional production is embedded in interregional input–output relationships.

The purpose of this study is to trace how regional production is realized within a multiregional production system by following how value added generated in one region is transmitted through successive stages of production and ultimately absorbed in final demand. In a setting where production is organized through tightly coupled input–output relationships, regional outcomes cannot be inferred from participation or position alone but depend on how production impulses propagate through the system as a whole. The analysis, therefore, shifts attention away from integration as a descriptive label and toward integration as an emergent property of interregional production interdependence under a Leontief equilibrium. This perspective is essential for

understanding why regions that appear similar in aggregate indicators can differ fundamentally in their exposure to shocks, their capacity to transmit disturbances, and their economic significance once the scale of production is taken into account.

Throughout this paper, the term "global value chains" is used as a shorthand for multistage production networks spanning multiple regions and countries. This usage aligns with the input–output literature on value-added trade and GVCs: we do not assume a literal, linear chain of firm-to-firm transactions, but rather capture production interdependencies as represented in an MRIO system (Miller & Blair 2009; Aslam et al. 2017). References to cross-border, interregional, or global linkages should thus be understood as referring to the spatial organization of production within the MRIO framework, rather than to any single firm's supply chain.

The remainder of the report is organized as follows. Chapter 2 introduces the multiregional input–output framework and formally defines the set of indicators used to quantify regional GVC integration. Chapter 3 describes the multiregional tables and their construction. Chapter 4 presents empirical analysis: it first examines traditional measures of GVC participation and functional position as a baseline, and then deploys our decomposition into activity space, value chain length, and system significance to disentangle structural configuration, indirect propagation, and scale effects in regional integration. This chapter also incorporates the demand-side exposure analysis, tracing where each region's value added is ultimately absorbed. Chapter 5 synthesizes the main findings and draws overall conclusions, and Chapter 6 discusses implications in light of the results. An extensive glossary of key terms is provided in the Appendix.

2. Modelling Framework

2.1 The multiregional input-output model

Since the pioneering work of Wassily Leontief (1936, 1941), input–output (IO) analysis has been used to trace structural relationships between production and final demand within an economy. A standard national IO table records how each industry's output is allocated between intermediate use and final demand. However, single-region models abstract from interregional production linkages and thus from the integration of regions into wider production networks through trade and global value chains. The first interregional applications emerged in the 1950s (Isard 1951, 1960; Leontief 1953; Chenery 1953; Moses 1955), extending the IO framework to capture production interdependencies across subnational units. Subsequent methodological developments further formalized and expanded interregional input–output modelling (see, e.g., Hewings & Oosterhaven 2014).

The Multiregional Input–Output (MRIO) model extends the standard IO framework by endogenizing interregional trade flows within a single accounting system. Rather than treating national economies in isolation, MRIO models represent production and demand as jointly determined across regions, allowing intermediate inputs and value added to be traced through multistage production networks. This representation allows identification of how regional production is structurally embedded in cross-regional input–output relationships and how production impulses propagate through the system under a Leontief equilibrium.

To illustrate how these conceptual relationships are operationalized in practice, the following section presents a simplified numerical example of a Multiregional Input-Output (MRIO) table. This example, based primarily on Aslam et al. (2017), demonstrates the structure and key components of an MRIO system, including intermediate transact-tions, final demand, and value-added across multiple regions and sectors. By examining this stylized case, we clarify how MRIO models capture interregional production link-ages, trace supply chains, and ensure consistency between total input and output flows in a globally integrated economy.

		Transaction matrix T (or Z)												Final demand FD (or Y)			Gross output Xout	Gross exports E
		Region 1				Region 2				Region 3				Region 1	Region 2	Region 3		
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Households	Households	Households	Total	Total export
Region 1	Sector 1	346	156	95	594	819	154	832	397	409	562	241	554	394	902	446	**6 901**	**5 316**
	Sector 2	354	443	7	908	42	92	561	839	470	770	83	368	514	694	512	**6 657**	**4 431**
	Sector 3	291	795	243	825	753	2	340	232	251	605	526	610	384	753	909	**7 518**	**4 980**
	Sector 4	637	259	289	813	500	716	947	645	856	221	898	41	91	653	301	**7 868**	**5 778**
Region 2	Sector 1	547	466	910	276	518	149	779	553	197	285	305	828	630	565	857	**7 864**	**5 300**
	Sector 2	752	936	822	638	611	496	98	924	608	689	872	972	847	209	37	**9 511**	**7 173**
	Sector 3	295	444	7	828	929	535	367	257	890	429	641	26	165	419	886	**7 117**	**4 610**
	Sector 4	113	518	791	459	79	748	254	218	586	673	424	157	800	355	501	**6 677**	**5 022**
Region 3	Sector 1	46	457	552	572	632	680	730	607	796	186	15	958	338	320	194	**7 082**	**4 934**
	Sector 2	962	96	544	96	675	113	711	337	787	571	241	211	479	14	608	**6 445**	**4 027**
	Sector 3	531	190	686	191	374	615	788	738	351	32	565	622	269	814	559	**7 326**	**5 197**
	Sector 4	857	776	897	18	915	482	308	458	253	145	982	270	700	822	729	**8 612**	**6 233**
		Value added VA															Sum of output	
Region 1	Value Added	1 172	1 120	1 676	1 648	-	-	-	-	-	-	-	-				**89 578**	
Region 2	Value Added	-	-	-	-	1 019	4 730	401	471	-	-	-	-					
Region 3	Value Added	-	-	-	-	-	-	-	-	626	1 278	1 532	2 995					
		Gross input Xin												Sum of input				
	Total	**6 901**	**6 657**	**7 518**	**7 868**	**7 864**	**9 511**	**7 117**	**6 677**	**7 082**	**6 445**	**7 326**	**8 612**	**89 578**				

Table 2.1. Numerical example of a MRIO table showing intermediate transactions T, final demand FD, and value-added VA across multiple regions and sectors. Source: Eora MRIO database: https://worldmrio.com/eora26/ (see also Lenzen et al. 2012, 2013).

An MRIO table is organized into sections that map the flow of goods and services across multiple regions and sectors. Table 2.1 shows the inputs (in columns) and the outputs (in rows) from each regional sector. Each entry shows the volume of inputs a sector acquires from the same region or other regions, along with data on final demand (household consumption, investments, and exports) and the value-added (wages, profits, and other non-input costs). All entries are expressed in monetary terms.

The transaction matrix T describes the intermediate inputs each sector purchases from other regions and sectors (including its own). The FD columns show the final demand from each region and sector, that is, how much of the output from each regional sector is consumed by end-users in each region. At the bottom, the VA matrix shows the value-added, capturing wages, profits, and other non-input costs. Note that the sum of the total input X_{in} equals the sum of the gross output X_{out}, ensuring total production equals total use (intermediate consumption plus final demand). In the table we also see the gross export E measured as the export from each region-sector to sectors and end users in other regions.

Building an MRIO table involves gathering national and regional IO data, aligning sector definitions, and balancing import–export discrepancies. The result is an integrated system linking all regions through trade flows.

2.2 The Leontief inverse

Consider a MRIO-table with n_r regions and n_s sectors which combine to $n = n_r \cdot n_s$ region-sectors. Each row and column in the transaction matrix T of size $n \times n$ represents the inputs and outputs of all firms in a specific region r and sector s. Consequently, row i and column j each denote a unique region-sector combination (r, s).

The column j of the transaction matrix T represents the inputs to region-sector j from all other region-sectors i. The total output x_j of region-sector j is then:

$$x_j = \sum_i T_{ij} + y_j$$

where y_j is the final demand for sector j calculated as the sum of the purchases from all regions r in the final demand FD matrix FD, i.e. $y_j = \sum_r f_{rj}$.

The technical coefficient matrix A is calculated by dividing each element in T with the corresponding column in the total output vector. Each element a_{ij} in A is the fraction of region-sector j's output that is purchased by sector i, or:

$$a_{ij} = \frac{T_{ij}}{x_j}$$

The A matrix normalizes the transaction values by the total output of the purchasing sector. Similarly, the value-added share va_j is:

$$va_j = \frac{VA_j}{x_j}$$

Where VA_j is the value-added for region-sector j and x_j is its total output.

The calculation for the numerical example is shown below.

Technichal coefficient matrix A

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	0,05	0,02	0,01	0,08	0,10	0,02	0,12	0,06	0,06	0,09	0,03	0,06
	Sector 2	0,05	0,07	0,00	0,12	0,01	0,01	0,08	0,13	0,07	0,12	0,01	0,04
	Sector 3	0,04	0,12	0,03	0,10	0,10	0,00	0,05	0,03	0,04	0,09	0,07	0,07
	Sector 4	0,09	0,04	0,04	0,10	0,06	0,08	0,13	0,10	0,12	0,03	0,12	0,00
Region 2	Sector 1	0,08	0,07	0,12	0,04	0,07	0,02	0,11	0,08	0,03	0,04	0,04	0,10
	Sector 2	0,11	0,14	0,11	0,08	0,08	0,05	0,01	0,14	0,09	0,11	0,12	0,11
	Sector 3	0,04	0,07	0,00	0,11	0,12	0,06	0,05	0,04	0,13	0,07	0,09	0,00
	Sector 4	0,02	0,08	0,11	0,06	0,01	0,08	0,04	0,03	0,08	0,10	0,06	0,02
Region 3	Sector 1	0,01	0,07	0,07	0,07	0,08	0,07	0,10	0,09	0,11	0,03	0,00	0,11
	Sector 2	0,14	0,01	0,07	0,01	0,09	0,01	0,10	0,05	0,11	0,09	0,03	0,02
	Sector 3	0,08	0,03	0,09	0,02	0,05	0,06	0,11	0,11	0,05	0,00	0,08	0,07
	Sector 4	0,12	0,12	0,12	0,00	0,12	0,05	0,04	0,07	0,04	0,02	0,13	0,03

Value added share va

Value Added	0,17	0,17	0,22	0,21	0,13	0,50	0,06	0,07	0,09	0,20	0,21	0,35

Table 2.2. Technical coefficient matrix A and value-added shares, va, for the numerical example.

The Leontief matrix $(I - A)$ shows how each region-sector's output requirements change once the direct region-sector interdependencies in A are removed. It is constructed by subtracting the technical coefficient matrix A from the identity matrix I.

Finally, the Leontief inverse B is calculated by calculating the inverse of $(I - A)$.

$$B = (I - A)^{-1}$$

It shows how a unit increase in final demand for any sector ripples through the entire system of sectors and regions. Each element b_{ij} in B captures the total (direct and indirect) output required from region-sector i to satisfy a one-unit increase in final demand for region-sector j.

Using this notation, the relationship between gross output X, intermediate goods, and final demand Y can be expressed as:

$$X = AX + Y$$

Bringing everything together, the fundamental input–output identity is:

$$(I - A)X = Y \rightarrow X = (I - A)^{-1}Y = BY$$

Hence, the Leontief inverse $B = (I - A)^{-1}$ is key to understanding how changes in final demand ripple through the entire system, affecting total production across all regions and sectors. The elements of the Leontief inverse matrix B indicate the total output, both direct and indirect, required to produce one unit of goods for final demand.

The calculation for the numerical example is shown below:

Leontief inverse matrix B

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	1,27	0,24	0,22	0,30	0,35	0,16	0,39	0,31	0,32	0,30	0,24	0,24
	Sector 2	0,27	1,28	0,20	0,34	0,24	0,15	0,35	0,37	0,33	0,34	0,21	0,20
	Sector 3	0,28	0,35	1,25	0,34	0,34	0,15	0,34	0,30	0,31	0,32	0,29	0,25
	Sector 4	0,38	0,33	0,32	1,41	0,38	0,27	0,50	0,44	0,48	0,33	0,40	0,24
Region 2	Sector 1	0,32	0,32	0,35	0,28	1,33	0,17	0,40	0,35	0,31	0,29	0,27	0,28
	Sector 2	0,46	0,50	0,45	0,44	0,46	1,28	0,45	0,54	0,50	0,47	0,45	0,40
	Sector 3	0,29	0,31	0,24	0,35	0,38	0,22	1,36	0,33	0,42	0,31	0,32	0,20
	Sector 4	0,24	0,30	0,31	0,28	0,25	0,22	0,30	1,28	0,34	0,33	0,26	0,19
Region 3	Sector 1	0,27	0,35	0,33	0,34	0,37	0,25	0,42	0,39	1,43	0,29	0,26	0,32
	Sector 2	0,36	0,24	0,28	0,24	0,34	0,15	0,38	0,30	0,38	1,32	0,24	0,21
	Sector 3	0,31	0,28	0,32	0,27	0,31	0,22	0,39	0,38	0,33	0,25	1,31	0,26
	Sector 4	0,38	0,38	0,37	0,27	0,40	0,21	0,37	0,37	0,33	0,29	0,38	1,25

Table 2.3. Leontief inverse matrix B for the numerical example.

2.3 Multipliers and economic linkages

Multiplier analysis provides insight into the systemic relevance of a region-sector, sector, or region by tracing how economic impulses propagate through global supply chains (Miller & Blair 2009). In the context of GVCs, this reveals how embedded a region is, not only in terms of participation but also in terms of structural influence.

In a multiregional economy, changes in demand for one region–sector affect industries across multiple regions through interlinked supply chains. Multipliers quantify these effects, measuring how shifts in one place spread through the system. Here, the system refers to the multiregional production network represented by the MRIO framework, encompassing all region–sector units and their input–output linkages as defined by the technical coefficients and the Leontief equilibrium.

Multipliers are divided into direct, λ^D, indirect, λ^I, and total effects, λ. Direct multipliers measure a sector's dependence on inputs from others (backward effect) and how much it supplies as an input to other sectors (forward effect). Indirect multipliers measure the extended backward and forward effects of a sector's output increase as it generates additional demand throughout the supply chain. Total multipliers measure the combined direct and indirect effects, showing the overall economic impact of a sector's output change[4]. While direct multipliers capture the first-round impact, indirect and total multipliers come from the higher-order terms in the Leontief inverse:

$$B = (I - A)^{-1} = I + A + A^2 + A^3 + \cdots$$

These additional powers of A (A^2, A^3, ...) account for the next rounds of purchasing triggered by the initial shock, eventually showing how changes in one region-sector permeate the entire economy (or region–sectors in MRIO).

Describing interregional dependencies, backward effects measure a sector's reliance on inputs from other regions, while forward effects show how its output supports production elsewhere. Together, these measures reveal the structure of global supply chains and regional economic connections.

The backwards and forwards multipliers are calculated as follows:

Direct backward multiplier

The direct backward multiplier for region-sector j is:

$$\lambda_j^{DB} = \sum_i a_{ij}$$

This measures how heavily sector j relies on direct inputs from all other sectors. If final demand for j increases, λ_j^{DB} indicates the fraction of j's output made up by immediate purchases from upstream suppliers.

Total backward multiplier

The total backward multiplier for region-sector j is:

$$\lambda_j^{B} = \sum_i b_{ij}$$

where b_{ij} is elements in the Leontief inverse matrix $B = (I - A)^{-1}$. This measures the total (direct and indirect) impact on upstream suppliers when final demand for sector j increases.

Indirect backward multiplier

[4] The IO literature also contains theoretical and empirical analyses of induced effects, i.e., effects feedback effects arising from increases in private consumption, see e.g. Miyazawa (1976). This volume has opened a large literature on Leontief multipliers. Only some of this work has yet been incorporated into the GVC literature.

The indirect backward multiplier for region-sector j is:

$$\lambda_j^{IB} = \lambda_j^{B} - \lambda_j^{DB} = \sum_i b_{ij} - \sum_i a_{ij}$$

This captures how additional rounds of input demand spread through the economy and is calculated as the difference between total backward effects and direct backward effects.

Direct forward multiplier

The direct forward multiplier for region-sector i is:

$$\lambda_i^{DF} = \sum_j a_{ij}$$

This measures how much of the output of region-sector i that is directly used by other sectors. It reflects how important i is as a provider of inputs in the next step of the supply chain.

