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Working Paper 19/2024

December 12, 2024

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Abstract

This paper explores the relationship between digitalization and the regionalization of Global Value Chains (GVCs) in European industries. The paper discusses the theoretical channels through which digital technologies may influence GVC regionalization and develops a conceptual framework to guide the empirical analysis. The analysis focuses on the manufacturing sectors of a sample of European countries in the period 2005-2018. To identify econometrically the causal effect of digital technologies on regionalization, we implement a Bartik instrumental variables approach exploiting patent data on information and communication technologies (ICT) and artificial intelligence (AI). Our main finding is that digital technologies enhance the intra-EU flows more than the extra-EU ones, thus pointing to the regionalization of GVCs in Europe.

Keywords: Global Value Chains; regionalization; digitalization.

JEL: O33, F10, F15

Acknowledgements: the authors wish to thank Filippo Bontadini, Paolo Guerrieri, Valentina Meliciani, Roberta Piermartini, Eleonora Pierucci, Lucia Tajoli, Serge Tseytlin and an anonymous referee for useful comments; the participants in: the 2024 EU-IOSAC inaugural workshop (LUISS-LEAP, Rome, 7th June); the 2024 SIEPI conference (University of Bergamo, 13-14 June); the 2024 ETSG (Athens University of Economics and Business, 12-14 September). All errors are ours.

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1 Introduction

From the second half of the 1980s to the 2008 Great Financial Crisis (GFC), world trade experienced consistent growth, with the trade-to-GDP ratio and trade elasticity doubling. This era saw a transformation in the international organization of production leading to the rise of Global Value Chains. Several factors influenced this trend. Some of the main ones include the reduction in transportation costs, trade policy liberalization, the establishment of regional trade agreements, and the expansion of the World Trade Organization (WTO), notably with the inclusion of China. Moreover, the diffusion of digitalization in the form of information and communication technologies (ICT) is generally considered to be among the main drivers of globalization (Baldwin, 2016).

After the GFC, however, the global trade landscape experienced a shift, with the trade-to-GDP ratio stabilizing at 30% and trade elasticity dropping to 1, indicating a parallel growth of trade and GDP that deviates from the previous upward trend (World Bank, 2020). The slowing down of GVCs expansion is attributed to several factors, such as: a slowdown in trade liberalization and a halt in the decline of transport and communication costs. Moreover, contrary to the earlier phase of GVCs expansion, recent technological advancements linked to digital technologies like automation and 3D printing could now potentially reverse globalization by altering relative costs (Antràs, 2020; Laplume et al., 2016; Seric & Winkler, 2020).

The last decade has been marked by unforeseen events that have heightened uncertainty and partially disrupted trade and integration. They include Brexit (2016), the US-China trade war (2018) and technological conflict, the Covid-19 pandemic (2020), Russia's incursion into Ukraine (2022) and the subsequent sanctions.[1] The ongoing conflict in the Middle East (2023) and the related geopolitical tensions further exacerbate this uncertainty.

All these structural trends and unforeseen events are contributing to a reorganization of GVCs, possibly leading towards more regionalized production networks whose new shape and

[1] During the Covid-19 pandemic, transport costs increased because of the lockdowns and the inactivity of several producers. See WTO (2020) on the increase of transport costs.

consequences for economies, firms, and people are still under scrutiny (Antràs, 2020; Goldberg & Reed, 2023).

Against this backdrop, in recent years there has emerged a debate on the potential effects of the new forms of digitalization on trade dynamics (Antras, 2020; Brun et al., 2019). The diffusion of new digital technologies affects firms' and industries' dynamics through several channels, such as the digitalization of processes, automation of labor, and coordination through platforms (Eurofound, 2018). The combination of the three phenomena also affects value creation and appropriation mechanisms (Teece, 2018), increases disintermediation, and leaves room for a larger role of intermediate service firms in manufacturing, i.e., servicification, due to the diffusion of platforms (Díaz-Mora et al., 2022; WTO, 2021). Moreover, the increasing diffusion of automation technologies and the digitalization of processes allow both for flexible production within firms and for the distribution of production across countries and regions.

Digital technologies have the potential to affect the global allocation of activities and reshape the specialization and the position of firms, sectors, and countries within GVCs. Importantly, the direction of change depends on the type of technologies that will prevail and their specific use (Baldwin, 2013; Butollo, 2021). In manufacturing, digital technologies already affect the formation and transmission of value through digitalized R&D, automated and intelligent production, and the servicification of sales and branding. The EU is explicitly tackling digital transformation and its relevance for GVCs as the European Commission presented three strategic documents in 2020: the White Paper on Artificial Intelligence, A European Strategy for Data, and Shaping Europe's Digital Future.[2]

In this scenario, the implications of digitalization for countries, industries, and their trade linkages are twofold. On the one hand, the increased efficiency gained through digital technologies and

[2] White Paper on Artificial Intelligence, available at https://commission.europa.eu/document/download/d2ec4039-c5be-423a-81ef-b9e44e79825b_en?filename=commission-white-paper-artificial-intelligence-feb2020_en.pdf; A European Strategy for Data, available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0066; Shaping Europe's Digital Future, available at https://eufordigital.eu/wp-content/uploads/2020/04/communication-shaping-europes-digital-future-feb2020_en_4.pdf.

the lower coordination cost may augment the possibilities of a further fragmentation of the international production structure (WTO, 2019). On the other hand, in many advanced economies, firms might have an incentive to relocate production since new technologies are more capital-intensive and require complementary investments in infrastructure and skilled labor (World Bank, 2020), although the scope for relocation and complementarities can be heterogeneous along value chain stages.

Along these lines, we identify two opposite forces exerted by digital technologies in production processes: a "centrifugal" force pushing toward a more fragmented production network, and a "centripetal" one incentivizing the relocation in advanced countries.

By affecting the production process, digital technologies may alter the economic incentives regarding the international allocation of the production stages; in particular, GVC linkages with geographically close partners versus distant partners are likely to be affected asymmetrically, implying that distribution of economic activities will change, possibly in the direction of more regionalization in some areas.

Building on this intuition, we investigate whether the diffusion of new digital technologies contributes to the recent reshaping of Global Value Chains (GVCs) in the European industries.
To this aim, by sourcing data from EUKLEMS and OECD-TiVA, we built an original dataset covering the manufacturing sectors of a set of European countries for the period 2005-2018. First, we look at the descriptive evidence on GVC participation, regionalization, and the diffusion of digital technologies. Then, we econometrically investigate the role of digitalization in explaining GVC dynamics. To account for possible endogeneity concerns and single out the causal effect of digitalization, we exploit a Bartik-like instrumental variable (IV) approach based on ICT and AI patent data.

Specifically, we proxy the use of digital technologies with the level of digital capital employed by countries and sectors (digital capital includes information technologies, communication technologies, and software and database). GVC participation and regionalization measures are computed from input-output tables. The latter is built as in Los et al. (2015) and Bontadini et al.

(2022) and takes a regional-to-global perspective: the measure is a ratio between intra-regional and extra-regional value-added flows, indicating which region is relatively more important for the country-sector trade in value-added. Since the regionalization measure is a ratio, we can easily assess which component is driving the main results by decomposing the overall effect of digitalization into the intra-EU GVC flows (i.e., the numerator) and the extra-EU GVC flows (i.e., the denominator). Finally, we perform a heterogeneity analysis, taking into consideration two dimensions. The first one is the technological dimension in which we split the sample according to the OECD taxonomy of sectoral digital intensity (Calvino et al., 2018). The second one regards the sourcing (backward) and destination (forward) perspectives of GVC participation and regionalization.

The econometric results can be summarized as follows. First, there is no evidence that digital technologies weaken GVCs linkages; on the contrary, our results show that they are more likely to enhance them: we find a positive correlation between digital capital and GVC trade, and a non-negative (positive in some specifications) correlation with GVC participation.

Second, there is a positive effect of digital capital on GVC regionalization: the main result stems from an asymmetric effect of digitalization on GVC linkages whereby intra-EU GVC trade is more strongly affected than extra-EU GVC trade. Third, all the above results particularly apply and are driven by the highly digital intensive manufacturing sectors; moreover, results hold on both the backward and forward GVC linkages. Finally, results are robust to different specifications as well as to an alternative IV approach.

Our findings contribute to the literature on GVCs and their reorganization since the GFC and to the literature on the effects of technological change on economies, regions, and firms. The evidence provided not only connects these two strands, but also sheds light on an emerging phenomenon, adding a new perspective that is supported by the empirical results: GVCs are not retracting, and digitalization is likely to keep expanding the scope for international production fragmentation. Yet, firms in GVCs are reorganizing to take advantage of new technologies and to face recent geopolitical tensions. The direction points to regionalization, at least for European GVCs.

The remainder of the paper is organized as follows: Section 2 presents the main literature on the interaction between recent trade dynamics and digitalization. Building on the economic channels highlighted in the literature, Section 3 describes the conceptual framework that guides our empirical analysis. In Section 4 we present the data and the methodology, while Section 5 provides the main descriptive evidence. Section 6 discusses the identification strategy, and reports the main econometric results, the heterogeneity, and the robustness analyses. Section 7 draws some conclusions.

2 Related literature

In the last two decades, international trade has been shaped by economic, geopolitical, and technological factors, which eventually call for a reorganization of international production networks. The increased number of regional trade agreements supported the regionalization of trade, prompting – and supporting – the tendency of GVCs to locate the stages of production in contiguous regions, reversing the trend of global expansion experienced since the 1990s. Moreover, increasing costs in emerging economies and geopolitical tensions pushed lead firms in GVCs to rationalize their supply chains by selecting more reliable firms, and expanding inventories to prevent the risk of supply disruption, that is, enhancing their resilience (Brun et al. 2019; Gereffi and Lee 2012).

In such a context, a technological shift, such as the one driven by digitalization in many manufacturing sectors, may lead to a reconfiguration of value chains. Digitalization may extend disintermediation due to the use of digital platforms in coordinating production and transactions, and it may increase servicification, leading to a relevant role for data creation and exploitation (Butollo and Schneidemesser, 2022; Eurofound, 2018). Lastly, massive digitization and automation of routine-intensive production tasks push for a flexible production, which may be distributed in a more agile way across different plants and which, eventually, might impact on productivity and labor (Acemoglu et al., 2020; Brun et al., 2019; Acemoglu et al., 2019).

On the other hand, "traditional ICT", that is, information and communication technologies that characterized the first wave of digitalization in the 1990s,[3] have greatly evolved in the last decade. These technologies continue to contribute to the reduction in communication costs, while constituting the basis of the recent advancements reached by advanced digital technologies.

To investigate the relationship between digitalization and GVC regionalization, we take a closer look at the effect of digital technologies on sectoral production processes. In line with Autio et al. (2021), we detect two opposite forces in trade triggered by digital technologies' adoption (see also Zhan, 2021), stemming from the direct or indirect impacts they have on production at the micro level. Some digital technologies, such as those related to physical production that have to be installed "*in situ*" (that is, on the plant's grounds), allow the firm to automate processes, to reduce waste, and to improve productivity. This category includes technologies such as advanced automated robots (Eurofound, 2018), additive manufacturing (Freund et al., 2022; Laplume et al., 2016), artificial intelligence (Yang, 2022; Rammer et al., 2022), and big data analytics (Niebel et al., 2019). The latter is associated with high-skill labor, innovation activities, and cost savings. It is important to emphasize that, in principle, some of these technologies—such as AI and big data analytics—do not need to be installed "*in situ*"; however, they require the hiring of ICT specialists (e.g., data analysts, engineers, etc.) at the headquarters to ensure their proper functioning.

These technologies allow upgrading processes in each geographical location, decreasing production costs and, through flexible production and being closer to the end users, eventually reduce the need to take advantage of cost differentials (World Bank, 2020). They thus may represent a "centripetal" force pushing for a relocation of some stages of production processes in advanced countries (Autio et al., 2021) where the adoption of technologies may be reinforced – and its effect enhanced – by the presence of: complementary assets (Teece, 2018), connectivity infrastructures, higher managerial quality and workers skills, and financial instruments (Nicoletti et al., 2020), which are relatively abundant in European countries.

[3] "Traditional ICT" have characterized the first wave of digitalization and driven "globalization's second unbundling" (Baldwin, 2016). Among them, we can find: Personal Computers, internet connections (and later broadband internet), and early versions of Supply Chain Management and Enterprise Resources Planning software.

These technologies are contrasted by digital communication technologies, which, representing a continuation of the ICT revolution, allow for lower entry and operative costs (Antràs, 2020; World Bank, 2020), eventually affecting coordination costs (within the firm) and transaction costs (between firms) (Sturgeon, 2021). This category includes Enterprise Resources Planning (ERP) software, Electronic Data Interchange (EDI) and Application Programming Interface (API) (Baldwin, 2016; Fort, 2017), digital platforms (Eurofound, 2018; Parker, 2016), and, in general, Internet connections, which reduce geographical distances, facilitating knowledge transfer within a firm (Forman and van Zeebroeck, 2019). These technologies exert a "centrifugal force" (Autio et al., 2021), given that connecting dispersed locations also represents an incentive for the further fragmentation of value chains. A schematic summary of the different digital technologies and their likely impact on the regionalization of GVCs, along with their characteristics and the main references, is outlined in Table 1.

Table 1: Main effects of digital technologies on production

Digital technology	**Main effect**	**Main references**	**Expected sign on regionalization**
Computers and ICT	Reducing communication costs	Baldwin (2016)	-
	Improving productivity	Biagi (2013); Draca et al. (2009)	+
	Lowers coordination costs	Fort (2017)	-
	Lower geographical distances facilitating knowledge transfer within firms	Forman and van Zeebroeck (2019)	-
Big data	Product innovation; higher likelihood of market success for new products	Niebel et al. (2019)	+
	Supports higher decision-making quality	Awan et al. (2021)	+/-
Robotics and automation	Positive impacts on employment; increase among workers with different kind of routine-related tasks	Domini et al. (2019)	+
	Negative effects on employment and wages in US commuting zones	Acemoglu and Restrepo (2019)	-
	Increase in intermediate inputs from foreign suppliers	Cilekoglu et al. (2024)	-
Additive manufacturing	Reduction in costs of production	Freund et al. (2022)	+
	Complementarity with labour, no labour-saving effects	Felice et al. (2021)	+/-
	Potential reduction of labor input; higher customization of products	Laplume et al. (2016)	+
Artificial Intelligence	Facilitate in creating new products; positively affects productivity; favours high-skilled labor demand	Yang (2022)	+
	Some AI tasks are complementary to human tasks	Mondolo (2021)	+
	Higher innovation performance; increase in sales for world-first product innovation; contribution in cost savings	Rammer et al. (2022)	+

Source: authors' elaboration.

3 Conceptual framework

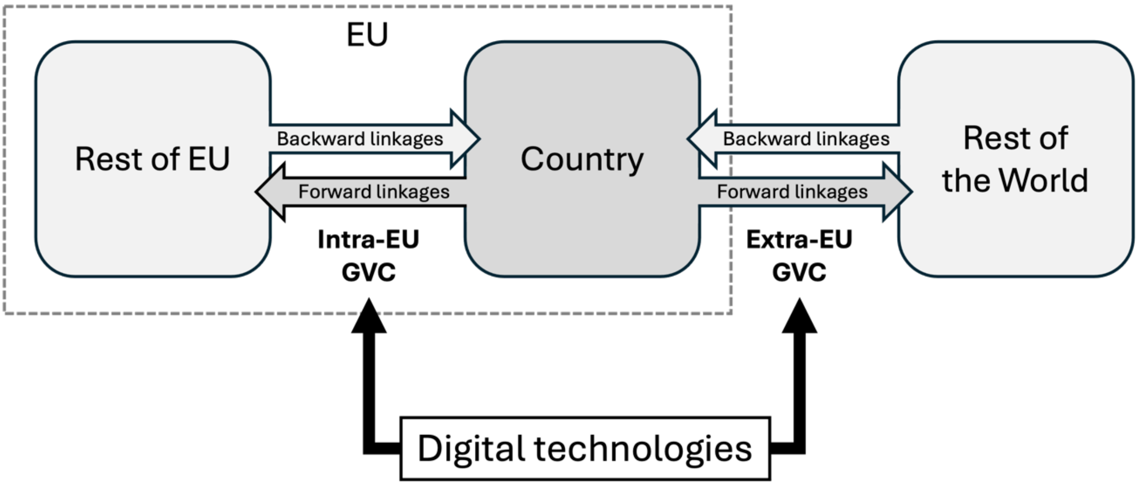
In Figure 1, based on the economic channels discussed in the previous section, we present a simplified diagram depicting the conceptual framework that guides our empirical analysis. GVC linkages – denoted by the arrows between countries and regions – regard flows of value-added contained in the traded goods that are processed internationally and cross at least two borders (Hummels et al., 2001; Borin and Mancini, 2019). Following the literature on GVCs, a country can be involved in GVCs through backward and forward linkages, being respectively a user or a provider of intermediate goods and value-added. Taking the perspective of an EU country, GVCs involvement – either backward or forward – may regard another EU country (intra-EU GVCs) or a country from the rest of the world (extra-EU GVCs). As discussed in the previous section, digital technologies, and their diffusion and adoption within the country, have the potential to affect production processes in several ways, also depending on the specific type of the prevailing technology, modifying the incentives for the international allocation of production stages across, closer or farer economies. Because intra-EU and extra-EU linkages have different characteristics, the impact of digital technologies is likely to be asymmetric, contributing to the increase or decrease of the regionalization of GVCs. In the diagram, the two arrows going from digital technologies to intra- and extra-EU GVC linkages represent these two potentially asymmetric channels. In this paper, our empirical aim is to investigate the impact of digital technologies on GVCs regionalization, where, in line with the conceptual framework illustrated above, our working definition of GVC regionalization refers to the relative importance of intra and extra-EU GVC linkages.