Total forward multiplier

The total forward multiplier for region-sector i is:

$$\lambda_i^{F} = \sum_j b_{ij}$$

This measures the total (direct and indirect) contribution of sector i as a supplier to other sectors and regions. It reflects the immediate and subsequent rounds of interdependencies in the economy, showing how much total output in other sectors depends on sector i.

Indirect forward multiplier

The indirect forward multiplier for region-sector i is:

$$\lambda_i^{IF} = \lambda_i^{F} - \lambda_i^{DF} = \sum_j b_{ij} - \sum_j a_{ij}$$

This reflects the ripple effects of sector i's output as it moves through successive supply chain stages, extending beyond direct interactions.

A calculation of the multipliers for the numerical example is shown below:

Technichal coefficient matrix A

		Region 1				Region 2				Region 3				Direct Forward Multiplier
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	
Region 1	Sector 1	0,05	0,02	0,01	0,08	0,10	0,02	0,12	0,06	0,06	0,09	0,03	0,06	0,70
	Sector 2	0,05	0,07	0,00	0,12	0,01	0,01	0,08	0,13	0,07	0,12	0,01	0,04	0,69
	Sector 3	0,04	0,12	0,03	0,10	0,10	0,00	0,05	0,03	0,04	0,09	0,07	0,07	0,75
	Sector 4	0,09	0,04	0,04	0,10	0,06	0,08	0,13	0,10	0,12	0,03	0,12	0,00	0,92
Region 2	Sector 1	0,08	0,07	0,12	0,04	0,07	0,02	0,11	0,08	0,03	0,04	0,04	0,10	0,79
	Sector 2	0,11	0,14	0,11	0,08	0,08	0,05	0,01	0,14	0,09	0,11	0,12	0,11	1,15
	Sector 3	0,04	0,07	0,00	0,11	0,12	0,06	0,05	0,04	0,13	0,07	0,09	0,00	0,76
	Sector 4	0,02	0,08	0,11	0,06	0,01	0,08	0,04	0,03	0,08	0,10	0,06	0,02	0,68
Region 3	Sector 1	0,01	0,07	0,07	0,07	0,08	0,07	0,10	0,09	0,11	0,03	0,00	0,11	0,82
	Sector 2	0,14	0,01	0,07	0,01	0,09	0,01	0,10	0,05	0,11	0,09	0,03	0,02	0,74
	Sector 3	0,08	0,03	0,09	0,02	0,05	0,06	0,11	0,11	0,05	0,00	0,08	0,07	0,76
	Sector 4	0,12	0,12	0,12	0,00	0,12	0,05	0,04	0,07	0,04	0,02	0,13	0,03	0,86
Direct Backward Multiplier		0,83	0,83	0,78	0,79	0,87	0,50	0,94	0,93	0,91	0,80	0,79	0,65	

Leontief inverse matrix B

		Region 1				Region 2				Region 3				Total Forward Multiplier
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	
Region 1	Sector 1	1,27	0,24	0,22	0,30	0,35	0,16	0,39	0,31	0,32	0,30	0,24	0,24	4,34
	Sector 2	0,27	1,28	0,20	0,34	0,24	0,15	0,35	0,37	0,33	0,34	0,21	0,20	4,27
	Sector 3	0,28	0,35	1,25	0,34	0,34	0,15	0,34	0,30	0,31	0,32	0,29	0,25	4,52
	Sector 4	0,38	0,33	0,32	1,41	0,38	0,27	0,50	0,44	0,48	0,33	0,40	0,24	5,48
Region 2	Sector 1	0,32	0,32	0,35	0,28	1,33	0,17	0,40	0,35	0,31	0,29	0,27	0,28	4,67
	Sector 2	0,46	0,50	0,45	0,44	0,46	1,28	0,45	0,54	0,50	0,47	0,45	0,40	6,39
	Sector 3	0,29	0,31	0,24	0,35	0,38	0,22	1,36	0,33	0,42	0,31	0,32	0,20	4,72
	Sector 4	0,24	0,30	0,31	0,28	0,25	0,22	0,30	1,28	0,34	0,33	0,26	0,19	4,30
Region 3	Sector 1	0,27	0,35	0,33	0,34	0,37	0,25	0,42	0,39	1,43	0,29	0,26	0,32	5,02
	Sector 2	0,36	0,24	0,28	0,24	0,34	0,15	0,38	0,30	0,38	1,32	0,24	0,21	4,45
	Sector 3	0,31	0,28	0,32	0,27	0,31	0,22	0,39	0,38	0,33	0,25	1,31	0,26	4,62
	Sector 4	0,38	0,38	0,37	0,27	0,40	0,21	0,37	0,37	0,33	0,29	0,38	1,25	5,01
Total Backward Multiplier		4,82	4,87	4,63	4,86	5,15	3,45	5,64	5,36	5,47	4,83	4,64	4,06	

Table 2.4. Calculation of direct and total backward and forward multipliers for the numerical example.

2.4 Activity space

Forward and backward multipliers are commonly analyzed separately, but important differences in production structure only become visible when the two dimensions are considered jointly. To capture the joint configuration of upstream dependence and downstream propagation, we define activity space as a two-dimensional representation of regional production linkages within the MRIO system.

Let λ_{rs}^{F} and λ_{rs}^{B} denote the total forward and total backward multipliers for region–sector (r, s), derived from the Leontief inverse as defined in Section 2.3. These multipliers summarize the total direct and indirect production effects associated with a unit change in final demand for, or supply from, a given region-sector.

Region-level total forward and backward multipliers are obtained by aggregating across sectors within each region. To abstract from economic scale and sectoral size, and to ensure that activity space captures structural configuration rather than volume, we define regional multipliers as simple averages across sectors:

$$\lambda_r^F = \frac{1}{n_s}\sum_s \lambda_{rs}^F, \quad \lambda_r^B = \frac{1}{n_s}\sum_s \lambda_{rs}^B$$

where n_s denotes the number of sectors in region r. This normalization ensures that regions are compared based on the structure of their production linkages rather than the magnitude of output or the number of transactions.

The activity space position of region r is defined as the ordered pair:

$$(\lambda_r^F, \lambda_r^B)$$

The backward dimension captures cumulative upstream production requirements embodied in regional production, while the forward dimension captures the extent to which regional production propagates downstream through successive production rounds in other regions and sectors. Activity space is therefore a purely structural representation of production interdependencies. It does not measure participation intensity, proximity to final demand, or economic scale.

Interpreting movements in activity space over time, an outward shift along the forward dimension reflects a deepening of downstream propagation, indicating that regional production increasingly passes through multiple intermediate stages before reaching final demand. This interpretation underpins the empirical analysis in Chapter 4, where changes in activity space are read as evidence of lengthening and increasing fragmentation of production networks.

Table 2.5 provides a numerical example of how activity space is constructed from regional indirect forward and backward multipliers aggregated across sectors. The relatively high values along both dimensions indicate substantial indirect embedding in multistage production networks, with slightly stronger upstream dependence than downstream propagation. Together, these values determine the region's position in activity space. At the regional level, total forward and backward values reflect the aggregation of sector-level propagation effects across all sectors and should not be interpreted as multipliers in the conventional scalar sense.

		Total Forward Multiplier	Direct Forward Multiplier	Indirect Forward Multiplier	Total Backward Multiplier	Direct Backward Multiplier	Indirect Backward Multiplier
Region 1	Sector 1	4,34	0,70	3,64	4,82	0,83	3,99
	Sector 2	4,27	0,69	3,58	4,87	0,83	4,04
	Sector 3	4,52	0,75	3,77	4,63	0,78	3,85
	Sector 4	5,48	0,92	4,55	4,86	0,79	4,07
Region 2	Sector 1	4,67	0,79	3,88	5,15	0,87	4,28
	Sector 2	6,39	1,15	5,24	3,45	0,50	2,94
	Sector 3	4,72	0,76	3,95	5,64	0,94	4,70
	Sector 4	4,30	0,68	3,62	5,36	0,93	4,43
Region 3	Sector 1	5,02	0,82	4,20	5,47	0,91	4,56
	Sector 2	4,45	0,74	3,71	4,83	0,80	4,03
	Sector 3	4,62	0,76	3,87	4,64	0,79	3,85
	Sector 4	5,01	0,86	4,15	4,06	0,65	3,41
	Region 1	4,65	0,77	3,89	4,80	0,81	3,99
	Region 2	5,02	0,84	4,18	4,90	0,81	4,09
	Region 3	4,78	0,80	3,98	4,75	0,79	3,96

Table 2.5. Calculation of indirect forward and indirect backward multipliers at the region-sector level and aggregated at the regional level for the numerical example.

2.5 Value chain length and net propagation

While activity space captures the configuration of forward and backward linkages, it abstracts from the depth of indirect propagation and from the directional balance between upstream dependence and downstream influence. To capture these dimensions explicitly, we define two complementary measures: value chain length and net propagation.

Value chain length

Value chain length is proxied by the indirect share of total production effects implied by the Leontief equilibrium. It measures the extent to which production effects are transmitted through higher-order propagation rounds, rather than being absorbed through direct input–output relationships.

Let λ_r^{DF} and λ_r^{DB} denote direct forward and direct backward effects and λ_r^{IF} and λ_r^{IB} denote indirect the corresponding effects for region r defined as:

$$\lambda_r^{IF} = \lambda_r^F - \lambda_r^{DF} = \frac{1}{n_s}\sum_s \lambda_{rs}^F - \frac{1}{n_s}\sum_s \lambda_{rs}^{DF}, \quad \lambda_r^{IB} = \lambda_r^B - \lambda_r^{DB} = \frac{1}{n_s}\sum_s \lambda_{rs}^B - \frac{1}{n_s}\sum_s \lambda_{rs}^{DB}$$

Direct effects correspond to first-order linkages captured by the technical coefficient matrix A, while indirect effects arise from higher-order terms in the Leontief inverse (A^2, A^3, ...), reflecting successive rounds of production interdependencies.

Forward and backward value chain lengths are defined as the indirect share of total effects (total = direct + indirect):

$$L_r^F = \frac{\lambda_r^{IF}}{\lambda_r^F} = \frac{\lambda_r^{IF}}{\lambda_r^{IF} + \lambda_r^{DF}}, \quad L_r^B = \frac{\lambda_r^{IB}}{\lambda_r^B} = \frac{\lambda_r^{IB}}{\lambda_r^{IB} + \lambda_r^{DB}}$$

An average measure of value chain length is defined as:

$$L_r = \frac{L_r^F + L_r^B}{2}$$

Higher values indicate deeper indirect embedding in multistage production networks, while lower values indicate a predominance of direct propagation. This measure captures indirect propagation depth rather than the number of discrete production stages or proximity to final demand and should be interpreted accordingly.

Net propagation

Net propagation summarizes the directional balance between downstream propagation and upstream dependence implied by the activity space configuration. It is defined as:

$$NP_r = \lambda_r^F - \lambda_r^B$$

Here, λ_r^F and λ_r^B denote the region-level total forward and backward multipliers defined in the activity space; these are constructed as simple averages across sectors. Positive values indicate that regional production propagates more strongly downstream than it relies on upstream inputs, while negative values indicate the opposite. Net propagation is a structural indicator derived from multiplier-based production interdependencies and is conceptually distinct from value-added–based measures of GVC position. While the two may be correlated in practice, they capture different aspects of regional integration: net propagation reflects how production effects spread through the system, whereas GVC position reflects where value added is generated relative to cross-border trade flows.

	Total Forward Multiplier	Direct Forward Multiplier	Indirect Forward Multiplier	Forward chain lengths	Value chain lengths
Region 1	4,65	0,77	3,89	0,84	0,83
Region 2	5,02	0,84	4,18	0,83	0,83
Region 3	4,78	0,80	3,98	0,83	0,83

	Total Backward Multiplier	Direct Backward Multiplier	Indirect Backward Multiplier	Backward chain lengths	Net propagation
Region 1	4,80	0,81	3,99	0,83	-0,14
Region 2	4,90	0,81	4,09	0,83	0,12
Region 3	4,75	0,79	3,96	0,83	0,02

Table 2.6. Calculation of the value chain length and the net propagation at the region level for the numerical example.

2.6 System significance and propagation mass

Activity space, value chain length, and net propagation capture normalized structural properties of regional production linkages and are deliberately constructed to abstract from economic scale. System significance reintroduces scale by capturing how consequential regional production is in aggregate terms for the magnitude of indirect propagation implied by the production system.

Propagation mass

Let X_r denote gross output in region r, measured as the sum of gross output across all sectors in the region.[5] Propagation mass is defined as:

$$PM_r = X_r \cdot (\lambda_r^{IF} + \lambda_r^{IB})$$

where λ_r^{IF} and λ_r^{IB} denote the indirect forward and indirect backward production effects, respectively. Since multipliers are dimensionless and gross output is measured in monetary units, propagation mass is measured in total output units and represents the aggregate magnitude of indirect production effects associated with regional production, conditional on observed input–output relationships, and independent of the final market in which these effects are ultimately absorbed.

Propagation mass reflects the interaction between structural embeddedness and economic scale. Regions with moderate multiplier values may nevertheless exhibit high propagation mass if their production volume is large, while regions with extreme structural positions may have limited system significance if their scale is small.

System significance

System significance is assessed by examining the distribution and concentration of propagation mass across regions. Regions located in the upper tail of this distribution are referred to as system-significant regions. This classification is purely descriptive and does not imply optimality or vulnerability; it identifies regions whose combination of

[5] As a robustness check, propagation mass is alternatively scaled by value added rather than gross output, yielding qualitatively similar results.

structural configuration and scale implies a disproportionate contribution to total indirect propagation within the multiregional production system.

	Total Forward Multiplier	Direct Forward Multiplier	Indirect Forward Multiplier	Total Backward Multiplier	Direct Backward Multiplier	Indirect Backward Multiplier	Gross output Total	Propagation mass
Region 1	4,74	0,79	3,95	4,88	0,82	4,06	28 944	231 804
Region 2	5,11	0,85	4,25	4,98	0,82	4,16	31 169	262 209
Region 3	3,52	0,59	2,93	3,38	0,56	2,82	29 465	169 524

Table 2.7. Calculation of the propagation mass at the region level for the numerical example.

2.7 Operationalizing GVC Participation and Positioning in a MRIO Model

GVCs describe the interconnected production processes where value is added across multiple regions before reaching final consumption. In a Multiregional Input-Output (MRIO) framework, GVC participation is measured by tracing domestic and foreign value-added (DVA and FVA) within trade flows, identifying backward and forward linkages, and assessing a region's position within cross-border production networks and supply chains. Here, domestic refers to value-added generated within the NUTS2 region under study. We use the more widely established term domestic rather than local to ensure consistency with the prevailing terminology in the literature.

To calculate GVC participation, we first compute the value-added coefficients matrix using value-added shares va and the diagonal matrix of gross export E.

The value-added shares matrix $\hat{V}$ can be calculated by placing va_j for each region-sector in a diagonal matrix:

$$\hat{V} = \begin{bmatrix} va_1 & 0 & \dots & 0 \\ 0 & va_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & va_n \end{bmatrix}$$

The matrix $\hat{V}$ can also be obtained by taking the row sum of the A matrix, putting them on the diagonal of a square matrix and subtracting it from an identify matrix:

$$\hat{V} = I - diag\left(\sum_i a_{i1}, \sum_i a_{i2}, \dots, \sum_i a_{in}\right)$$

The matrix of gross exports E is in a similar way defined as matrix with gross exports e_i by region-sector on the main diagonal and zeros elsewhere.

$$E = \begin{bmatrix} e_1 & 0 & \dots & 0 \\ 0 & e_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & e_n \end{bmatrix}$$

From these matrices we can calculate the trade in value-added matrix T_v as follows:

$$T_v = \hat{V}BE$$

where B is the Leontief inverse matrix, or if written out:

$$T_v = \begin{bmatrix} va_1 & 0 & \dots & 0 \\ 0 & va_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & va_n \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{bmatrix} \begin{bmatrix} e_1 & 0 & \dots & 0 \\ 0 & e_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & e_n \end{bmatrix}$$

This matrix converts gross sectoral output into the corresponding value-added share, allowing us to track the domestic contribution in a global trade network.