Importantly, because the relationships depicted in the diagram are also likely to have a relevant sectoral dimension, specifically concerning sectors with a different scope for digitalization, which may moderate the strength of the differential effects of digital technologies on intra and extra-EU GVC linkages, this simplified conceptual framework is more appropriately understood once applied at the sectoral level.

The scheme is also useful in clarifying that the perspective we adopt in this paper – as well as the unit of observation in the empirical analysis – is that of an EU country-sector, its GVC linkages within and outside the EU, and its adoption of digital technologies.

In the next section, we describe the data sources, the measurement and methodological approach that we follow to empirically investigate the relationship between digitalization and GVCs regionalization.

Figure 1: Conceptual framework



Source: authors' elaboration.

4 Data and methodology

We built an original dataset constructed by integrating different data sources. We used data from OECD-TiVA to calculate GVC value-added trade flows, which, in turn, are used to calculate the GVC participation and regionalization indicators. Digital capital data and the other control variables are sourced from EUKLEMS. The countries included in the final sample are Austria, Belgium, Czech Republic, Germany, France, UK, Italy, Netherlands, and Slovakia. The sectors covered are all the 2-digit ones from the NACE C division (i.e. manufacturing).[4] The time coverage spans from 2005 to 2018.

[4] Regarding the sectoral concordance, since the OECD-TiVA and EUKLEMS sectoral classifications do not perfectly overlap, some sectors had to be aggregated.

The countries selected are those whose data availability was sufficient to allow for our empirical investigation, particularly regarding digital capital and related patents (needed for the construction of the instrumental variables). On the other hand, this group of countries, while representing the bulk of aggregate EU manufacturing value-added and GDP, play a relevant role in the EU GVCs;[5] nonetheless, some important economies – e.g. Spain and Poland – are excluded from the empirical sample because of data limitations. However, it is important to point out that our analysis still implicitly includes GVC information on the excluded countries that are either European or are from the rest of the world. In fact, we calculate GVC linkages of each country included in the final sample with all the intra and extra-EU countries available in the complete OECD-TiVA database. This ensures that our results are fully representative of countries' GVC involvement. We focus on the manufacturing sectors because, in the period under analysis, they are the ones mostly involved in the globalization of production and GVC activity. Moreover, limiting the analysis to manufacturing simplifies the interpretation of results, given that the digitalization of services involves specificities that raise different economic issues.

The regionalization indicators based on OECD-TiVA data are built following Los et al. (2015) and Bontadini et al. (2022), adopting a regional-to-global perspective. Let us define as intra-regional flows the GVC value-added trade flows whose origin and destination are the EU countries (intra-EU). By contrast, the extra-regional flows involve the EU as either the origin or the destination while partner countries belong to the rest of the world (extra-EU).[6] GVC value-added trade flows are calculated from the OECD-TiVA input-output tables according to the most recent approaches (Borin and Mancini, 2019; Los and Timmer, 2018).[7] For each country-sector pair we retrieve: (i) the foreign value-added in gross exports (FVADEX) distinguishing between intra-EU and extra-EU flows; and (ii) the domestic value-added in foreign export (DVAFEX) distinguishing, again, intra-EU and extra-EU flows. In detail, we use four GVC trade variables of sector s of EU countries c in year t:

[5] The countries in the sample account, on average, for the 33% of foreign value-added in gross export (EXGR_FVA) as a share of the total EXGR_FVA of the EU-28 in the years of our analysis, against the 17% of the other EU countries out of the sample. A similar pattern holds for the domestic value-added in gross export (EXGR_DVA), as a share of the European total, which is, on average 16% for the countries in the sample, against the 10% for those outside. More details, with the countries' breakdown, are provided in the Appendix, Table A1.

[6] That is, we exclude GVC trade flows between non-EU countries.

[7] The calculations have been performed in Stata using the command "icio" (Belotti et al., 2021).

- $FVADEX_{cst}^{intra}$ is the foreign value-added in gross exports that is sourced from other EU countries;
- $FVADEX_{cst}^{extra}$ is the foreign value-added in gross exports that is sourced from non-EU countries;
- $DVAFEX_{cst}^{intra}$ is the domestic value-added in gross exports that is further re-exported by other EU countries;
- $DVAFEX_{cst}^{extra}$ is the domestic value-added in gross exports that is further re-exported by other non-EU countries.

The sum of the first two variables gives the total foreign value-added in gross exports of EU countries ($FVADEX_{cst}$), which measures the so-called backward GVC linkages. Similarly, the sum of the last two variables gives the total domestic value-added in gross exports of EU countries that is further re-exported by other EU or non-EU countries ($DVAFEX_{cst}$), and it represents a measure of the so-called forward GVC linkages.

The standard measure of GVC participation, composed of backward and forward participation, can be calculated as the share of GVC value-added trade in gross exports X_{cst}:

$$GVC\_Part_{cst} = \frac{FVADEX_{cst} + DVAFEX_{cst}}{X_{cst}} \tag{1}$$

Finally, the GVC regionalization indicator is calculated as the ratio between the intra-EU and the extra-EU flows and it is, therefore, a relative measure of whether the regional EU flows are comparatively more important than the extra-regional ones:

$$GVC\_Regio_{cst} = \frac{FVADEX_{cst}^{intra} + DVAFEX_{cst}^{intra}}{FVADEX_{cst}^{extra} + DVAFEX_{cst}^{extra}} \tag{2}$$

What really matters for our analysis is the trend in the GVC regionalization ratio rather than its level. The former is more suited to capture the reorganization of GVCs, while the level of the indicator is a measure of how globally fragmented the GVCs are, something that clearly depends also on the level of geographical aggregation and other factors. Here we are primarily interested in whether EU GVCs are becoming more or less regional, not in whether the regionalization level can be gauged to be high or low relative to other countries or areas.

As for digitalization, we use data from EUKLEMS to build a proxy. Specifically, digital capital (*Kq_Digital*) is the sum of Information Technologies, Communication Technologies, and Software & Database capital. All the measures are the net capital stock, in volume at 2015 reference prices. We also use as control variables: the value of "other capital" (*Kq_Other*), that is, the Gross Fixed Capital Formation net of the measure of digital capital; the number of persons employed (EMP); and the value-added (VA). Table 2 shows the variables, along with their description, source, and the main descriptive statistics.

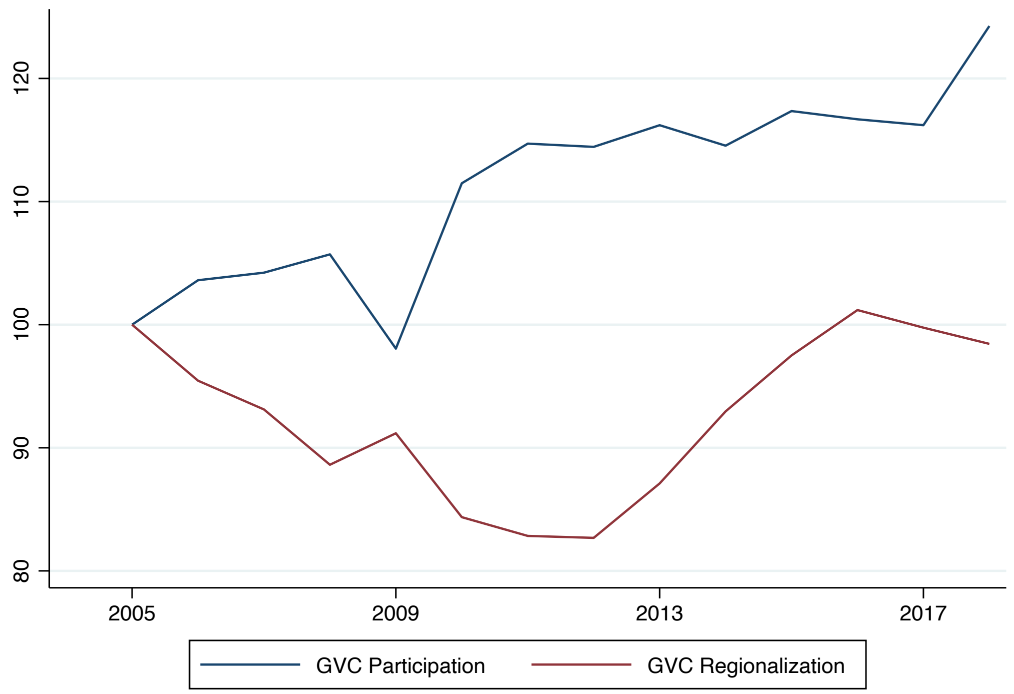
Table 2: Variables' description and descriptive statistics

Variable	Description	Source	N	Mean	SD	Median	Min	Max
GVC_Part	GVC Participation (GVC VA/Gross Export)	OECD-TiVA	1,398	0.46	0.24	0.43	0.17	7.37
GVC_Regio	GVC Regionalization (GVC_Intra/GVC_Extra)	OECD-TiVA	1,398	2.05	0.84	2.01	0.10	4.38
GVC_Intra	GVC intra-EU VA (FVADEX+DVAFEX)	OECD-TiVA	1,398	5,548	7,613	3,233	161	75,094
GVC_Extra	GVC extra-EU VA (FVADEX+DVAFEX)	OECD-TiVA	1,398	3,270	4,247	1,862	87	31,091
Kq_Digital	Digital capital (volume)	EUKLEMS	1,386	1,509	3,857	525	7	54,253
Kq_Other	Other capital (volume)	EUKLEMS	1,386	37,741	66,187	13,216	1,012	539,184
EMP	N. of persons employed (thousands)	EUKLEMS	1,398	189	236	98	1	1,208
VA	Value-Added (volume)	EUKLEMS	1,398	22,323	35,117	8,902	-302	311,676

5 Descriptive evidence

As outlined in the introduction, in the period under study many phenomena have affected trade dynamics. A shock, easily identified in the data, is the Great Financial Crisis (2008), which caused a temporary drop in GVC participation and an increase in EU regionalization, as shown in Figure 2. After the 2009 collapse, GVC participation quickly recovered, also reaching higher rates, above the values recorded at the beginning of the series. The GVC regionalization trend is, instead, a more recent phenomenon. From the figure we can trace it as starting from 2012, where the regionalization ratio begins to grow after about ten years of decline (from 2005 to 2012). Further inspection reveals that the temporary surge of the regionalization ratio in 2009 right after the GFC was due to the faster reduction in the extra-EU flows (the denominator) relative to the intra-EU flows (the numerator). After the GFC, the pre-crisis globalization trend continues until 2012; from this year on, we observe a regionalization trend, with the intra-regional flows growing comparatively faster than the extra-regional ones. The regionalization ratio increases back to its 2005 level at the end of the period under study.

Figure 2: GVC Participation and Regionalization.



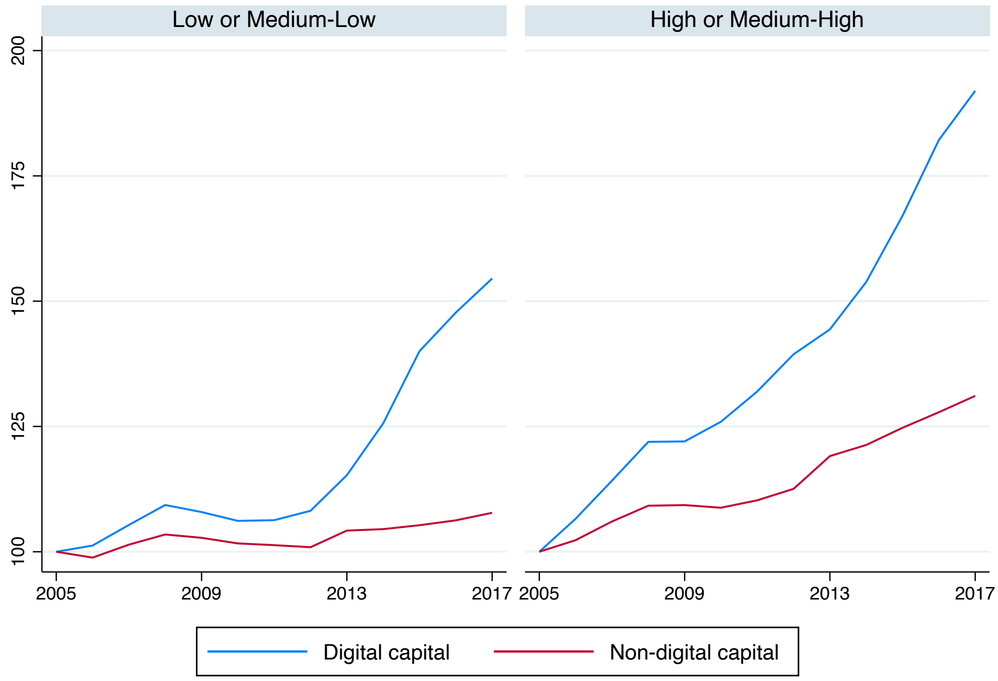
Authors' elaboration on OECD-TiVA data. 2005 = 100.

Regarding digital capital, the data are very clear: digital capital increases basically in every country-sector, generally faster than other forms of capital, thus rapidly augmenting its importance as a production factor. In Figure 3 we look at sectoral digital and non-digital[8] capital through the lens of the taxonomy of digital intensive sectors (Calvino et al., 2018). The taxonomy is used here to account for the degree of pervasiveness of digital technologies. When we look at the High digital sectors (Figure 3, right panel), we notice a dynamism both in terms of non-digital

[8] Here the non-digital capital is defined as the (real) Gross Fixed Capital Formation net of the digital capital (that is, capital in Information Technology, Communication Technology, and Software & Database).

and digital capital. The latter grew by more than 80%, while non-digital capital grew by about 25% in the same period. The difference in the growth of digital and non-digital in the low digital intensive sectors is also worth noting (Figure 3, left panel). Here, the dynamics of non-digital capital has been pretty flat, while digital capital grew by about 50%, with about 40% of the variation being in the last 5 years. This evidence clearly highlights how digital capital is becoming pervasive, not only in high digital sectors but also in more traditional manufacturing sectors.

Figure 3: Digital and non-digital capital by sectoral digital intensity.



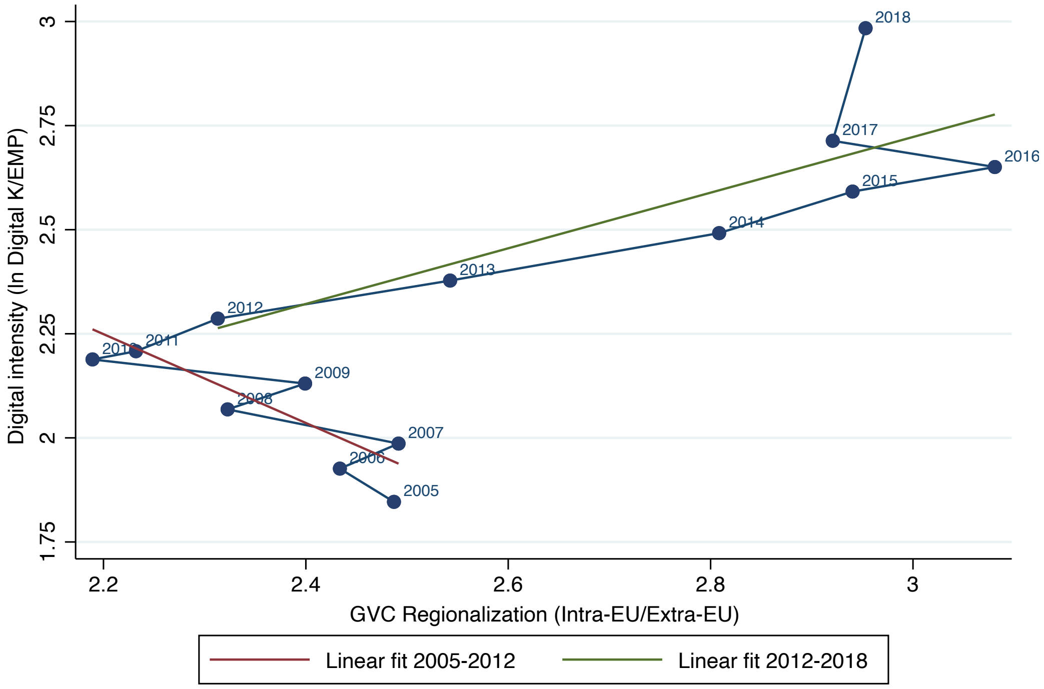
Authors' elaboration on EUKLEMS data. 2005 = 100. Taxonomy on digital intensive sectors by Calvino et al. (2018)