For the numerical example this results in the following matrices:

Value added shares matrix V

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Sector 2	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Sector 3	0,00	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Sector 4	0,00	0,00	0,00	0,21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Region 2	Sector 1	0,00	0,00	0,00	0,00	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Sector 2	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00
	Sector 3	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,00	0,00	0,00	0,00	0,00
	Sector 4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,00	0,00
Region 3	Sector 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,09	0,00	0,00	0,00
	Sector 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,00	0,00
	Sector 3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,21	0,00
	Sector 4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,35

Gross exports matrix E

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	5316	0	0	0	0	0	0	0	0	0	0	0
	Sector 2	0	4431	0	0	0	0	0	0	0	0	0	0
	Sector 3	0	0	4980	0	0	0	0	0	0	0	0	0
	Sector 4	0	0	0	5778	0	0	0	0	0	0	0	0
Region 2	Sector 1	0	0	0	0	5300	0	0	0	0	0	0	0
	Sector 2	0	0	0	0	0	7173	0	0	0	0	0	0
	Sector 3	0	0	0	0	0	0	4610	0	0	0	0	0
	Sector 4	0	0	0	0	0	0	0	5022	0	0	0	0
Region 3	Sector 1	0	0	0	0	0	0	0	0	4934	0	0	0
	Sector 2	0	0	0	0	0	0	0	0	0	4027	0	0
	Sector 3	0	0	0	0	0	0	0	0	0	0	5197	0
	Sector 4	0	0	0	0	0	0	0	0	0	0	0	6233

Trade in value added matrix Tv

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	1148	182	188	290	314	194	305	261	269	208	215	249
	Sector 2	238	951	169	326	211	186	268	310	278	230	187	213
	Sector 3	331	342	1387	436	407	235	349	338	339	291	337	348
	Sector 4	421	310	330	1705	427	412	480	459	493	275	440	317
Region 2	Sector 1	219	183	223	212	916	155	240	229	197	152	184	230
	Sector 2	1227	1099	1113	1256	1205	4557	1028	1359	1219	936	1171	1229
	Sector 3	86	77	66	115	114	88	353	92	117	70	93	72
	Sector 4	88	93	108	115	92	109	97	454	119	93	96	86
Region 3	Sector 1	126	137	145	176	173	156	170	175	622	105	119	178
	Sector 2	380	210	280	277	361	219	350	300	372	1052	246	260
	Sector 3	344	257	333	324	343	331	380	398	337	207	1424	344
	Sector 4	709	591	637	545	736	531	589	649	572	409	686	2708

Table 2.8. Value-added shares matrix $\hat{V}$, gross exports matrix E, and trade in value-added matrix T_v for the numerical example.

From the Tv matrix, we can now calculate DVA, FVA, and DVX. These metrics quantify a country's role in global trade, distinguishing between domestic production, foreign dependencies, and upstream contributions to GVCs. The domestic value-added DVA is the share of exports produced domestically, given by the diagonal elements of the T_v matrix. Foreign value-added FVA is the imported input content in exports, calculated as the column sum minus the diagonal. Finally, DVX the indirect value-added exports DVX measures domestic inputs used in foreign exports, obtained from the row sum minus the diagonal. The calculations can be conducted at either the region-sector level or the region level by aggregating the relevant part of the matrices accordingly.

Domestic value-added DVA, foreign value-added FVA and indirect value-added exports DVX for each sector or region-sector. An illustration of the calculation for the numerical example is shown below:

DVA DVX FVA

Trade in value added matrix Tv

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	1148	182	188	290	314	194	305	261	269	208	215	249
	Sector 2	238	951	169	326	211	186	268	310	278	230	187	213
	Sector 3	331	342	1387	436	407	235	349	338	339	291	337	348
	Sector 4	421	310	330	1705	427	412	480	459	493	275	440	317
Region 2	Sector 1	219	183	223	212	916	155	240	229	197	152	184	230
	Sector 2	1227	1099	1113	1256	1205	4557	1028	1359	1219	936	1171	1229
	Sector 3	86	77	66	115	114	88	353	92	117	70	93	72
	Sector 4	88	93	108	115	92	109	97	454	119	93	96	86
Region 3	Sector 1	126	137	145	176	173	156	170	175	622	105	119	178
	Sector 2	380	210	280	277	361	219	350	300	372	1052	246	260
	Sector 3	344	257	333	324	343	331	380	398	337	207	1424	344
	Sector 4	709	591	637	545	736	531	589	649	572	409	686	2708

DVA =	1148
DVX =	2674
FVA =	4168

Table 2.9. Illustrating how trade in value-added is decomposed within an MRIO framework for a region-sector. Calculation of domestic value-added DVA, foreign value-added FVA, and indirect value-added exports DVX for region-sector 1 (region 1 and sector 1) in the numerical example.

DVA DVX FVA

Trade in value added matrix Tv

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	1148	182	188	290	314	194	305	261	269	208	215	249
	Sector 2	238	951	169	326	211	186	268	310	278	230	187	213
	Sector 3	331	342	1387	436	407	235	349	338	339	291	337	348
	Sector 4	421	310	330	1705	427	412	480	459	493	275	440	317
Region 2	Sector 1	219	183	223	212	916	155	240	229	197	152	184	230
	Sector 2	1227	1099	1113	1256	1205	4557	1028	1359	1219	936	1171	1229
	Sector 3	86	77	66	115	114	88	353	92	117	70	93	72
	Sector 4	88	93	108	115	92	109	97	454	119	93	96	86
Region 3	Sector 1	126	137	145	176	173	156	170	175	622	105	119	178
	Sector 2	380	210	280	277	361	219	350	300	372	1052	246	260
	Sector 3	344	257	333	324	343	331	380	398	337	207	1424	344
	Sector 4	709	591	637	545	736	531	589	649	572	409	686	2708

DVA =	9842
DVX =	8753
FVA =	11753

Table 2.10. Calculation of domestic value-added DVA, foreign value-added FVA, and indirect value-added exports DVX at the regional level for region 1 in the numerical example.

Following Koopman et al. (2014) and Aslam et al. (2017), we define the following two indices for measuring GVC participation and position in GVCs using an MRIO framework. GVC participation is measured by assessing the extent to which a region or sector relies on foreign inputs (FVA) and supplies intermediate goods to foreign exports (DVX). The GVC position determines whether a region-sector is more upstream (supplier of intermediates) or downstream (final producer using foreign inputs) in global production networks.

GVC participation captures the total involvement of a region-sector in international production networks, measured as:

$$GVC_{Participation} = \frac{FVA + DVX}{E}$$

A high value indicates strong global integration, either by the import of many foreign inputs (FVA) or exporting intermediates that support foreign exports (DVX). A low value implies limited reliance on foreign inputs or indirect re-exports.

The GVC position index shows whether a region-sector is mostly upstream (supplier of intermediate components), or downstream (assembler of foreign components):

$$GVC_{Position} = \ln\left(1 + \frac{DVX}{E}\right) - \ln\left(1 + \frac{FVA}{E}\right)$$

A positive index ($GVC_{Position} > 0$) means the region is upstream and contributes more value than it imports. A negative index ($GVC_{Position} < 0$) signals a downstream position, showing that the region-sector is relying more on foreign inputs. The logarithmic form ensures balance, captures relative differences, and avoids extreme values, enabling consistent interpretation across regions and sectors.

In table 2.11, values of DVA, DVX, FVA, GVC Participation, and GVC Position are calculated for the numerical example at the region-sector level in table 2.9. For example, for region 1 and sector 1, DVX is calculated as the sum of the first row minus cell for region 1 and sector 1 corresponding to the blue marked cells in the table. This sum is 2674. The values for DVA and FVA are calculated in a similar way by taking the corresponding sums in the table. To calculate GVC Participation and GVC Position we also need the gross exports from that region and sector. From table 2.1 this is 6316. GVC Participation and GVC Position can now be calculated using the equation above as $GVC\ Participation = \frac{4168+2674}{5316} = 1.29$ and $GVC\ Position = \ln\left(1 + \frac{2674}{5316}\right) - \ln\left(1 + \frac{4168}{5316}\right) = 0.18 - 0.25 = -0.07$.

GVC calculations

	Region 1				Region 2				Region 3			
	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Dom. value added DVA	1148	951	1387	1705	916	4557	353	454	622	1052	1424	2708
Indirect value added DVX	2674	2615	3751	4364	2222	12843	990	1097	1660	3256	3598	6653
Foreign value added FVA	4168	3480	3593	4073	4384	2616	4257	4568	4311	2975	3774	3524
Gross exports E	5316	4431	4980	5778	5300	7173	4610	5022	4934	4027	5197	6233
GVC Participation	1,29	1,38	1,47	1,46	1,25	2,16	1,14	1,13	1,21	1,55	1,42	1,63
GVC Position	-0,07	-0,05	0,01	0,01	-0,11	0,31	-0,20	-0,20	-0,15	0,02	-0,01	0,12

Table 2.11. Calculation of domestic value-added DVA, foreign value-added FVA, and indirect value-added exports DVX at the region-sector level for the numerical example. Illustrating how trade in value-added is decomposed within an MRIO framework.

As we will show in the following chapters, these measures provide a quantitative basis for understanding global trade integration, production structures, and vulnerabilities to supply chain disruptions. Policymakers and researchers can use these metrics to guide trade policy, industrial strategies, and economic vulnerability planning.

2.8 Trading Partner Exposure

Trading Partner Exposure (TPE) measures the extent to which domestic gross value added (DVA) produced in a specific region or region–sector is ultimately absorbed by final demand in a particular partner region, either through direct exports or indirect exports via third regions. Unlike traditional trade statistics, which primarily capture direct bilateral flows, TPE reflects how deeply a region is embedded in global consumption structures. It thus serves as a powerful indicator of both international market integration and potential exposure to external shocks (Aslam et al. 2017; Eurostat 2023). TPE can be calculated at both the regional and regional-sector levels.

For a given region–sector i and partner region-sector j, TPE is defined as:

$$TPE_{ij} = DVA_{ij}^{final} + DVA_{ij}^{indirect}$$

where DVA_{ij}^{final} is the regional value-added from region–sector i embedded in goods and services directly exported to final demand in region j, and $DVA_{ij}^{indirect}$ is the domestic value-added from region–sector i that reaches final demand in region-sector j via intermediate exports to third regions that re-export to j. If i and j belong to different sectors, trade must pass through other sectors or regions, making TPE a comprehensive measure of **all pathways** through which value added reaches a specific foreign market's final demand, whether the products are sent directly or indirectly.

TPE can be computed using standard input–output techniques by combining the value-added share matrix ($\widehat{V}$), the Leontief inverse matrix (B), and the expanded final demand matrix ($\widehat{Y}$). The expanded final demand matrix ($\widehat{Y}$) is a diagonalized version of the conventional final demand matrix, in which each column corresponds to a unique region–sector. It allocates final demand by origin and destination at the highest level of disaggregation. TPE can now be calculated using matrix multiplication as:

$$TPE = \hat{V} B \hat{Y}$$

For the example above this is as follows:

Final demand FD (or Y) expanded by sector

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	394	0	0	0	902	0	0	0	446	0	0	0
	Sector 2	0	514	0	0	0	694	0	0	0	512	0	0
	Sector 3	0	0	384	0	0	0	753	0	0	0	909	0
	Sector 4	0	0	0	91	0	0	0	653	0	0	0	301
Region 2	Sector 1	630	0	0	0	565	0	0	0	857	0	0	0
	Sector 2	0	847	0	0	0	209	0	0	0	37	0	0
	Sector 3	0	0	165	0	0	0	419	0	0	0	886	0
	Sector 4	0	0	0	800	0	0	0	355	0	0	0	501
Region 3	Sector 1	338	0	0	0	320	0	0	0	194	0	0	0
	Sector 2	0	479	0	0	0	14	0	0	0	608	0	0
	Sector 3	0	0	269	0	0	0	814	0	0	0	559	0
	Sector 4	0	0	0	700	0	0	0	822	0	0	0	729
Final demand by sector		1 361	1 840	818	1 591	1 787	917	1 986	1 830	1 497	1 157	2 354	1 531

Table 2.12. Expanded final demand matrix where each column corresponds to its own sector. The row sum below is the final demand in each region for goods from each sector.

Trading Partner Exposure TPE

		Region 1				Region 2				Region 3			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	141	69	37	74	246	35	90	84	158	53	116	70
	Sector 2	62	160	32	78	81	155	79	87	65	146	102	73
	Sector 3	96	102	137	100	122	61	294	119	107	85	356	97
	Sector 4	116	117	65	136	149	61	163	267	124	79	200	172
Region 2	Sector 1	139	58	35	66	148	34	84	70	174	45	107	61
	Sector 2	318	777	183	374	416	308	445	400	346	292	527	345
	Sector 3	28	28	23	25	34	15	57	29	30	20	90	24
	Sector 4	26	35	17	84	32	18	40	56	27	25	49	61
Region 3	Sector 1	73	47	23	51	80	26	56	56	63	32	72	47
	Sector 2	97	175	47	81	127	43	113	87	105	184	145	75
	Sector 3	89	93	113	107	117	51	308	110	98	63	287	97
	Sector 4	179	180	106	416	236	109	257	465	201	133	303	410

Table 2.13. Trading partner exposure for the numerical example. The row sums correspond to final demand by sector and the column sums to the value added in each region-sector. TPE hence links final demand in each region-sector to the value added from different region-sectors.

The TPE matrix provides a detailed mapping from production origins to final demand destinations. Specifically, row sums represent the share of a region-sector's total GVA that is absorbed across different final demand markets, a measure of export dependence. Column sums indicate the origin of value added embedded in a region–sector's own final demand – a measure of import dependence.

A high TPE value for a particular region-sector pair indicates significant exposure to that final demand market. This implies strong GVC integration but also greater vulnerability to shocks in the partner economy (e.g., geopolitical tensions, economic slowdowns). Conversely, a low TPE value signals a more domestically oriented production structure with lower external exposure.

TPE is therefore a dual-purpose indicator. It identifies strategic export opportunities and signals where a region is internationally competitive. At the same time, it reveals exposure risks, enabling ex ante assessment of how demand-side shocks may propagate through regional economies. This makes TPE highly relevant for policy design under increasing geopolitical and supply chain uncertainty.

From table 2.13, we can also calculate how the value added produced in each region is ultimately consumed as final demand across different regions and sectors, serving as a measure of export dependence. Table 2.14 shows how value added from each region and sector is absorbed into final use in other regions and sectors. This is a measure of a region's export dependence. For example, the value of 8% in the first row and eighth column shows that 8% of the value added from region 1 and sector 1 ends up as final consumption in region 2 as commodities from sector 3.

Share of Exported Value Added by Final Consumption Location (in Percent)

		Region 1				Region 2				US			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	12%	6%	3%	6%	21%	3%	8%	7%	13%	5%	10%	6%
	Sector 2	6%	14%	3%	7%	7%	14%	7%	8%	6%	13%	9%	7%
	Sector 3	6%	6%	8%	6%	7%	4%	18%	7%	6%	5%	21%	6%
	Sector 4	7%	7%	4%	8%	9%	4%	10%	16%	8%	5%	12%	10%
Region 2	Sector 1	14%	6%	3%	6%	14%	3%	8%	7%	17%	4%	10%	6%
	Sector 2	7%	16%	4%	8%	9%	7%	9%	8%	7%	6%	11%	7%
	Sector 3	7%	7%	6%	6%	9%	4%	14%	7%	8%	5%	22%	6%
	Sector 4	5%	7%	4%	18%	7%	4%	9%	12%	6%	5%	10%	13%
Region 3	Sector 1	12%	7%	4%	8%	13%	4%	9%	9%	10%	5%	11%	8%
	Sector 2	8%	14%	4%	6%	10%	3%	9%	7%	8%	14%	11%	6%
	Sector 3	6%	6%	7%	7%	8%	3%	20%	7%	6%	4%	19%	6%
	Sector 4	6%	6%	4%	14%	8%	4%	9%	16%	7%	4%	10%	14%

Table 2.14. Share of exported value added by final consumption based on calculated TPE for the numerical example. Each row sums to 100%.