Broadly speaking, we thus observe a regionalization trend at least since 2012 accompanied by the pervasive emergence of digital capital across European industries. The aggregate correlation between these two phenomena is informative of the broad tendencies. In Figure 4, we plot the sectoral digital intensity,[9] our measure of digitalization, against the GVC regionalization ratio. In the figure, two periods are clearly distinguishable: the first one spanning 2005-2011, where the aggregate correlation between digital intensity and GVC regionalization is negative, and the second one, going from 2012 to 2018, characterized by a positive correlation. In the earlier period, digitalization seems connected to a globalization trend, where the extra-regional GVC linkages

[9] The measure is here scaled by the number of employees and weighted by the gross output.

become relatively more important than the intra-regional ones. By contrast, in the last part of the period analysed, the rapid increase in the use of digital capital by manufacturing sectors is associated with the regionalization trend. While speculation regarding the timing of the change in correlation is not warranted and does not fall within the scope of this paper, the evidence is suggestive of some underlying structural changes, especially considering the recent geopolitical and technological developments as highlighted by the literature discussed in the previous sections.

Figure 4: Correlation between digital capital and GVC regionalization



Authors' elaboration. Digital capital per empl. weighted by Gross Output (source: EU-KLEMS).

6 Econometric analysis

6.1 Identification

The aim of our empirical analysis is to identify a potential causal effect of sectoral digitalization on GVC linkages and regionalization. To this purpose, we employ four dependent variables (all in log), namely, GVC participation (*lnGVC_Part*), the GVC regionalization ratio (*lnGVC_Regio*), intra-EU value-added (*lnGVC_Intra*), and extra-EU value-added (*lnGVC_Extra*). The main explanatory variable is sectoral digitalization, proxied by the (log of) digital capital (*lnKq_Digital*). The baseline specification of the model is presented in equation (3):

$$y_{cst} = \alpha + \beta lnKq\_Digital_{cs,t-1} + \gamma Controls_{cs,t-1} + \delta_{cs} + \delta_1 D09 + \delta_2 D12 + \varepsilon_{cst} \quad (3)$$

where y_{cst} denotes our dependent variables, subscript *c* refers to the country, *s* to the industry, and *t* to the year. We also control for the non-digital capital stock, employment, and total value-added; all sectoral controls are in log and lagged by one year. Moreover, we use individual (country-sector) fixed effects for the panel estimations so as to account for country-sector specific time-invariant characteristics and, hence, allow the regression to capture the within variation. Lastly, as a further check, we include two time dummies, one for 2009 and the other for 2012, controlling for the two major common shocks visible in the series in the period analysed.

The primary coefficient of interest in equation (1) is the estimand β, which measures the elasticity of the dependent variables with respect to sectoral digital capital, holding other factors constant. The main empirical challenge is that the causal interpretation of the coefficient estimated via OLS is compromised due to endogeneity concerns. There are essentially two reasons for these concerns. Firstly, regionalization dynamics are influenced by various economic and non-economic factors, such as geopolitical considerations, which may lead to an omitted variable bias. Although this bias is somewhat mitigated by the inclusion of controls and panel fixed effects, it remains a concern. Secondly, the OLS estimates may be biased due to potential simultaneity arising from reverse causality: while our primary interest lies in examining the impact of digitalization on GVC regionalization, it is also possible that GVC linkages influence firms' decisions to invest in digital capital.

To address these issues, we employ a Bartik instrumental variable approach (Goldsmith-Pinkham et al., 2020; Bartik, 1993). To this aim, we build two shift-share instrumental variables, each composed of two elements: i) the digital capital share of the sector with respect to the country total (the "share" elements); ii) the (log of) the total number digital-related patents at the world level (the "shift" elements). We focus on two types of patents, ICT and AI, according to the OECD definitions; therefore, our two instruments capture these two aspects of digitalization.[10]

Following the intuition of Caselli et al. (2024), the rationale for the choice of patents as "shift" elements lies in capturing the existing opportunities provided by the digital technologies to which sectors might be exposed. The world patents stock is exogenous to the trade dynamics, and is "mediated" (i.e., potentially absorbed) into the sector through the pre-existing degree of digitalization of the sector itself (with respect to the degree of digitalization of the country). Furthermore, the introduction of an exogenous variation related to technological progress, such as the evolution of the world stock of digital-related patents of different types, also allows us to consider the qualitative evolution of digital technologies which has been substantial in the last decades.

The Bartik-like instrument is constructed as shown in equation (4):

$$BtkIV_{cst}^{T} = \frac{Kq\_Digital_{cs,t-1}}{Kq\_Digital_{c,t-1}} \times lnPatent_{t}^{T} \qquad (4)$$

where *lnPatent* indicates the world stock of patents (in log), and the superscript *T* identifies the different technologies, that is, in turn, ICT-related and AI-related patents.

In the next section, we present the results for the 2SLS-IV model, while extended results using the pooled OLS model and the fixed-effect panel model are available in the Appendix. All estimations employ clustered standard errors at country-sector level which accounts for within-group (country-sector) correlation and heteroskedasticity.

[10] The Bartik-like IV is built using as a "shift" the number of the world patent stock in ICT-related fields, following the definition of Inaba and Squicciarini (2017), and the world patent stock in AI-related fields, following the definition of Baruffaldi et al. (2020).

6.2 Main results

6.2.1 Digitalization effect on GVC participation and regionalization

Table 3: Main results (2SLS-IV)

	(ln) GVC		Regionalization	
	Part.	Region.	(ln) Intra-EU VA	(ln) Extra-EU VA
	(1)	(2)	(3)	(4)
(ln) Digital capital, t-1	0.018	0.117***	0.184***	0.067
	(0.025)	(0.031)	(0.038)	(0.043)
Country-sector FE	Yes	Yes	Yes	Yes
Oth. Controls	Yes	Yes	Yes	Yes
Constant	0.162	-0.183	4.153***	4.336***
	(0.275)	(0.340)	(0.421)	(0.466)
Observations	1,291	1,291	1,291	1,291
Underid. test (Chi-sq)	616.77			
Weak id. test (F)	306.56			
R-squared	0.224	0.051	0.337	0.310

IV-2SLS estimations. Oth. Controls include: (ln) non-digital capital, (ln) employment, (ln) value-added, dummies for 2009 and for 2012. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

In Table 3 we present the results for the main coefficient (i.e., industry digitalization) on the GVC participation (Column 1) and on the measures of GVC regionalization. All the specifications make use of the full set of controls and are estimated using the Two Stage Least Square procedure. Concerning the regionalization measures, in Column 2 we report the impact on the overall measure (i.e., the ratio), while Columns 3 and 4 show the results on the ratios' components, that is, the numerator (Column 3, Intra-EU value-added), and the denominator (Column 4, Extra-EU value-added).

The impact of industry digitalization, that is, the diffusion of digital capital in European country-sectors, is always positive on the measures under study, even though the coefficients are not always statistically significant.

In particular, digital capital impacts positively the GVC participation, but the coefficient is not significant. On the other hand, the impact is positive on the overall measure of regionalization: an increase of 1% in digital capital leads to an increase of 0.12% in regionalization (Column 2).