In a similar way, we can calculate in which regions and sectors the goods and services consumed in a given region originate, i.e., a measure of import dependence. This is shown in table 2.15. For example, the value of 5% in the first row and eighth column here means that 5% of the final demand in region 2 of commodities from sector 3 comes from value added from region 1 and sector 1.

Share of Final Consumption by Production Origin (in Percent)

		Region 1				Region 2				US			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4	Sector 1	Sector 2	Sector 3	Sector 4
Region 1	Sector 1	10%	4%	4%	5%	14%	4%	5%	5%	11%	5%	5%	5%
	Sector 2	5%	9%	4%	5%	5%	17%	4%	5%	4%	13%	4%	5%
	Sector 3	7%	6%	17%	6%	7%	7%	15%	7%	7%	7%	15%	6%
	Sector 4	8%	6%	8%	9%	8%	7%	8%	15%	8%	7%	8%	11%
Region 2	Sector 1	10%	3%	4%	4%	8%	4%	4%	4%	12%	4%	5%	4%
	Sector 2	23%	42%	22%	24%	23%	34%	22%	22%	23%	25%	22%	23%
	Sector 3	2%	2%	3%	2%	2%	2%	3%	2%	2%	2%	4%	2%
	Sector 4	2%	2%	2%	5%	2%	2%	2%	3%	2%	2%	2%	4%
Region 3	Sector 1	5%	3%	3%	3%	4%	3%	3%	3%	4%	3%	3%	3%
	Sector 2	7%	10%	6%	5%	7%	5%	6%	5%	7%	16%	6%	5%
	Sector 3	7%	5%	14%	7%	7%	6%	16%	6%	7%	5%	12%	6%
	Sector 4	13%	10%	13%	26%	13%	12%	13%	25%	13%	11%	13%	27%

Table 2.15. Share of final consumption by product origin based on calculated TPE for the numerical example. Each column sums to 100%.

3. Data

Multiregional Input–Output (MRIO) tables are collected from the FIGARO project (Full International and Global Accounts for Research in Input–Output Analysis), a joint initiative by Eurostat and the European Commission's Joint Research Centre (European Commission 2019; European Commission & Joint Research Centre 2020; Eurostat 2025). FIGARO provides harmonized input–output tables for all EU Member States and selected partner economies, designed to capture the socio-economic and environmental impacts of globalization.

We employ FIGARO-REG, the regional extension of FIGARO, which disaggregates national tables to the NUTS2 level. FIGARO-REG enables detailed empirical analysis of intra- and interregional production and trade flows across roughly 240 EU regions, complemented by a set of non-EU countries or aggregates.[6]

These regional accounts are consistent with national input–output tables and comply with ESA accounting standards. Each table contains three standardized blocks:

1. Intermediate use – capturing inter-industry flows within and between regions.
2. Final use – covering household and government consumption, gross fixed capital formation, changes in inventories, and exports.
3. Output and value-added – reporting gross output and decomposing value added into compensation of employees, operating surplus, and net taxes on production.

Figure 3.1 illustrates the accounting structure of FIGARO-REG, showing how intermediate inputs are transformed into final demand and value added. The official FIGARO-REG release provides annual data for 2000–2010 and for 2017. In addition, we also draw on an unofficial but more sectorally detailed 2017 extension developed within an ongoing research project (Thissen et al. forthcoming). Although not formally released by Eurostat or JRC, this extension adheres to the same methodological principles as FIGARO and is benchmarked to national totals. Consistency checks confirm close alignment between regional aggregates and national accounts, with minor deviations.

FIGARO-REG			Intermediate use: Region1 (Industry 1 … Industry 56)	Intermediate use: … (Industry 1 … Industry 56)	Intermediate use: Region 305 (Industry 1 … Industry 56)	Final Use: Government consumption	Final Use: Households consumption	Final Use: Gross Capital Formation	Final Use: Changes in inventories	Output
Intermediate Inputs	Region 1	Industry 1 … Industry 56	$DOMESTIC_{1,1}$	$TRADE_{1,\ldots}$	$TRADE_{1,305}$	G_1	H_1	$GFCF_1$	CI_1	X_1
	…	Industry 1 … Industry 56	$TRADE_{\ldots,1}$	$DOMESTIC_{\ldots,\ldots}$	$TRADE_{\ldots,305}$	$G_{\ldots}$	$H_{\ldots}$	$GFCF_{\ldots}$	$CI_{\ldots}$	$X_{\ldots}$
	Region 1	Industry 1 … Industry 56	$TRADE_{305,1}$	$TRADE_{305,\ldots}$	$DOMESTIC_{305,305}$	G_{305}	H_{305}	$GFCF_{305}$	CI_{305}	X_{305}
		Tax Less Subsidies on Products				TLS_G	TLS_H	TLS_{GFCF}	TLS_{CI}	
Value Added		Gross Operating Surplus	GOS_1	$GOS_{\ldots}$	GOS_{305}					
		Compensation of Employees	D_1	$D_{\ldots}$	D_{305}					
		Othet Net taxes on Production	$ONTP_1$	$ONTP_{\ldots}$	$ONTP_{305}$					
Output			X_1	$X_{\ldots}$	X_{305}					

Figure 3.1. Structure of FIGARO-REG. Source: López-Álvarez et al. (2024). The harmonized, cross-country nature of FIGARO-REG makes it particularly well suited for comparative and interregional analysis across countries. Recent applications have used it to study positioning, spillovers, and vulnerability in GVCs (Almazán-Gómez et al. 2023; Rueda-Cantuche & Valderas-Jaramillo 2023; López-Álvarez et al. 2024).

[6] For Ireland, Bulgaria, and Romania, disaggregated regional MRIO data are not available in FIGARO-REG; accordingly, national values are assigned to each NUTS2 region within these countries. Furthermore, the correspondence between the FIGARO-REG regional classification and the NUTS2 delineation (2016 revision) is not fully consistent. Minor boundary adjustments and classification discrepancies therefore necessitated manual reconciliation to ensure alignment with the 2016 NUTS2 framework applied in the empirical analysis. FIGARO-REG covers approximately 240 regions, whereas the 2016 NUTS2 classification comprises 268 regions.

4. Tracing Regional Integration into Global Value Chains

This chapter examines patterns of regional integration into GVCs using the indicators developed in Chapter 2 and the data described in Chapter 3.

4.1 Participation

This section examines participation as a first-order indicator of GVC integration. Participation captures the overall intensity of production linkages between regions by combining backward dependence on foreign inputs with forward provision of domestic value added embodied in other regions' exports. As such, it establishes the baseline degree of integration across regions.

4.1.1 Aggregate participation levels over time

Table 4.1 reports summary statistics for all European NUTS2 regions in total for the years 2000, 2010, and 2017. Participation increases over time, indicating a broad intensification of interregional production linkages. The mean rises from 0.53 in 2000 to 0.69 in 2017, with the entire distribution shifting upward. The 25th percentile increases from 0.48 to 0.65, the median from 0.52 to 0.71, and the 75th percentile from 0.60 to 0.75, suggesting that rising participation is not driven by a small subset of highly integrated regions but reflects a general deepening of regional involvement in GVCs.

Year	N	Mean	SD	P25	P50	P75	Min	Max
2000	268	0,53	0,09	0,48	0,52	0,6	0	0,73
2010	268	0,54	0,11	0,49	0,55	0,62	0	0,79
2017	268	0,69	0,08	0,65	0,71	0,75	0,44	0,86

Table 4.1. Summary statistics for GVC participation across European NUTS2 regions, 2000, 2010, and 2017.

Changes over time are not uniform. Between 2000 and 2010, average participation increased only modestly, and dispersion widened slightly, as reflected in a higher standard deviation. This pattern is consistent with a period of adjustment during which integration deepened unevenly across regions. By contrast, the period from 2010 to 2017 is characterized by a pronounced upward shift combined with a compression of the distribution. Participation rises sharply across most regions, while dispersion declines, indicating a more synchronized deepening of integration.

The upper tail of the distribution expands over time, with maximum participation rising from 0.73 in 2000 to 0.86 in 2017. Minimum values in the early years are close to zero and largely reflect data limitations and aggregation rather than the absence of interregional linkages. By 2017, minimum participation is substantially higher, underscoring that virtually all regions are embedded in GVCs to some extent.

Taken together, the summary statistics point to a structural shift in the organization of production across Europe. Regional economies have become more tightly connected through GVCs, not only at the core but across the entire distribution. At the same time, persistent dispersion indicates that regions differ markedly in the intensity of their integration, motivating a closer examination of relative positions and functional roles in the subsequent sections.

4.1.2 Participation by region

Figure 4.1 presents GVC participation by region in 2000, 2010, and 2017. Regions are grouped into year-specific quartiles, illustrating their relative positions within the European distribution rather than absolute participation levels. Regions within the same quartile may differ in underlying intensity, and movements across quartiles reflect changes in relative standing rather than uniform changes in integration.

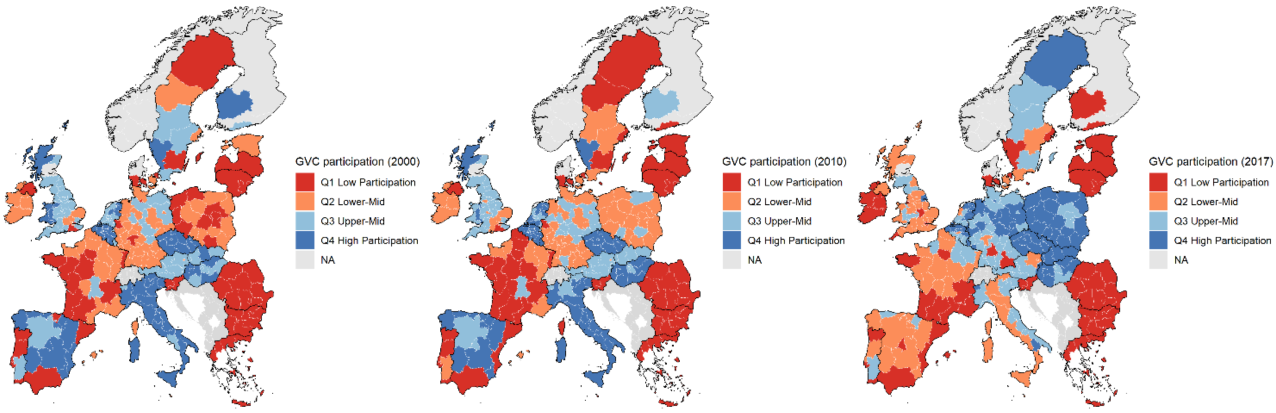

Figure 4.1. GVC participation by region 2000, 2010, and 2017.

In 2000, participation exhibits a pronounced core–periphery structure. High-participation regions are concentrated in Central Europe, particularly in Czechia, Slovakia, and Hungary, with extensions into parts of Italy and Belgium. Some regions in Spain, the Netherlands, Sweden, and the United Kingdom also appear in the upper quartile. By contrast, many regions in Southern Europe, as well as the Baltic states and northern Sweden, are positioned in the lowest quartile. Germany, Ireland, and Poland are predominantly located in intermediate quartiles, indicating substantial but not leading levels of integration at this stage.

By 2010, participation had increased across most regions, while the relative structure of integration remained largely intact. Central European regions consolidate their positions in the upper quartiles, and several regions in Germany and Poland move upward within the distribution. At the same time, regions in Southern Europe and the Baltic states remain concentrated in the lower quartiles, indicating limited changes in relative standing despite the overall increase in participation reported in Table 4.1. This stability in the relative distribution suggests a high degree of persistence in regional integration patterns.

By 2017, participation forms a more continuous belt of high relative integration stretching from southern Germany through Central Europe to western Poland and the Czech–Slovak–Hungarian corridor. Much of Germany and Poland move further upward within the distribution, and the Netherlands strengthens its regional presence in the upper quartiles. Several Swedish regions also shift upward on average, while Finnish regions move toward lower participation tiers. Italy exhibits a relative rebalancing, transitioning from predominantly high participation to a more mixed pattern, whereas Spain and France remain largely concentrated in the lower quartiles. The Baltic states and much of Southern Europe continue to display low relative participation.

Overall, the maps point to consolidation rather than convergence. While participation increases across Europe in absolute terms, relative upgrading remains concentrated within an expanded but still hierarchical core. Peripheral regions generally experience deeper integration without closing the relative gap to the most strongly embedded regions, underscoring the persistence of structural asymmetries in European production networks.

Participation summarizes the intensity of regional involvement in global value chains but abstracts from the organization of production linkages. Similar participation levels may conceal substantial differences in functional roles, and changes in participation do not necessarily imply changes in where regions operate along the value chain. To uncover these distinctions, the next section examines functional position, focusing on the balance between forward and backward production linkages.

4.2 Functional position

While participation captures the intensity of integration into GVCs, it does not indicate where regions operate along value chains. Functional position addresses this limitation by capturing whether regions primarily act as suppliers of intermediate value added to other regions or as users of inputs produced elsewhere, as measured by the balance between forward and backward linkages. Positive values indicate upstream, input-providing roles, while negative values indicate downstream activities closer to final assembly and demand. This distinction shifts the analytical focus from the scale of integration to its orientation. Regions with similar participation rates may occupy very different functional roles, and changes in participation do not necessarily imply changes in position. This section examines functional positions across regions and sectors to assess how upstream and downstream roles vary across spatial and sectoral dimensions, as well as the extent to which these roles persist over time.

4.2.1 Functional position by region

Figure 4.2 reports functional position by region in 2000, 2010, and 2017, distinguishing upstream- and downstream-oriented regions based on the balance between forward and backward linkages. Regions are first classified by the sign of the position index and then divided into moderate and strong orientations according to their distance from zero. As in the participation analysis, the classification is relative and reflects regions' positions within the European distribution in each year.

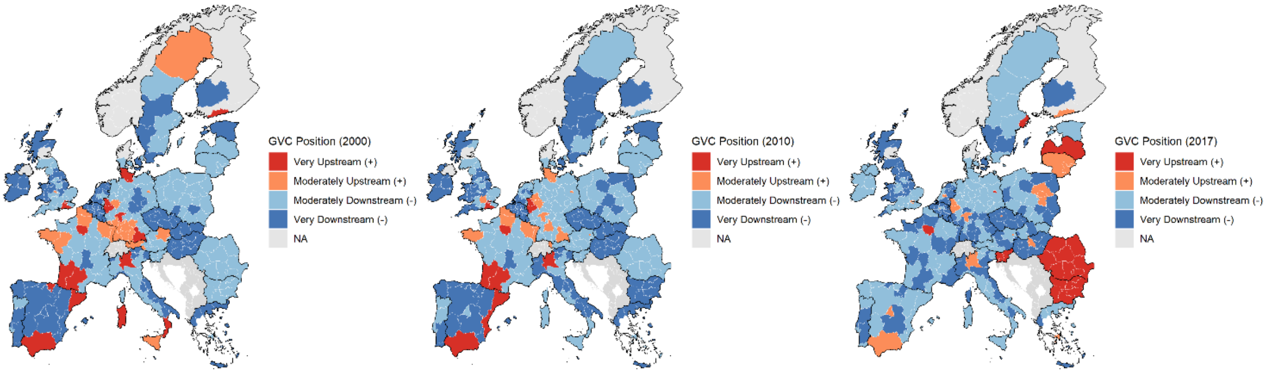

Figure 4.2. GVC functional position by region, 2000, 2010, and 2017. Upstream orientation reflects regions primarily supplying intermediate inputs, whereas downstream orientation reflects activities closer to final assembly and demand.

In 2000, functional positioning reveals a pronounced upstream–downstream divide across Europe, indicating a clear differentiation of regional roles within interregional production networks. Upstream-oriented regions are concentrated in Central and Eastern Europe, including large parts of Czechia, Slovakia, Hungary, and Poland, consistent with specialization in intermediate production stages and component supply. These regions frequently combine upstream positions with relatively high participation, suggesting deep integration into interregional production processes without a predominant orientation toward final assembly or market-facing activities. By contrast, downstream orientations are concentrated in Western Europe's industrial core—notably in France, Germany, the Netherlands, and Belgium—where regions are positioned closer to final production stages, system integration, and final demand. Southern Europe displays a more heterogeneous configuration, with countries such as Italy combining upstream- and downstream-oriented regions, highlighting that functional specialization already operates below the national level at the outset of the period.

By 2010, the broad upstream–downstream structure remains largely intact, indicating substantial persistence in regional functional roles despite increasing overall participation. Central European regions continue to occupy upstream positions, consistent with sustained specialization in manufacturing inputs and intermediate goods. While some adjustment is visible—particularly in parts of Belgium, the Netherlands, and Northern Europe, which shift modestly toward upstream orientations—these changes remain limited in scope. Downstream specialization continues to be pronounced in Germany and other parts of Western and Central Europe. Taken together, the mid-period maps suggest consolidation of existing functional roles rather than a substantive reallocation of regions along the value chain.

By 2017, functional asymmetries remain a central feature of European production networks, although a limited number of regions exhibit more pronounced shifts in relative position. Spain exhibits a more clearly downstream-oriented configuration, suggesting a reconfiguration of its role within European value chains rather than a uniform increase in participation. France is positioned closer to a neutral or mildly upstream orientation, consistent with a partial rebalancing between forward and backward linkages. Germany continues to occupy predominantly downstream positions, but with increasing internal heterogeneity, indicating that similar aggregate roles may conceal divergent regional production structures. The Nordic countries and the United Kingdom likewise display substantial internal variation, underscoring that functional specialization operates below the national level and cannot be inferred from country-level averages.

Taken together, the maps point to persistence rather than convergence in functional roles across European regions. While some regions adjust their relative positions over time, deeper integration has primarily reinforced existing patterns of specialization rather than reshaped them. Regions that are positioned upstream tend to remain oriented toward input-intensive and component-producing activities, whereas downstream regions continue to be associated with activities closer to final demand, assembly, and coordination. This persistence suggests that functional roles are shaped by cumulative and mutually reinforcing factors—such as production capabilities, existing supplier–buyer relationships, and institutional arrangements—that constrain large-scale reallocation along value chains. To further detail these patterns, the next section examines functional position across broad sectoral groupings.

4.2.2 Functional position by regional sector

Figure 4.3 decomposes functional position in 2017 by sector. The purpose is to demonstrate how aggregate regional functional positions are shaped by sector-specific roles within fragmented value chains. The maps reveal systematic differences across sectors, reflecting variation in task content, tradability, and the extent to which production is organized across stages and regions.

Agriculture, forestry, and fishing (A) display a predominantly upstream orientation across Europe. This pattern is consistent with the sector's role as a supplier of primary inputs into downstream processing and manufacturing, with limited involvement in fragmented, multi-stage production networks. Functional positions are relatively uniform across regions, indicating a narrow scope for functional differentiation within primary activities.

Manufacturing and extraction (B_E) exhibit a markedly downstream orientation across much of Western and Central Europe. This pattern is consistent with the organization of European manufacturing value chains, in which final assembly, system integration, and other market-facing production stages are concentrated in specific regions, while many component-producing and intermediate stages are located elsewhere. Consequently, upstream specialization within manufacturing is relatively limited and spatially concentrated, and most industrial regions engage in value chains primarily through downstream activities rather than as major suppliers of intermediates embodied in other regions' exports.

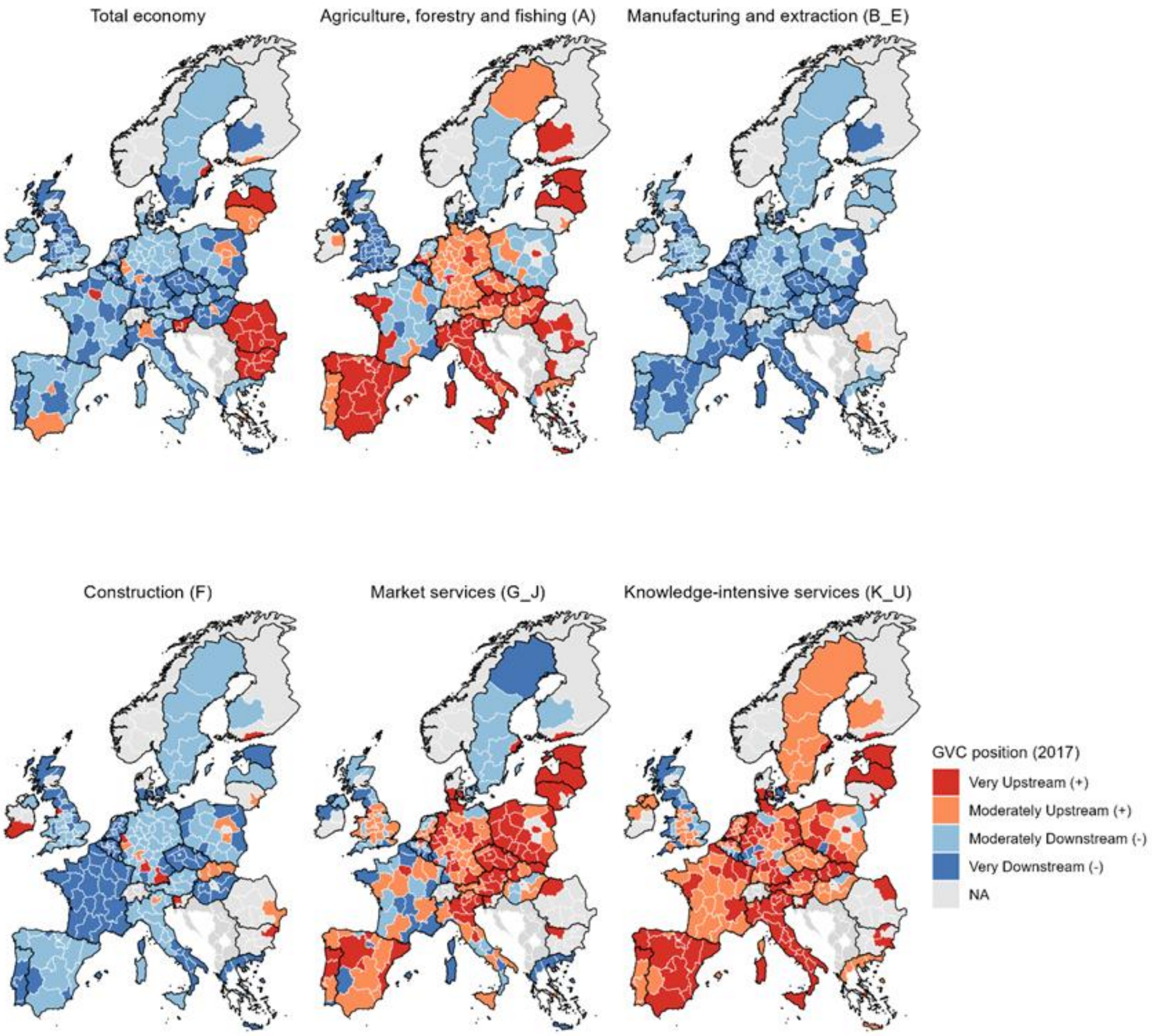

Figure 4.3. GVC Position by regional sector 2017. Upstream orientation denotes supplier-related activities, whereas downstream orientation reflects activities closer to final demand.

Construction (F) occupies a largely neutral functional position. This pattern is consistent with the sector's predominantly domestic orientation and its weak integration into interregional production networks. Even in highly open economies, construction activity remains closely tied to local demand, regulatory frameworks, and institutional conditions, which limit its involvement in fragmented value chains.

Service sectors display a distinct functional profile. Market services (G_J) and knowledge-intensive services (K_U) are predominantly upstream, particularly in Western and Northern Europe. This upstream orientation does not reflect direct participation in goods exports, but rather the role of services as indirect input providers embedded in manufacturing value chains. Business services, R&D, logistics, design, and other intangible activities enter exports through intersectoral linkages, shaping production processes without appearing as final goods. As a result, service-oriented regions may occupy upstream positions despite limited manufacturing activity and modest direct export volumes.

Taken together, the sectoral patterns add to the understanding of how aggregate regional functional positions are formed. Aggregate upstream or downstream orientations arise from the interaction between sectoral specialization and the typical value-chain roles associated with those sectors. Regions with manufacturing structures dominated by downstream-oriented activities tend to appear downstream in the total economy even when they host upstream-oriented service sectors, because final assembly and other market-facing stages exert a strong pull on the balance between forward and backward linkages. Conversely, regions specialized in business and knowledge-intensive services may appear upstream despite limited involvement in manufacturing, reflecting the indirect embedding of service inputs in other regions' exports.

At the same time, the sectoral perspective has clear analytical limits. Sector aggregates encompass heterogeneous activities that may occupy very different positions along value chains, and even similar sectoral compositions can therefore give rise to distinct functional outcomes depending on how activities are organized, connected, and configured across regions. In this sense, value-chain fragmentation implies that functional roles are increasingly determined at the level of activities and interregional production linkages rather than industries or sectors as such. This motivates a shift beyond sectors and sectoral decomposition toward a focus on activity space and the depth of indirect value chain propagation, which more directly capture the mechanisms through which functional roles emerge in the MRIO-system. Before turning to this decomposition, however, it is useful to first examine how functional position is expressed in patterns of intermediate flows across regions.

4.3 Functional position and intermediate flow patterns

Functional position is inherently an input–output concept, defined by how regional production is absorbed within the multiregional production system and can therefore be empirically examined through observed patterns of intermediate and final absorption. Regions are upstream to the extent that their output is predominantly absorbed as intermediate input in other regions' production processes, and downstream to the extent that production is absorbed late in the value chain, either through final demand or through short production sequences. Because global value chains are constituted through sequential interregional exchanges of intermediates, patterns of intermediate flows provide a direct and transparent representation of upstream and downstream roles.

Figure 4.4 illustrates how functional positions (quartile groups) are reflected in the allocation of gross output across intra-regional intermediate use, interregional intermediate trade within Europe, trade with the rest of the world, and final demand. The figure presents absorption patterns for 2000 and 2017, together with the change in shares between these years expressed in percentage points. By organizing the information as a full absorption matrix, the figure links functional position directly to the structure of production and trade through which regional roles are realized. This shifts attention from relative positioning to the concrete flow structure that underpins upstream and downstream specialization.

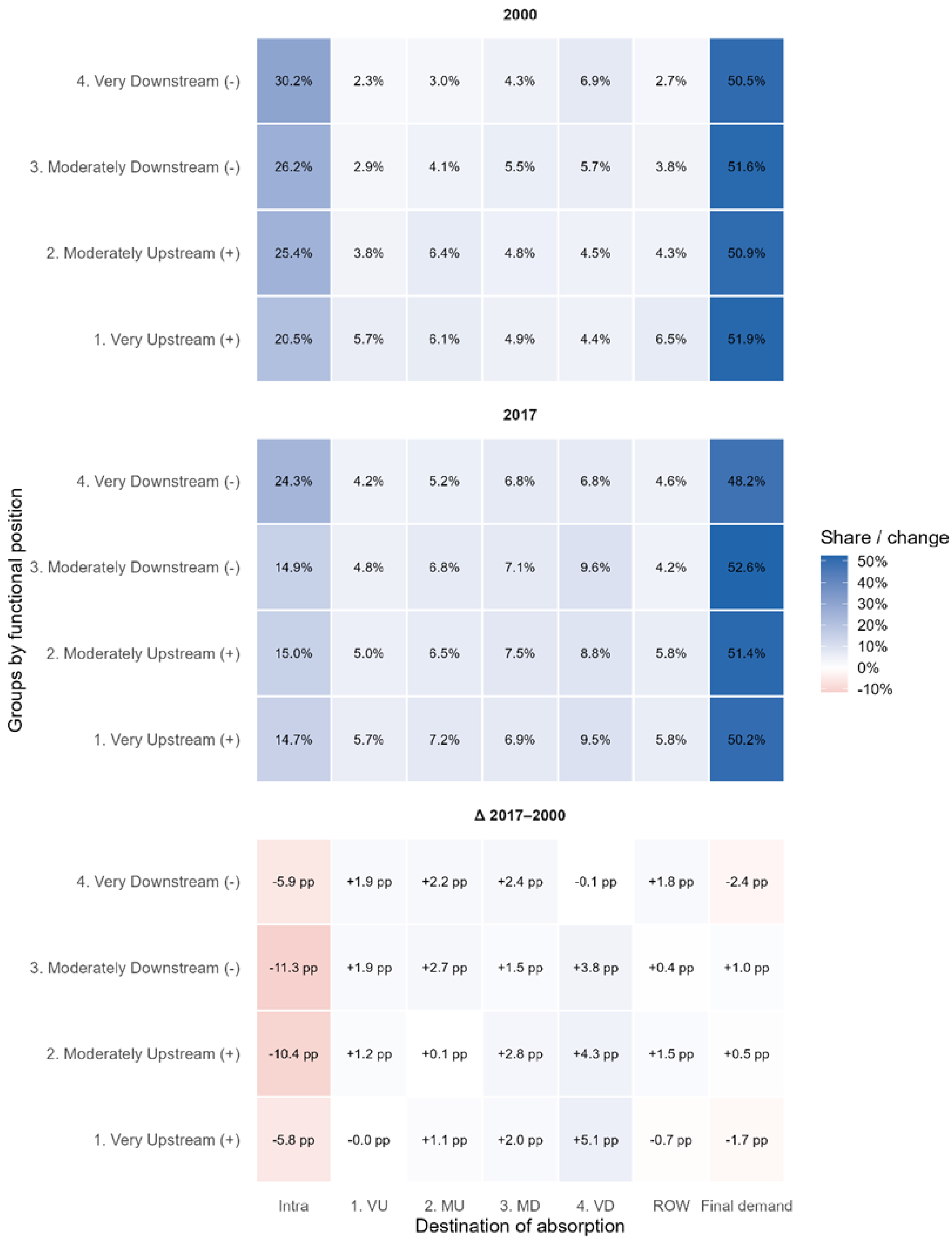

Figure 4.4. Distribution of gross output by functional position and destination of absorption. Shares of gross output originating in regions grouped by functional position, allocated to intra-regional intermediate use, interregional intermediate trade within Europe (by functional position of destination), trade with the rest of the world, and final demand. Panels report levels in 2000 and 2017, and the change between 2000 and 2017 is expressed in percentage points. Rows sum to 100 percent.

A first and dominant pattern is the systematic decline in intra-regional intermediate absorption across all functional positions. Between 2000 and 2017, the share of output absorbed locally as intermediate input fell markedly for all quartile groups, with particularly large reductions for moderately upstream and moderately downstream activities. This uniform decline indicates a broad structural shift away from locally self-contained production systems towards deeper interregional fragmentation. In value chain terms, production stages increasingly rely on inputs sourced from other regions, reflecting a reorganization of production networks rather than a simple expansion of trade in final goods.

The change panel shows that this fragmentation is not neutral with respect to functional position. For upstream activities, declining intra-regional use is accompanied by rising intermediate deliveries to downstream positions. Both very and moderately upstream groups increase their shares of output absorbed by downstream quartiles, especially by very downstream activities. This pattern points to a strengthening of vertical complementarities along the value chain, in which upstream regions increasingly specialize in supplying inputs that feed into later-stage processing and market-facing activities located elsewhere. The reallocation of upstream output thus reflects a clearer functional separation between early-stage and late-stage production rather than a generalized increase in interregional trade.