When we look at the components of the regionalization measure, we find a significant effect only on the value for the Intra-EU value-added flows, while the effect is not significant for the Extra-EU value-added, even though the sign is positive. Hence, a 1% increase in the digital capital used by the industries leads to an increase in the regional value-added of 0.18% in the intra-regional flows. The asymmetrical effect on the components of the ratio, with a significant effect only on the intra-regional flows, leads to an increase of the overall regionalization: the intra-regional flows grow due to digitalization, with respect to the extra-regional flows.

6.3 Heterogeneity

6.3.1 Sectoral digital intensity

Digital technologies may exert their effects with a different intensity, depending on the extent to which the sector may use "digital opportunities", that is, how much of the production process may be conducted using digital technologies.

Given this possible sectoral heterogeneity, we test our hypotheses differentiating the sectors. We follow the OECD Taxonomy on Digital Intensive Sectors (Calvino et al., 2018) and cluster the sectors into two classes: (1) Low and Medium-Low Digital Intensive sectors, (2) Medium-High and High Digital Intensive sectors. The results are reported in Table 4.

Table 4: Digitalization impacts on regionalization by sectoral digital intensity

	(ln) GVC				Regionalization			
	Participation		Regionalization		(ln) Intra-EU VA		(ln) Extra-EU VA	
	Low	High	Low	High	Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(ln) Digital capital, t-1	0.024	0.072**	-0.035	0.182***	0.084*	0.235***	0.119**	0.053
	0.032	0.029	0.042	0.033	0.050	0.043	0.056	0.047
Country-sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-2.215	1.246***	0.319	-0.385	4.161***	3.837***	3.842***	4.222***
	0.508	0.300	0.672	0.341	0.800	0.445	0.900	0.485
Observations	643	648	643	648	643	648	643	648
Underid. test (Chi-sq)	657.94	362.17	657.94	362.17	657.94	362.17	657.94	362.17
Weak id. test (F)	325.06	178.95	325.06	178.95	325.06	178.95	325.06	178.95
R-squared	0.211	0.322	0.070	0.046	0.287	0.448	0.294	0.369

IV-2SLS estimations. Sectoral digital intensity defined following Calvino et al. (2018). Low refers to "Low" and "Medium-Low" digital sectors, High to "Medium-High" and "High" digital sectors. Oth. Controls include: (ln) non-digital capital, (ln) employment, (ln) value-added, dummies for 2009 and for 2012. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

There emerges (Table 4) a clear positive association between digitalization and GVC participation and regionalization for Medium-High and High digital intensive sectors (Columns 2 and 4), while the coefficients are not significant for Low and Medium-Low sectors. A 1% increase in digital capital increases GVC participation by 0.07% and GVC regionalization by 0.18% for Medium-High and High digital intensive sectors. These results suggest that it is the spread of digitalization in high-digital sectors which is boosting both GVC participation and regionalization, claiming, instead, no role in the case of the low digital intensive sector.

On the other hand, when we decompose the regionalization measure (Table 4, Column 5-8), there emerges a mixed picture. Digital capital exerts a positive impact on the Intra-EU value-added, with a different magnitude on sectors with different digital intensity. A 1% increase in digital capital increases the intra-regional value-added flows by 0.08% for Low and Medium-Low digital intensive sectors, and by 0.23% for Medium-High and High digital intensive sectors.

When we look at the extra-regional flows, the picture is rather different. The diffusion of digital capital in European industries increases the extra-regional trade for Low and Medium-Low digital intensive sectors, while displaying a non-significant coefficient for High and Medium-High sectors. In particular, a 1% increase in digital capital is associated with an increase in extra-regional value added, for Low and Medium-Low digital intensive sectors, of 0.12% (Column 7).

In conclusion, digital capital affects participation and regionalization through the impact on the high digital intensive sectors (i.e., the more digitalized is a sector, the higher is the participation and the regionalization).

On the other hand, there is a twofold asymmetric impact when we decompose the regionalization index. For low digital intensive sectors (Columns 5 and 7), the impact on the intra-regional flows is slightly smaller than the one on the extra-regional ones. Then, the impact on the overall measure becomes non-significant, since the two components are comparable in terms of magnitude. By contrast, when we look at the high digital intensive sectors (Column 6 and 8), digitalization has a stronger impact on the intra-regional flows, while it is not significant for the extra-regional ones.

6.3.2 Backward and forward GVC trade

When analysing trade in value-added, it is important to disentangle two crucial aspects: the so-called backward and forward perspectives. The backward index identifies the input-sourcing perspective, that is, the origin of the value-added content in the country-sector's exports. The second one, the forward trade, traces the output-destination perspective, that is, the destination of the value-added content.

We disentangle the trade flows under study by building the regionalization measures, using separately the backward and the forward indicators. Table 4 reports the results for backward and forward GVC trade: sectoral digitalization seems to play no role in enhancing GVC participation if we distinguish the backward and forward perspectives. The result is also consistent with the one on the overall GVC participation (Table 3, column 1), where the coefficient of digital capital is not statistically significant.

When we look at the GVC regionalization distinguishing the backward and the forward perspective (Table 5, columns 2 and 6), we find a more composite scenario. An increase of 1% in digital capital leads to an increase of 0.10% in backward regionalization, and to a 0.18% increase in forward regionalization. Both the effects are significant, yet the impact on forward regionalization is twice the magnitude with respect to the one for backward regionalization. It follows that digitalization impacts more intensively the regionalization of the output destination perspective with respect to the input sourcing.

We then distinguish the impacts on the numerator and on the denominator of the ratio (columns 3-4 and 7-8). Digitalization affects positively both the backward flows, that is, intra- and extra-regional backward value-added, but with a differentiated magnitude. The effect on the dependent variable due to a 1% increase in digital capital is 0.19% for intra-regional flows, against the 0.09% for the extra-regional flows. Digital capital seems to stimulate a backward type of GVC participation, regardless of the origin, intra- or extra-EU.

On the other hand, looking for the differentiated effects of the numerator and denominator for the forward trade, we find a positive effect of digitalization for the intra-regional flows (with an associated increase of 0.15%), while the effect for extra-regional flows is non-significant. Then, overall increase in forward regionalization, which is also larger than the one for backward regionalization, is due to an increase in the intra-regional value-added trade.

In conclusion, the picture that emerges looking at the input-sourcing and the output-destination perspectives tells us that the regionalization phenomenon is mainly driven by the digitalization effect on the forward trade side, where the effect of digitalization is twice the coefficient of the backward trade. At the same time, disentangling the internal dynamics of the ratio, digitalization is found, again, to enhance the intra-regional flows, while having a weak or non-significant effect on the extra-regional flows, regardless of the trade perspective.

Table 5: Digitalization impacts on Backward and Forward GVC trade

	Backward Value-Added				Forward Value-Added			
	(ln) GVC		Regionalization		(ln) GVC		Regionalization	
	Participation	Region.	(ln) Intra-EU VA	(ln) Extra-EU VA	Participation	Region.	(ln) Intra-EU VA	(ln) Extra-EU VA
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(ln) Digital capital, t-1	0.024	0.096***	0.186***	0.090*	-0.009	0.180***	0.155***	-0.025
	0.028	0.036	0.048	0.049	0.034	0.030	0.033	0.031
Country-sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.808***	-0.797**	2.880***	3.677***	-0.460	0.983***	3.996***	3.013***
	0.303	0.392	0.523	0.534	0.373	0.329	0.361	0.341
Observations	1,291	1,291	1,291	1,291	1,291	1,291	1,291	1,291
Underid. test (Chi-sq)				616.77				
Weak id. test (F)				306.56				
R-squared	0.179	0.065	0.271	0.292	0.210	0.105	0.377	0.293

IV-2SLS estimations. Oth. Controls include: (ln) non-digital capital, (ln) employment, (ln) value-added, dummies for 2009 and for 2012. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

6.4 Robustness

To test the robustness of our main results, we perform an econometric analysis using an alternative share to define the Bartik-like instrument.

Following the same intuition, we use the same “shift” as in the main econometric analysis (i.e., based on the ICT- and AI-related patents), while the “share” is defined as the sectoral share of the sector with respect to the country total of the (real) capital in innovative property (sourced from EUKLEMS). The latter is defined as the aggregate containing R&D, other intellectual property products, design and new financial products (Bontadini et al., 2024). Since digital capital is also related to innovative outcomes, both in terms of product and process innovations (Benassi et al., 2020; Niebel et al., 2019), this should correlate (i.e., be relevant) to instrument the explanatory variable, and again by construction be exogenous to the dependent variables (e.g., regionalization, intra- and extra-regional value-added flows).