Downstream activities exhibit a distinct but complementary adjustment. While intra-regional absorption also declines for moderately and very downstream positions, the increase in interregional intermediate flows is concentrated within downstream-to-downstream exchanges. By 2017, deliveries between downstream groups exceeded flows from downstream to upstream positions. This indicates a consolidation of multiple late-stage production steps within downstream-oriented regions. In input–output terms, downstream regions increasingly exchange intermediates among themselves before final absorption, reflecting dense internal production structures close to end markets.

This pattern is consistent with theories of value chain governance (Gereffi et al. 2005; Ponte & Sturgeon 2014) and agglomeration (Krugman 1991; Duranton & Puga 2004). Late-stage activities tend to co-locate assembly, coordination, logistics, and market-facing functions, generating dense networks of intermediate exchange prior to final demand. The observed increases in downstream–downstream flows therefore reflect not only spatial concentration but also the functional clustering of complementary production stages near final markets.

Final demand absorbs approximately half of gross output across all functional positions throughout the period. However, its interpretation differs across the value chain. Upstream activities display final demand shares comparable to downstream activities, despite being functionally distant from end consumers. This reflects the input–output definition of final demand, which includes investment, public demand, inventory changes, and exports. In this sense, final demand does not imply proximity to consumption markets but captures direct demand for upstream outputs such as energy, basic materials, and capital goods that bypass further intermediate processing.

Taken together, the figure demonstrates that similar functional positions can be associated with different underlying configurations of production linkages and different trajectories of structural change. Positional indicators summarize whether regions tend to operate upstream or downstream, but they do not reveal how these roles are implemented through concrete patterns of intermediate exchange and absorption. The observed reallocation away from intra-regional use and towards more structured interregional linkages underscores the limits of positional measures alone.

To uncover these underlying linkage structures and to distinguish between different modes of integration that share similar functional orientations, the next section moves beyond functional position to examine activity space and value chain length. These concepts capture how forward and backward linkages are configured and how deeply regional value added propagates through indirect production stages within global value chains.

4.4 Activity space and value chain length

Functional position identifies upstream and downstream orientation, but as an aggregate net measure, it conceals the underlying linkage structures through which these positions are realized. To address this limitation, functional position is decomposed along two complementary dimensions: activity space and value chain length. Activity space characterizes the configuration of forward and backward linkages that underpin a region's functional orientation, while value chain length captures the depth of indirect propagation by measuring how many intermediate production stages regional value-added will pass through before reaching final demand. The analysis proceeds by first examining regions' activity space and then using variation in value chain length to differentiate modes of participation in global value chains[7].

4.4.1 Activity space

Activity space is defined as a two-dimensional representation of regions' forward and backward production linkages within the MRIO system. It is not a new metric, but a structural representation that builds on established forward and backward linkage measures and uses them for a distinct analytical purpose. Activity space characterizes how regional production is embedded in the MRIO system by describing the configuration of direct and indirect linkages through which output and value added propagate across regions and sectors. Unlike indicators of functional position, activity space does not locate regions along a value chain sequence relative to final demand but captures the underlying structure of production interdependencies from which such positional outcomes emerge.

The two dimensions of activity space correspond to forward and backward production linkages. Forward linkages reflect the extent to which a region's production contributes as an intermediate input to production processes elsewhere in the system, capturing how far regional output propagates downstream through successive production stages. Backward linkages capture the degree to which regional production relies on intermediate inputs sourced from other regions and sectors, reflecting the depth of upstream interdependencies embedded in the production system. Together, these dimensions describe

[7] See Wang et al. (2017) for an analysis of production length and upstreamness in GVCs. Their definition differs from the one used here, which focusses on activity space and GVCs.

how regional production is structurally connected to the wider network of multistage production relations.

Operationally, activity spaces are constructed using total forward and backward multipliers derived from the Leontief inverse of the MRIO system. The Leontief inverse summarizes how changes in final demand propagate through the production network by capturing both direct and successive rounds of intermediate input requirements across regions and sectors. The total backward multiplier measures the cumulative upstream production response generated throughout the system by an increase in final demand for a given region–sector, capturing reliance on externally sourced intermediates across all production stages. The corresponding forward multiplier captures how far production originating in a region–sector propagates through downstream production stages, reflecting the extent to which regional output is embedded in longer and more fragmented production sequences within the multiregional production network.

The key insight of the activity space representation lies in the joint consideration of forward and backward linkages. While backward multipliers capture how deeply regional production is embedded in upstream input structures, forward multipliers capture how far regional output propagates through successive downstream production stages. It is only by considering these two dimensions together that distinct modes of integration into the production system become visible. Read in this way, activity space is not a ranking of regions by the size of their multipliers, nor a classification into discrete regional types, but a structural map that highlights continuous variation in how regions participate in multistage production networks.

Figure 4.5 maps all European regions into this activity space for the years 2000, 2010, and 2017.[8] The horizontal axis measures total backward linkages, while the vertical axis measures total forward linkages. The diagonal line serves as a visual reference indicating whether a region's forward propagation is relatively large or small compared to its backward dependence. Regions are colored by the sign of the GVC position index, distinguishing upstream- and downstream-oriented regions, while density contours indicate where observations are most concentrated in each year.

[8] For regions in total, forward and backward multipliers are computed as simple averages across sectors rather than output-weighted aggregates. This normalization abstracts from scale effects and ensures that positions in the activity space reflect differences in production structure rather than regional size.

Figure 4.5. Activity space of European regions (total economy), 2000, 2010, and 2017. Total backward and forward multipliers derived from the Leontief inverse define the horizontal and vertical axes. Colors indicate the sign of functional position, while contours show regions of highest observation density (50, 80, and 95 percent). The diagonal line provides a visual reference for the balance between forward propagation and backward dependence.

Figure 4.5 reveals several clear and consistent patterns. Across all three years, regions are relatively closely grouped along the backward dimension, indicating that once direct and indirect effects are considered, regions tend to rely on upstream inputs to a broadly similar extent. In contrast, there is substantially greater dispersion along the forward dimension, showing that regions differ much more in how far their production propagates through successive production stages in the wider system.

Over time, the activity space expands primarily in the forward direction, as seen in the upward shift of the density contours. This pattern points to a gradual lengthening and fragmentation of production chains, in which regional value-added passes through more intermediate stages before reaching final demand. Importantly, this change is not accompanied by a comparable widening along the backward dimension. This suggests that production has become more extended and interconnected downstream, rather than more input-intensive upstream.

Upstream- and downstream-oriented regions tend to separate relative to the diagonal, but with substantial overlap in the areas where most regions are concentrated. Functional orientation varies gradually across regions, rather than separating them into distinct upstream and downstream categories. Regions that are classified as upstream or downstream may thus differ in meaningful ways in how they are connected to the production system, even when their aggregate functional position appears similar.

Taken together, these patterns illustrate that similar aggregate functional positions can arise from markedly different configurations of forward and backward linkages. Regions may also share similar activity space positions but differ in indirect propagation depth. This perspective motivates the next analytical step, which turns to value chain length to further unpack the vertical dimension of activity space and examine how differences in fragmentation and indirect propagation shape regional modes of GVC integration.

4.4.2 Value chain length as indirect propagation depth

While activity space characterizes how regions are structurally embedded in production networks through the configuration of forward and backward linkages, it does not distinguish between production structures in which propagation is primarily direct and those in which indirect effects dominate. Value chain length addresses this dimension by capturing the degree to which regional production is transmitted through indirect, higher-order production linkages before reaching final demand. It therefore complements activity space by differentiating between regions that may occupy similar positions in terms of linkage structure but differ in how strongly their participation relies on indirect propagation within the production system.

In this context, value chain length should be understood as a measure of indirectness rather than as a count of discrete production stages. Higher values indicate that a larger share of total production effects arises through indirect production rounds, consistent with more fragmented and layered production sequences. Lower values indicate that production effects are concentrated in more direct linkages, implying a closer connection between regional production and final demand. Value chain length thus captures the depth of indirect embedding in production networks, rather than the direction, intensity, or scale of linkage propagation.

Operationally, value chain length is proxied by the indirect share of total forward and backward effects derived from the Leontief inverse. The indirect share is computed as the ratio of aggregated indirect effects to aggregated total effects at the regional level, rather than as an average of sector-specific indirect shares. This measure reflects the relative importance of higher-order production rounds in the transmission of regional production through the MRIO-system. A higher indirect share indicates that indirect linkages account for a larger portion of total propagation, while a lower share indicates that direct production relationships dominate. Importantly, this measure does not identify the number of production stages involved, nor does it measure proximity to final demand. Instead, it isolates the extent to which regional participation in production networks is mediated through indirect propagation.

Figure 4.6a integrates this measure of indirect propagation depth into the activity space by coloring regions according to their indirect share of total effects. Regions retain their positions defined by total forward and backward multipliers, while color intensity reflects the relative importance of indirect linkages. Darker shades indicate a higher degree of indirect propagation, whereas lighter shades correspond to more direct forms of production embedding. This visualization makes it possible to assess how indirectness varies within the same structural configuration of forward and backward linkages.

Figure 4.6a. Value chain length in the activity space of European regions, 2000, 2010, and 2017. Regions are positioned according to total backward and forward multipliers. Color indicates value chain length, proxied by the indirect share of total production effects. The measure captures the degree of indirect propagation implied by production linkages, rather than distance to final demand or overall integration intensity.

Regions characterized by relatively weak forward propagation, combined with broadly comparable backward dependence, tend to display higher indirect shares. In these configurations, regional production is not transmitted primarily through strong direct downstream linkages but instead propagates through higher-order rounds of the production system. This implies that a larger share of total effects arises through indirect linkages rather than immediate input–output relationships.

Figure 4.6b relates the indirect propagation depth directly to net functional orientation, measured as the difference between total forward and total backward propagation. Net propagation captures the directional balance of production linkages, while value chain length captures how these linkages are realized in terms of direct versus higher-order propagation.

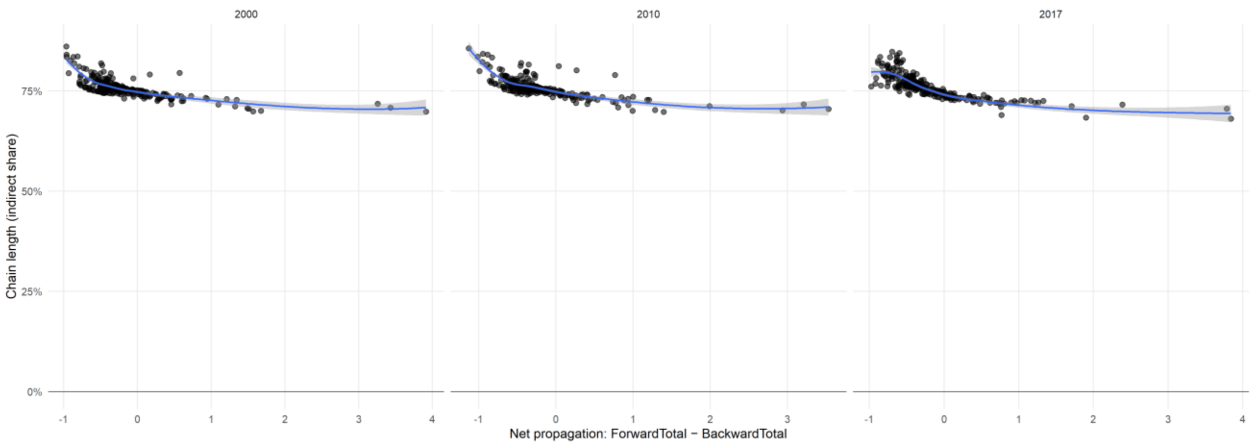

Figure 4.6b. Value chain length and forward–backward imbalance in the total economy. Value chain length is proxied by the indirect share of total forward and backward linkages derived from the Leontief inverse. The horizontal axis reports net propagation, defined as the difference between total forward and total backward propagation (ForwardTotal − BackwardTotal), capturing the net direction of production impulse transmission within the system.

The vertical axis shows the degree of indirect propagation, indicating the extent to which production effects are mediated through higher-order linkages rather than direct relationships.

The figure shows that the indirect share of total effects is highest for regions located close to a balance between forward and backward propagation. In these configurations, neither downstream nor upstream linkages dominate the transmission of production effects. As a result, a larger share of total propagation arises through higher-order rounds in the Leontief system rather than through strong first-round linkages.

By contrast, regions with pronounced positive or negative net propagation exhibit systematically lower indirect shares. When forward or backward propagation dominates, production effects are transmitted more directly through the system, and the contribution of higher-order propagation rounds is reduced. This pattern reflects differences in the structure of production linkages rather than differences in distance to final demand or the number of discrete production stages.

A further important observation is that variation in indirect propagation depth is more compressed than variation in linkage structure. Over all three years, most regions cluster within a relatively narrow range of indirect shares. This indicates that indirect propagation is a pervasive feature of regional participation in European production networks, rather than a characteristic of a small subset of regions. Differences across regions, therefore, reflect variation in the relative importance of indirect effects, not sharp contrasts between short and long production structures in any literal sense. Values corresponding to implicit stages in an input–output sense should therefore be interpreted as a normal structural outcome of fragmented, multi-stage production systems represented in an MRIO framework.

Taken together, these results highlight an important asymmetry. Strong forward propagation does not imply a high degree of indirectness, and a high indirect share does not require dominance in either forward or backward linkages. Separating linkage structure from indirect propagation depth is therefore essential for interpreting functional specialization and for understanding how regions are integrated into multiregional production systems. Value chain length, understood as indirect propagation depth, refines the interpretation of activity space by clarifying whether regional participation is charactererized by predominantly direct or indirect transmission of production effects.

Up to this point, the analysis has focused on normalized structural measures that abstract from economic scale, describing how regions are embedded in production networks and how deeply production effects propagate, but not how much these structures matter in absolute, system-wide terms. This distinction provides a necessary foundation for the subsequent analysis of system significance, where the interaction between linkage structure, indirect propagation, and economic scale becomes central.

4.4.3 System significance: propagation mass and concentration

While activity space and value chain length characterize the structural configuration and indirectness of regional production linkages, they abstract from economic scale. Regions with similar structural profiles may therefore differ substantially in the aggregate magnitude of indirect effects generated by their production. System significance captures this interaction by reintroducing scale to identify regions whose production is most consequential for system-wide propagation.

Regions may occupy similar locations in activity space and exhibit comparable degrees of indirect propagation yet differ markedly in the absolute magnitude of indirect effects generated by their production activities. These differences arise because linkage structure and indirectness interact with economic scale. Capturing this interaction is essential for identifying which regional nodes are structurally most consequential for the functioning of the European production system.

This subsection, therefore, shifts the analytical focus from relative position and structural configuration to system significance. The question is no longer how regions are connected, but how much indirect propagation they generate in aggregate terms. System significance is defined as the extent to which a region's production contributes to total indirect production effects in the MRIO system, once both linkage structure and production scale are considered. A region may thus be system-significant even if its normalized linkage measures are unexceptional, provided that typical interdependencies are combined with sufficiently large production volumes.

Propagation is used here in a strictly structural sense. It refers to the magnitude of indirect production effects implied by the Leontief equilibrium, conditional on observed production levels and input–output relationships. It does not refer to realized shock transmission, adjustment dynamics, or engineering-style cascade processes. Instead, it captures latent system significance embedded in the production network, that is, the potential for regional production to generate indirect effects throughout the system under marginal changes in demand or supply.

System significance is assessed using mass-based measures of propagation rather than intensity-normalized indicators. Whereas activity space and value chain length rely on multipliers that abstract from scale, the measure introduced here explicitly retains information on economic size. In the main analysis, indirect propagation is weighted by gross output. This choice follows directly from the production-based logic of the MRIO framework: forward and backward multipliers describe responses in terms of total production requirements, and weighting indirect effects by gross output preserves the internal coherence of the Leontief system. System significance, therefore, measures how much production activity a given region potentially sets in motion through indirect channels, rather than how strongly it propagates per unit of output.

Analytically, attention is directed to the concentration of propagation mass within the system. Rather than classifying all regions symmetrically, the focus is on identifying those located in the upper tail of the distribution of indirect propagation mass. These regions represent nodes whose production structures imply an unusually large capacity to generate indirect effects at the system level, either upstream, downstream, or in both directions, once scale is considered. The objective is descriptive rather than normative: to document how system significance is distributed across regions and how this distribution evolves over time.

Figure 4.7 illustrates the concentration of system significance within the activity space for the total economy in 2000, 2010, and 2017. Regions are positioned according to total backward and forward multipliers, while system significance is captured by the magnitude of indirect propagation mass. Regions are grouped into low, medium, and high propagation mass within each year to enhance interpretability. The figure shows that system-significant regions are not confined to extreme positions in activity space but frequently emerge from the dense core of the distribution, reflecting the interaction between common linkage structures and large production scale.

A central insight from the system significance analysis is that system-significant regions are not predominantly located at the extremes of the activity space but are instead concentrated in its dense core. This indicates that system significance does not primarily arise from exceptional or highly specialized linkage structures. Rather, it emerges from the interaction between structurally typical production configurations and large economic scale. Regions located in the dense middle of the activity space combine broadly representative forward and backward linkage structures with substantial production volumes, causing their output to generate disproportionately large indirect effects at the system level. As a result, system-wide propagation is driven less by structurally extreme regions and more by large regions whose production structures closely mirror the dominant organization of the multiregional production system.

As a robustness check, indirect propagation has also been weighted by value added instead of gross output.[9] This alternative weighting yields a closely related concentration pattern, indicating that the identification of system-significant regions is not driven solely by high-throughput, low-value-added activities. Taken together, the results confirm that system significance reflects the joint influence of structural embeddedness and economic scale, rather than any single dimension in isolation.

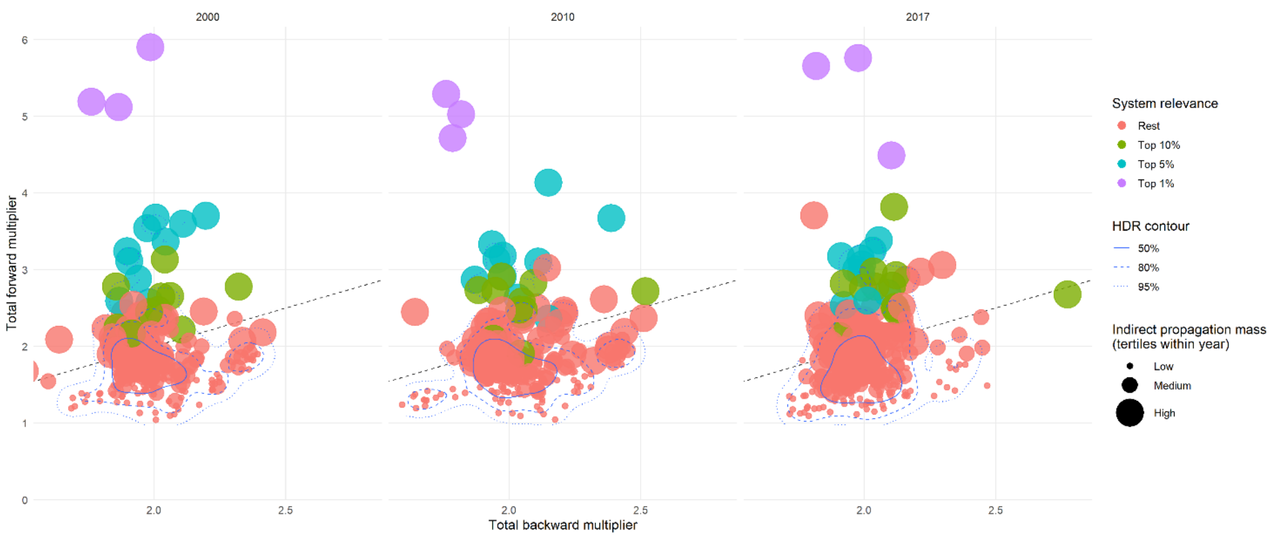

Figure 4.7. System significance within the activity space for the total economy in 2000, 2010, and 2017. Regions are positioned by total backward and forward multipliers derived from the Leontief inverse. System significance is measured as indirect propagation mass, defined as gross output multiplied by the sum of forward and backward indirect effects. Point size groups regions into low, medium, and high propagation mass within each year, while colors indicate regions in the upper tail of the distribution (top 10, 5, and 1 percent). Density contours (50, 80, and 95 percent) delineate the structural core of the European production system.

By reintroducing scale into the analysis, this subsection completes the production-side characterization of regional GVC integration. The results show that system significance in

[9] Results based on value-added weighting are not reported here, as they do not alter the substantive conclusions, but are available upon request.

European production networks is highly concentrated and shaped by the interaction between structural embeddedness and economic scale. Regions therefore differ not only in how they are integrated into value chains, but also in how consequential their production activities are for system-wide propagation. Regions with high system significance are not necessarily extreme or highly specialized nodes, but often large and structurally typical regions whose production underpins a substantial share of indirect interdependencies. The next section shifts the perspective from production to absorption by examining where the value added generated through these production structures is ultimately absorbed in final demand.

Together, the results from activity space, value chain length, and system significance show that production-side integration operates along multiple, non-equivalent dimensions, distinguishing between structural orientation, indirect propagation depth, and system-wide relevance.

4.5 Trade partner exposure

This section shifts the analytical perspective from production to absorption by tracing regional value added to its destination in final demand across domestic, European, and non-European (Rest of World) markets. The analysis is based on Trade Partner Exposure (TPE) measures derived from the MRIO framework, which capture the final absorption of regional value added through both direct and indirect trade linkages. Unlike conventional trade statistics, TPE does not measure gross export flows but identifies where value added generated by regional production is ultimately absorbed, as traced through the final demand matrix of the MRIO system.

The purpose of this section is not to introduce an additional measure of GVC integration, but to complement the production-side analysis by linking regional production structures to patterns of market orientation and demand-side exposure. By relating final demand absorption to functional position and system significance, this section completes the empirical account of regional GVC integration and establishes a coherent transition from supply-side structure to demand-side orientation within a unified accounting framework.

4.5.1 Aggregate patterns in trade partner exposure

Figure 4.8 presents the distribution of trade partner exposure across regions in 2000, 2010, and 2017, distinguishing between absorption in domestic markets, within the European market, and in markets outside Europe. The figure shows substantial heterogeneity in demand orientation across regions in all three years. The share of value added absorbed in each market category varies widely, indicating that demand-side exposure differs markedly across regions.

In 2000, the median region absorb the largest share of its value added domestically, with European markets constituting the second most important destination and world markets accounting for a smaller share. The distribution is wide, with many regions displaying either a strong European or a strong world market orientation. This dispersion indicates that, already at the beginning of the period, regions differ substantially in how their production is connected to final demand beyond national borders.

By 2010, the overall pattern remains broadly similar, with only modest shifts in the distributions. Median absorption shares change little relative to 2000, suggesting limited reorientation in the typical region's demand-side exposure. While some regions exhibit increased orientation toward European final demand, domestic markets remain the primary absorption destination for most regions. Heterogeneity across regions persists, with substantial overlap between regions that are mainly domestically oriented and those more strongly exposed to European or world markets.

In 2017, dispersion remains pronounced. Domestic markets continue to be the single largest destination for value added for the median region, but variation across regions is wide for all three market categories. The wide dispersion in the distributions indicates that, within the population of regions, final demand orientation varies substantially: while domestic absorption dominates for the typical region, the upper tails of the distributions show that European and world markets account for a large share of final absorption in a subset of cases. These patterns coexist within the same institutional and macroeconomic environment, suggesting that common external conditions alone cannot account for the observed differences in demand orientation.

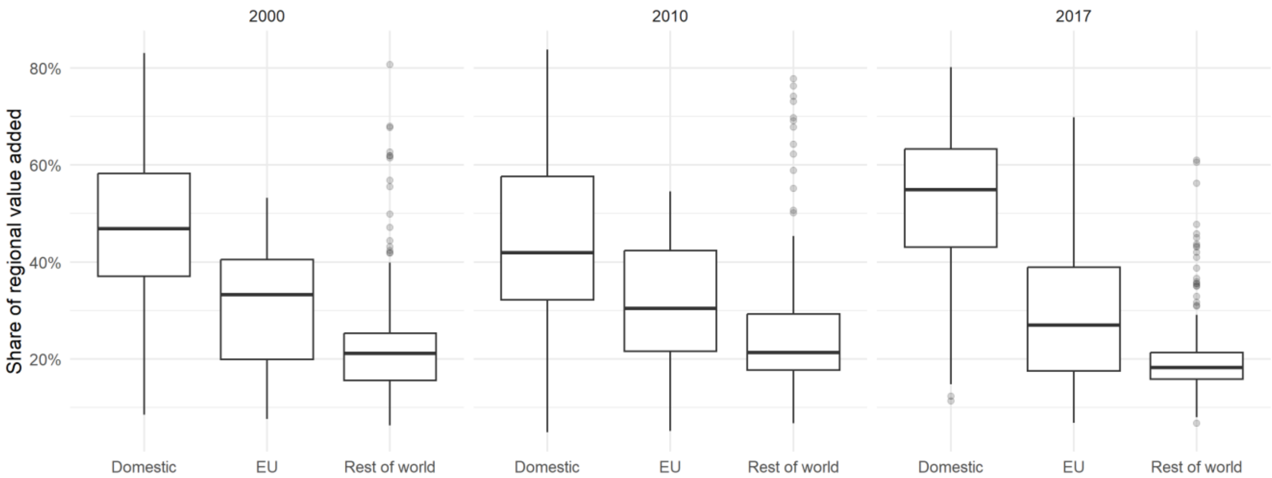

Figure 4.8. Trade partner exposure across regions 2000, 2010, 2017. Distribution of final demand absorption by market.

Taken together, Figure 4.8 shows modest changes across time alongside persistent differences in trade partner exposure across regions. For the median region, domestic final demand remains the dominant absorption channel throughout the period and strengthens modestly over time, while European and world markets play more limited and uneven roles. At the same time, substantial dispersion within each market category indicates that demand-side orientation differs markedly across regions and does not converge. Importantly, these aggregate distributions are silent on whether variation in demand orientation reflects systematic differences in regions' functional roles within production networks or arises independently of production-side integration. This motivates the subsequent analysis, which explicitly relates TPE to regions' upstream–downstream positions in GVCs.

4.5.2 Trade partner exposure and functional position

Figure 4.9 relates regions' trade partner exposure to their functional position in global value chains. The figure shows how the share of regionally generated value-added absorbed in domestic markets, the European market, and markets outside Europe varies along a continuous upstream–downstream dimension, where negative values indicate upstream-oriented regions and positive values indicate downstream-oriented regions. For each year, regions are ordered by functional position and grouped into equally sized segments; within each segment, median trade partner exposure is shown together with the interquartile range. This presentation reduces the influence of extreme observations and makes broad patterns linking functional position to demand-side orientation more visible.

Three main patterns emerge. First, domestic absorption is clearly related to functional position, and this relationship becomes stronger over time. In both 2000 and 2010, domestic absorption is relatively high among regions with strongly upstream positions, declines toward intermediate positions, and rises again for the most downstream regions. This U-shaped pattern shows that both upstream and downstream roles can be associated with a strong domestic orientation, although for different structural reasons. By 2017, the relationship becomes more clearly increasing: regions positioned further downstream tend to exhibit higher domestic absorption shares. This indicates that downstream specialization is increasingly associated with reliance on domestic final demand, while upstream regions more often generate value added that is absorbed outside the domestic market.

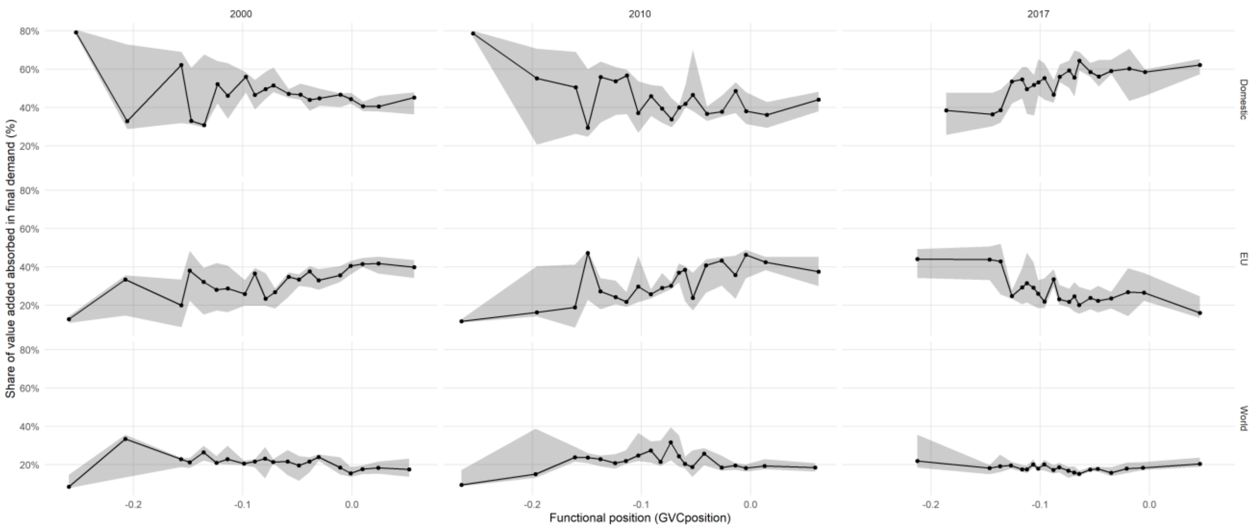

Figure 4.9. Trade partner exposure and functional position (total economy). Median shares of regional value added absorbed in domestic, European, and world markets along the upstream–downstream dimension of functional position in global value chains. Shaded areas indicate the interquartile range within bins of regions ordered by functional position. Negative values denote upstream-oriented regions, while positive values denote downstream-oriented regions.

Second, exposure to the European market shows an inverse relationship with functional position. In 2000 and 2010, regions in intermediate and moderately downstream positions tend to have the highest shares of European absorption, while both strongly upstream and strongly downstream regions are less EU-oriented. This pattern is consistent with production structures in which intermediate processing and assembly stages are closely linked to cross-border European demand. By 2017, this gradient becomes more pronounced: downstream regions display markedly lower European absorption shares, while upstream and intermediate regions retain stronger exposure to European final demand.

Third, absorption in markets outside Europe remains comparatively low and shows only limited variation along the upstream–downstream dimension in all years. The share absorbed in world markets varies modestly with functional position and displays no stable or systematic gradient. Interquartile ranges overlap substantially across bins, indicating that exposure to extra-European final demand is not closely aligned with functional position at the aggregate level. This suggests that world-market exposure is influenced by other dimensions of specialization, such as sectoral composition or firm-level export orientation, rather than by functional position alone.

Across all three market categories, variation within bins is substantial. Regions with similar upstream or downstream positions often display markedly different trade partner exposure profiles. Functional position, therefore, does not uniquely determine where regional value added is ultimately absorbed. Instead, it captures a production-side role that can be linked to final demand through different configurations within the multiregional production system.

Taken together, the results show that functional position is related to demand-side orientation, but in different ways across markets. Domestic and European markets display clear, and partly opposing, patterns along the upstream–downstream dimension, while exposure to markets outside Europe shows no clear relationship to functional position. These patterns change over time, indicating that production roles influence, but do not fully determine, how regions are exposed to final demand. Whether demand-side exposure is concentrated in regions that are also system-significant in production terms is examined in the following section.

4.5.3 Trade partner exposure and system significance

This section shifts the perspective from regions to markets and examines how final demand is linked to the most system-significant parts of the production network. While the preceding sections focused on where regional value added is absorbed and how demand-side exposure varies with functional position, the analysis here asks which final demand markets rely most heavily on production originating in system-critical regions. System-critical regions are those whose production contributes disproportionately to total indirect propagation in the multiregional production network, due to the interaction of structural embeddedness and economic scale; that is, regions whose production has wide-reaching effects across the economy because they are both highly interconnected and large in economic terms.