Table 6: Robustness analysis - Alternative IV

	(ln) GVC		Regionalization	
	Participation	**Region**	**(ln) Intra-EU VA**	**(ln) Extra-EU VA**
	(1)	**(3)**	**(4)**	**(5)**
(ln) Digital capital, t-1	0.191***	0.408***	0.553***	0.144**
	0.044	0.061	0.073	0.069
Country-sector FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Constant	-0.148	-1.600***	2.757***	4.357***
	0.357	0.489	0.585	0.557
Observations	1,147	1,147	1,147	1,147
Underid. test (Chi-sq)		189.85		
Weak id. test (F)		94.29		
R-squared	0.151	-0.259	0.109	0.301

IV-2SLS estimations. Alternative Bartik IV based on the country-level share of (real) capital in Innovative Property (share), and ICT- and AI-related world stock of patents as defined by OECD (shift). Oth. Controls include: (ln) non-digital capital, (ln) employment, (ln) value-added, dummies for 2009 and for 2012. Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

The results reported in Table 6 are consistent in sign with the main results, while we gain significance and also stronger magnitude for some coefficients. Using the alternative IV, the impact of digital capital on participation become significant (column 1) and with a stronger magnitude. The regionalization measure (i.e., the ratio, column 2) remains significant, but with a larger magnitude, due to the impacts on the two components. Both the numerator and the denominator are impacted positively and it is confirmed that the intra-regional flows grow more than the extra-regional ones. A 1% increase in digital capital leads to a growth of 0.55% in intra-regional flows, and of 0.14% of extra-regional ones (columns 4 and 5). Therefore, with the numerator being larger than the denominator, the overall regionalization measure increases by 0.41%.

In conclusion, we have introduced an alternative measure to build the Bartik IV, which builds on the relationship between digital capital and innovation. This relationship represents the innovativeness of the sector with respect to digital innovations codified in the (ICT- and AI-related) patents. The results remain consistent in sign, and, most importantly, they also gain in magnitude and significance, confirming the overall pattern emerging from the main results.

7 Conclusion

The last two decades have been characterized by the expansion of GVCs until the GFC, and then by the slowdown due to the effects of multiple crises – economic and then geopolitical – on firms, sectors, and countries. The international trade dynamics in the last decade has also been shaped by the uncertainty of the geopolitical and socioeconomic scenario, characterized by Brexit, the USA-China trade war, the Covid pandemic, the recent developments in the conflicts between Russia and Ukraine and in the Middle East.

Finally, a new technological paradigm – the Fourth Industrial Revolution – is also emerging, driving firms, sectors, and markets to deal with new production processes, where digital technologies, data, and platforms are changing the way value is produced and captured.

The combination of the phenomena just mentioned – geopolitical and economic turmoil, along with technological developments – led to a debate on the possible reshape in international trade dynamics, with the potential ultimate effect of value chain regionalization. Our paper builds on this debate to analyse the role of industrial digitalization – that is, the widespread diffusion of digital technologies in manufacturing sectors – in the regionalization of GVCs' trade in a sample of European countries.

We analyse the dynamics of GVC participation and regionalization, and we correlate these indicators with the diffusion of digital capital (that is, our proxy for industrial digitalization), also distinguishing between sectors with different digital intensity.

We have produced two main findings: i) digitalization does not reduce GVC participation – having a non-significant or a positive coefficient, depending on the specification – and positively impacts GVC regionalization. This latter result is due to the asymmetric impact of digitalization on the trade flows, with a stronger (and significant) effect on the intra-regional flows, which grow more with respect to the extra-regional ones; ii) regionalization is driven by high digital-intensive sectors, for which intra-regional trade in value-added grow more than the extra-regional one. Looking at the buyer-seller perspective (i.e., the backward and forward GVC linkages), the results indicate a clear predominance of the effect of digitalization on the intra-regional flows, which grow more than the extra-regional ones. The diffusion of digital capital increases the intra-regional flows more than the extra-regional ones, both for the backward and for the forward value-added.

The results are robust to a different IV, which is defined by building on the capital in innovative property. With the alternative IV, the results also gain in magnitude and significance, confirming the picture that emerged with the main analysis.

The scenario depicted by the analyses shows an increasing digitalization in many manufacturing sectors, which impacts asymmetrically the trade in value-added. We contribute to the debate on the implications of technological advancement and trade regionalization in two ways.

The first contribution relates to the role of digital capital in connecting firms and markets. Digital technologies – in the sample and in the period under study – continue to play the role of easing communications, knowledge and information flows and, indeed, we found no evidence of de-globalization associated with digitalization.

The second contribution relates to the asymmetric effect of digital technologies on the regional trade flows. Digitalization is causing a reshape in value-added, contributing to the expansion of trade, with positive effects on both intra- and extra-regional value-added, but with different intensity.

The latter result paves the way to further analyses in terms of the impact of new technologies on regional trade. In the case of European countries, digital technologies positively influence productivity and employment, even though with heterogeneous effects (Lamperti et al., 2023;

Sorbe et al., 2019; and for Italy: Cirillo et al., 2022; Bratta et al., 2022). This upgrade may push European manufacturing sectors to be placed in value-chains' segments with higher value-added. Moreover, since digitally enhanced production processes increase their complexity, it may also be the case that a certain degree of complementarity between processes may be required with the aim to further push for regional trade integration.

Our findings also convey significant policy implications, indicating that the adoption of new digital technologies is contingent upon pre-existing digital capital which, subsequently, enhances the robustness of European GVC linkages. Consequently, industrial policies aimed at advancing European technology and GVC upgrading should prioritize both investments in digital capital and the research and development of new technologies.

8 Appendix

8.1 Sample selection

Table A1 reports the descriptive values for the relevance of the countries in the sample for the European (EU-28) trade in value-added (source: OECD-TiVA 2023 edition).

We calculate for each year, and for the total economy: i) the countries' foreign value-added in gross exports (EXGR_FVA) as a share of the total EU-28 EXGR_FVA, which is reported in the left panel (a); and ii) the countries' domestic value-added in gross exports (EXGR_DVA) as a share of the total EU-28 EXGR_DVA, which is reported in the right panel (b).

The countries composing the sample under study (highlighted in bold) show a higher (cross years) average value, and a lower variability (SD). We also report the values for the median, even though there is no substantive difference with respect to the mean, ruling out concerns about the presence of outliers in the time series.

Table A 1: Foreign and Domestic VA in gross exports as a share of total EU-28 value

	(a) Foreign Value-Added			(b) Domestic Value-Added		
Country	**Mean**	**SD**	**Median**	**Mean**	**SD**	**Median**
AUT	**0,153**	**0,012**	**0,148**	**0,057**	**0,003**	**0,056**
BEL	**0,293**	**0,045**	**0,274**	**0,078**	**0,007**	**0,074**
CZE	**0,150**	**0,006**	**0,150**	**0,034**	**0,001**	**0,034**
DEU	**0,859**	**0,074**	**0,823**	**0,433**	**0,021**	**0,428**
DNK	0,146	0,025	0,131	0,040	0,003	0,039
ESP	0,263	0,042	0,243	0,126	0,006	0,126
EST	0,015	0,001	0,015	0,004	0,000	0,004
FIN	0,082	0,024	0,072	0,028	0,006	0,026
FRA	**0,448**	**0,075**	**0,410**	**0,230**	**0,022**	**0,221**
GBR	**0,316**	**0,056**	**0,298**	**0,241**	**0,027**	**0,233**
GRC	0,049	0,007	0,049	0,020	0,003	0,019
HUN	0,138	0,020	0,129	0,023	0,002	0,023
IRL	0,322	0,065	0,301	0,062	0,014	0,059
ITA	**0,372**	**0,076**	**0,339**	**0,188**	**0,025**	**0,174**
LTU	0,018	0,003	0,018	0,006	0,001	0,007
LUX	0,170	0,022	0,175	0,016	0,001	0,016
LVA	0,007	0,000	0,008	0,004	0,000	0,004
NLD	**0,327**	**0,031**	**0,333**	**0,123**	**0,009**	**0,118**
POL	0,155	0,016	0,154	0,060	0,006	0,060
PRT	0,059	0,005	0,059	0,022	0,001	0,022
SVK	**0,086**	**0,008**	**0,087**	**0,016**	**0,001**	**0,016**
SVN	0,030	0,005	0,029	0,008	0,001	0,008
SWE	0,150	0,044	0,125	0,065	0,007	0,063
Total sample	0,200	0,191	0,150	0,082	0,102	0,039
Sample						
0	0,174	0,240	0,119	0,099	0,243	0,023
1	0,334	0,222	0,303	0,155	0,127	0,118