Figure 4.10 shows, for each year and final demand market, the share of absorbed value added that originates from regions in the upper tail of the distribution of system significance, measured as VA-weighted indirect propagation mass. The figure, therefore, adopts a market-level perspective, highlighting the extent to which domestic, European, and world markets are anchored in system-critical parts of the production network.

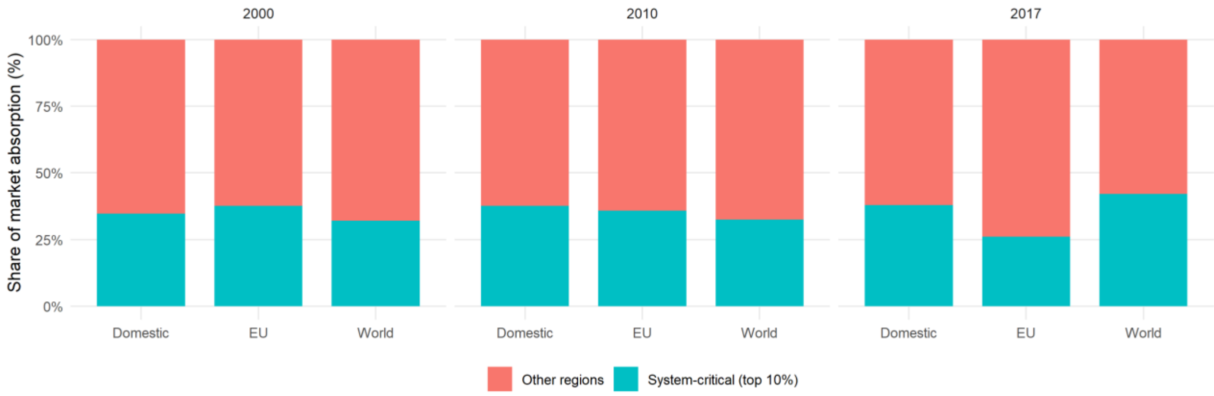

Figure 4.10. Trade partner exposure and system significance (total economy). For each year and final demand market, the figure shows the share of absorbed value-added originating from system-critical regions and from other regions. System-critical regions are defined as the top decile of regions in terms of indirect propagation mass, that is, regions whose production has particularly wide-reaching effects across the economy. Bars sum to 100 percent within each market and year.

Across all years and markets, system-critical regions account for a substantial, though not dominant, share of absorbed value added, typically on the order of 30–40 percent. This indicates a clear concentration of demand-side absorption in the structural core of the production network, while at the same time showing that a large share of final demand continues to draw on a broader set of regions outside this core.

The degree of anchoring differs systematically across markets. World-market absorption exhibits the strongest reliance on system-critical regions, particularly in 2017, implying that value added absorbed outside Europe is more strongly concentrated in regions with high indirect propagation potential. European final demand, by contrast, shows the lowest degree of anchoring in system-critical regions, especially in the later years, suggesting that European markets draw value added from a wider range of regions. The domestic market occupies an intermediate position, with a relatively stable level of anchoring over time.

Changes over time are moderate rather than dramatic, but the relative ordering of markets is stable. The increasing anchoring of world-market absorption in system-critical regions between 2010 and 2017 contrasts with a declining share for European final demand, pointing to a gradual reorientation of system-significant production toward global rather than European final markets.

Taken together, the figures show that final demand markets differ in how tightly they are connected to the most system-significant parts of the production network. While system-critical regions play an important role across all markets, their relative importance varies systematically across demand destinations, underscoring that market orientation and system significance intersect in ways that are not visible from a regional perspective alone. In this sense, differences in demand-side anchoring complement the production-side measures of system significance by indicating which final markets are structurally most exposed to the system's critical core.

5. Conclusions

This study has examined how European regions are integrated into global value chains by moving beyond single-index descriptions of participation and upstream–downstream position and adopting a system-based perspective grounded in multiregional input–output analysis. The results show that regional integration is inherently multidimensional and that no single indicator provides a sufficient description of how regions are embedded in contemporary production systems. Three main conclusions emerge.

First, participation and positional indicators capture only limited aspects of regional integration. Participation summarizes the overall intensity of interregional production linkages, while functional position indicates whether regions tend to operate upstream or downstream. However, regions that appear similar according to these measures may differ fundamentally in how their production is organized, how indirect effects propagate through the system, and where the value added they generate is ultimately absorbed. As a result, regions with comparable participation levels or similar upstream–downstream orientations can occupy qualitatively different roles within global value chains. Analyses that make use of single indicators therefore risk conflating intensity with structure and overlooking important sources of heterogeneity in regional production roles.

Second, structural configuration and economic scale play analytically distinct roles and cannot be treated as interchangeable. By decomposing functional position into activity space and value chain length, the analysis shows that regions differ not only in orientation but also in how their production is structurally embedded and how deeply production effects propagate through indirect linkages. Over time, European production systems have become more fragmented, primarily through longer downstream propagation rather than increased upstream dependence. These structural characteristics are normalized by construction and abstracted from differences in size. Reintroducing scale through measures of propagation mass and system significance reveals that system significance depends on the interaction between structural embeddedness and economic scale. Regions with structurally typical production configurations may therefore be highly system-significant if their scale is large, while structurally extreme regions may have limited aggregate impact if their production volume is small. Ignoring this distinction leads to systematic misinterpretation of which regions matter most for system-wide propagation.

Third, system significance is concentrated but not extreme. A limited set of regions accounts for a disproportionate share of indirect propagation in the European production system, reflecting the combined influence of scale and structural embeddedness. At the same time, system significance is not confined to a small number of highly specialized or exceptional regions. Many system-significant regions are located in the dense core of the activity space and exhibit structurally typical production patterns. Their importance arises from the magnitude of their production rather than from unusual linkage configurations. This implies that analyses focusing exclusively on highly specialized, export-intensive, or peripheral regions risk overlooking large parts of the production system that are central to how value-added and production effects propagate across regions.

Complementing the production-side results, the analysis of final demand exposure reinforces the multidimensional nature of regional integration. Regional value added is absorbed across domestic, European, and global markets in markedly different ways, and these patterns are relatively stable over time. Domestic demand remains the primary destination for most regions, but exposure to European and global final demand varies substantially. These differences are only weakly related to participation or functional position. Linking demand exposure to system significance shows that global final demand is more strongly anchored in system-significant regions, whereas European final demand is absorbed more broadly across regions with varying degrees of system significance. This anchoring is again moderate rather than extreme, reinforcing the picture of a production system characterized by neither full dispersion nor excessive concentration.

Taken together, the results demonstrate that regional integration into global value chains cannot be inferred from national aggregates or single indicators. Regions within the same country differ substantially in structural embeddedness, system significance, and demand exposure. Without a system perspective, such differences remain hidden, obscuring where adjustment pressures, structural dependencies, and growth opportunities, are concentrated. By explicitly separating participation, structural configuration, indirect propagation, and system significance, the analysis provides a coherent framework for understanding how regional roles in global value chains differ in kind rather than merely in degree. This sets the stage for the subsequent discussion of adjustment, exposure, and policy-relevant constraints.

6. Implications

The main contribution of this study lies in clarifying how regional production and demand are connected within multiregional production systems, and in identifying analytically distinct dimensions of integration that shape regional roles in global value chains. These distinctions provide an explicit analytical basis for both future research and policy-oriented analysis. The study does not assess vulnerability, welfare effects, or policy outcomes, nor does it deliver forecasts or policy prescriptions.

A central implication for research is that commonly used indicators of GVC integration are insufficient to capture the diversity of regional roles within multistage production systems. Measures of participation and functional position remain informative as first-order descriptors, but they collapse analytically distinct dimensions of integration into single indices. As shown in this study, regions that appear similar in terms of participation rates or upstream–downstream orientation may differ fundamentally in the configuration of their production linkages, in the depth through which value added propagates via indirect connections, and in their aggregate system significance.

Reliance on one-dimensional GVC measures, therefore, risks drawing incomplete or misleading conclusions about regional integration. Positional indicators summarize net orientations but abstract from the linkage structures through which these positions are realized, while normalized indicators facilitate comparison across regions at the cost of obscuring the role of economic scale in shaping system-wide propagation. Future empirical research on global value chains and regional development should therefore treat structural configuration, indirect propagation, and scale as analytically separate dimensions rather than as interchangeable proxies for integration.

The framework developed in this study provides a concrete basis for such analyses. By separating normalized structural properties from scale-dependent system significance within a single MRIO accounting structure, it enables researchers to distinguish between regions that are structurally similar but differ markedly in aggregate importance, as well as between regions that share similar participation levels but are embedded in production networks in qualitatively different ways. This perspective is particularly valuable for empirical research on structural change, adjustment processes, resilience, and exposure, where outcomes depend not only on relative position but on how production effects propagate through the system.

For policy-oriented analysis, a central implication of these findings is that global integration has distinctly regional consequences that cannot be inferred from national averages or from single indicators of openness. Regions within the same country may differ substantially in functional orientation, structural embeddedness, system significance, and exposure to different final demand markets. Analyses conducted solely at the national level therefore risk misidentifying where adjustment pressures, structural dependencies, or potential bottlenecks are concentrated within the production system.

Activity space and system significance are particularly important in this context. Activity space clarifies how regional production is embedded in multistage production systems, while system significance identifies which regions are most consequential for system-wide propagation once economic scale is taken into account. A key implication is that regions that matter most for aggregate production effects are not necessarily those that are most specialized, most export-intensive, or most extreme in structural terms. Instead, system-significant regions are often structurally typical but large in scale, meaning that their aggregate production underpins a disproportionate share of indirect propagation. Policy analyses that focus narrowly on highly specialized or outward-oriented regions, therefore, risk overlooking parts of the economy that are central to how production effects spread across regions.

Demand-side exposure further reinforces the need for a system perspective. The analysis shows that regional value added is absorbed across domestic, European, and global markets in markedly different ways, and that these patterns are only weakly related to production-side indicators such as participation or functional position. Global final demand tends to be more strongly anchored in system-significant regions, whereas European demand is absorbed more broadly across regions with varying degrees of system significance. These stable patterns imply that exposure to external demand shocks depends on the interaction between demand-side anchoring and production-side structure, rather than on trade intensity alone.

Taken together, these findings indicate that policy-oriented analyses relying on national averages, export shares, or single integration indicators risk overlooking critical dimensions of regional exposure and adjustment capacity. Regions differ not only in their degree of openness, but in their structural roles within multiregional production systems, in how value added propagates through indirect linkages, and in their system significance once economic scale is taken into account. Distinguishing between regions that are central to production networks and those primarily exposed via demand provides a more nuanced and empirically grounded basis for assessing the regional implications of globalization, structural change, and economic transitions.

A place-based perspective follows directly from this differentiation. If regions perform structurally distinct roles within interconnected production systems, policy analysis cannot assume homogeneous adjustment processes or uniform exposure across territories. Rather than privileging certain regions at the expense of others, the analytical objective is to identify complementarities and coordination mechanisms that shape how production effects propagate across the system. Policies that recognize the interaction between production structures, demand anchoring, and system significance are therefore better positioned to foster system-wide resilience and productive capacity than approaches based solely on aggregate openness or export intensity.[10]

Finally, the framework employed in this study is inherently structural. It captures production interdependencies implied by observed input–output relationships but does not model dynamic adjustment or welfare effects. The indicators developed here should therefore be interpreted as structural descriptors of interregional interconnectedness rather than as direct measures of vulnerability or policy outcomes. The contribution of the analysis lies in making indirect dependencies and system significance visible within a transparent accounting framework, thereby establishing a rigorous analytical foundation for subsequent consequence assessments, scenario analysis, and policy-oriented research.

[10] See Suedekum (2025) for a discussion of place-based policy and interregional complementarities

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Appendix - Glossary

Activity space – A two-dimensional description of how regions are connected to the production system through their use of inputs and supply of intermediates. It shows how regions are structurally embedded in production networks, not where they are located along a linear value chain.

Backward linkages – An indicator of how much production in a region depends on inputs from other regions and sectors. High backward linkages mean that production relies heavily on external suppliers.

Direct effects – The immediate production response following a change in final demand. Direct effects capture only the first round of input use and exclude knock-on effects further down the production network.

Domestic value added (DVA) – The part of export value that is created within the exporting region itself. DVA reflects how much local income is generated by exports, rather than how much is imported content.

Final demand – Demand for goods and services that are not used as inputs in further production. It includes household and government consumption, investment, inventory changes, and exports, and represents the endpoint of production chains.

Final absorption – Where value added is ultimately consumed in final demand, regardless of whether it reaches that market directly or via intermediate trade. Final absorption differs from gross exports by tracing where income is finally used.

Forward linkages – An indicator of how much a region's production is used as input in other regions' production. High forward linkages indicate that a region supplies inputs that are widely used elsewhere in the economy.

Functional position – A summary indicator showing whether a region tends to operate more upstream or downstream in production networks. It reflects the balance between supplying inputs to others and using inputs from others, but does not measure size, system significance, or economic impact.

Global value chains (GVCs) – Production processes in which value is created across multiple regions and sectors before goods and services reach final users. In this study, GVCs are understood as networks of production linkages rather than simple, linear chains.

Gross output – The total value of production in a region, including both value added and intermediate inputs. Gross output reflects the overall scale of production activity.

Indirect effects – Production responses that occur beyond the first round of input use, as suppliers increase their own demand for inputs. Indirect effects show how production changes spread through multiple layers of the economy.

Indirect propagation – The spread of production effects through indirect linkages in the production system. It summarizes indirect effects across multiple rounds and underlies the indirect share of total production effects.

Indirect share – The share of total production effects that arises from indirect rather than direct effects. A higher indirect share indicates that production is more deeply embedded in multi-stage production networks.

Leontief inverse – A core input–output tool that summarizes how changes in final demand affect total production across regions and sectors. It captures both direct and indirect production requirements.

Market orientation – The distribution of a region's value added across different final demand markets, such as domestic, European, and non-European markets. Market orientation describes where income from production is ultimately absorbed. In this study, market orientation is operationalized using trade partner exposure.

MRIO system – A multiregional input–output system that links production, input use, and final demand across regions and sectors within a consistent accounting framework. It allows production interdependencies to be traced across space.

Multipliers – Measures that show how strongly production responds to changes in final demand. Larger multipliers indicate that changes in demand generate larger total production effects across the system.

Net propagation – A structural measure of a region's functional orientation, defined as the difference between total forward propagation and total backward dependence.

Normalized measure – An indicator that is scaled to remove the influence of economic size. Normalized measures allow structural comparisons across regions but do not reflect absolute economic impact.

Participation – A measure of how strongly a region is involved in global value chains. It captures both the use of foreign inputs and the supply of inputs that support production in other regions.

Propagation mass – A measure of how much indirect production a region generates in total, taking both its linkage structure and its production size into account. Propagation mass identifies regions with large system-wide production effects.

Scale (economic scale) – The absolute size of production activity in a region, measured by gross output or value added. Scale determines how important a region's production is in aggregate terms.

Structural measure – An indicator that reflects properties of the production system implied by observed input–output relationships. Structural measures describe potential interdependencies, not observed behavior or outcomes.

System significance – A structural measure of a region's importance in overall production interdependencies, based on the magnitude of indirect production it generates. The measure does not assess risk, resilience, or vulnerability, and does not imply heightened vulnerability or strategic importance in a policy sense.

Trade partner exposure (TPE) – A measure of where a region's value added is ultimately absorbed across final demand markets. TPE traces income flows to final users rather than tracking gross trade flows.

Upstream / downstream – Terms describing whether a region mainly supplies inputs to other producers (upstream) or is closer to final demand (downstream). The terms are relative and describe production roles, not stages in a fixed sequence.

Value added – The part of production value that is not used to pay for intermediate inputs. Value added corresponds to income generated through wages, profits, and taxes.

Value chain length – A measure of how strongly production effects rely on indirect linkages. Longer value chains indicate deeper embedding in multi-stage production networks, not a count of observable production stages or a measure of proximity to final demand.

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