8.2 Extended regressions' tables

Table A 2: Main results (2SLS-IV) - Extended table

	(ln) GVC		Regionalization	
	Participation	**Regionalization**	**(ln) Intra-EU VA**	**(ln) Extra-EU VA**
	(1)	**(2)**	**(3)**	**(4)**
Digital capital, t-1	0.0183	0.1168***	0.1838***	0.0670
	0.025	0.031	0.038	0.043
Non-digital capital, t-1	0.0857***	0.0776**	0.0993**	0.0217
	0.030	0.037	0.046	0.051
Employees, t-1	-0.3925***	-0.1806***	0.3209***	0.5015***
	0.039	0.048	0.059	0.065
Value Added, t-1	-0.0170	0.0133	0.0438**	0.0305
	0.011	0.014	0.017	0.019
Year 2009	-0.1184***	0.0151	-0.3522***	-0.3672***
	0.011	0.013	0.017	0.018
Year 2012	0.0056	-0.1103***	-0.0081	0.1022***
	0.010	0.013	0.016	0.017
Country-sector FE	Yes	Yes	Yes	Yes
Constant	0.1622	-0.1831	4.1529***	4.3360***
	0.275	0.340	0.421	0.466
Observations	1,291	1,291	1,291	1,291
R-squared	0.224	0.051	0.337	0.310

IV-2SLS estimations. All the explanatory variables are expressed in natural logarithm. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A 3: First stage (2SLS) for IV models - Extended table

			Digital intensity		
		Main	**Low**	**High**	**Robustness**
		(1)	**(2)**	**(3)**	**(4)**
Bartik AI-related, t-1		7,052	-22,202	15,889	2,199***
		8,679	16,167	9,731	0,294
Bartik ICT-related, t-1		12,240*	60,602***	2,343	1,460
		6,668	12,553	7,450	1,259
(ln) Oth. K, t-1		-0,121**	-0,015	-0,067	0,073
		0,050	0,068	0,067	0,057
(ln) Empl., t-1		0,261***	0,182**	0,281***	0,448***
		0,064	0,079	0,086	0,073
(ln) VA, t-1		-0,024	0,011	-0,107**	-0,157***
		0,019	0,017	0,043	0,030
Year2009		-0,035**	-0,023	-0,034	-0,017
		0,017	0,021	0,024	0,022
Year2012		-0,010	-0,014	-0,008	0,014
		0,017	0,020	0,023	0,020
Observations		1291	643	648	1147
Underidentification					
	SW (Chi-2)	616.77	657.94	362.17	178.96
	P-value	0.0000	0.0000	0.0000	0.0000
Weak identification					
	SW (F)	306.56	325.06	178.95	88.88

1st stage of the 2SLS-IV procedure. Dependent variable: (ln) Digital capital. Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A 4: Digitalization impacts by sectoral digital intensity - Extended table

	(ln) GVC				Regionalization			
	Participation		Regionalization		(ln) Intra-EU VA		(ln) Extra-EU VA	
	Low	High	Low	High	Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capital, t-1	0.0238	0.0716**	-0.0350	0.1817***	0.0844*	0.2346***	0.1194**	0.0529
	0.032	0.029	0.042	0.033	0.050	0.043	0.056	0.047
Non-digital capital, t-1	0.3365***	-0.0392	0.1193*	0.0122	0.2100**	-0.0625	0.0908	-0.0746
	0.054	0.036	0.072	0.041	0.086	0.054	0.096	0.059
Employees, t-1	-0.4613***	-0.3674***	-0.2047**	-0.1390***	0.2556***	0.3769***	0.4603***	0.5159***
	0.061	0.046	0.081	0.052	0.096	0.068	0.109	0.074
Value Added, t-1	-0.0035	-0.0439*	0.0067	0.0530**	0.0223	0.1820***	0.0156	0.1290***
	0.014	0.023	0.018	0.026	0.022	0.035	0.024	0.038
Year 2009	-0.1142***	-0.1244***	0.0138	0.0102	-0.3720***	-0.3382***	-0.3858***	-0.3484***
	0.017	0.013	0.022	0.015	0.026	0.020	0.029	0.021
Year 2012	0.0054	0.0114	-0.1242***	-0.0966***	0.0330	-0.0538***	0.1573***	0.0428**
	0.016	0.013	0.021	0.014	0.025	0.019	0.028	0.020
Country-sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-2.2150***	1.2464***	0.3190	-0.3851	4.1614***	3.8368***	3.8424***	4.2219***
	0.508	0.300	0.672	0.341	0.800	0.445	0.900	0.485
Observations	643	648	643	648	643	648	643	648
R-squared	0.211	0.322	0.070	0.046	0.287	0.448	0.294	0.369

IV-2SLS estimations. Sectoral digital intensity defined following Calvino et al. (2018). All the explanatory variables are expressed in natural logarithm. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A 5: Digitalization impacts on Backward and Forward VA - Extended table

	Backward Value-Added				Forward Value-Added			
	(ln) GVC		Regionalization		(ln) GVC		Regionalization	
	Participation	Regionalization	(ln) Intra-EU VA	(ln) Extra-EU VA	Participation	Regionalization	(ln) Intra-EU VA	(ln) Extra-EU VA
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capital, t-1	0.0239	0.0957***	0.1861***	0.0904*	-0.0087	0.1801***	0.1547***	-0.0254
	0.028	0.036	0.048	0.049	0.034	0.030	0.033	0.031
Non-digital capital, t-1	0.0832**	0.1176***	0.1175**	-0.0001	0.2122***	-0.1329***	0.1476***	0.2805***
	0.033	0.043	0.057	0.058	0.041	0.036	0.040	0.037
Employees, t-1	-0.2759***	-0.1335**	0.4506***	0.5841***	-0.7479***	0.0006	0.0460	0.0454
	0.043	0.055	0.073	0.075	0.052	0.046	0.051	0.048
Value Added, t-1	-0.0110	0.0097	0.0486**	0.0389*	-0.0343**	0.0387***	0.0397***	0.0010
	0.012	0.016	0.021	0.022	0.015	0.013	0.015	0.014
Year 2009	-0.1364***	0.0326**	-0.3636***	-0.3962***	-0.0671***	-0.0713***	-0.3265***	-0.2552***
	0.012	0.015	0.021	0.021	0.015	0.013	0.014	0.013
Year 2012	0.0008	-0.1327***	-0.0246	0.1081***	0.0095	-0.0286**	0.0302**	0.0588***
	0.011	0.015	0.019	0.020	0.014	0.012	0.013	0.013
Country-sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.8083***	-0.7974**	2.8795***	3.6769***	-0.4598	0.9830***	3.9958***	3.0128***
	0.303	0.392	0.523	0.534	0.373	0.329	0.361	0.341
Observations	1,291	1,291	1,291	1,291	1,291	1,291	1,291	1,291
R-squared	0.179	0.065	0.271	0.292	0.210	0.105	0.377	0.293

IV-2SLS estimations. All the explanatory variables are expressed in natural logarithm. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A 6: Robustness analysis - Alternative IV, extended table

	(ln) GVC		Regionalization	
	Participation	Regionalization	(ln) Intra-EU VA	(ln) Extra-EU VA
	(1)	(3)	(4)	(5)
Digital capital, t-1	0.1910***	0.4084***	0.5526***	0.1442**
	0.044	0.061	0.073	0.069
Non-digital capital, t-1	0.0537	0.0551	0.0127	-0.0424
	0.034	0.047	0.056	0.054
Employees, t-1	-0.4288***	-0.3235***	0.2007***	0.5242***
	0.045	0.061	0.073	0.070
Value Added, t-1	-0.0460***	0.0602**	0.0926***	0.0324
	0.017	0.024	0.028	0.027
Year 2009	-0.1048***	0.0316*	-0.3229***	-0.3546***
	0.012	0.017	0.020	0.019
Year 2012	0.0033	-0.1049***	-0.0054	0.0994***
	0.012	0.016	0.019	0.018
Country-sector FE	Yes	Yes	Yes	Yes
Constant	-0.1479	-1.5997***	2.7569***	4.3566***
	0.357	0.489	0.585	0.557
Observations	1,147	1,147	1,147	1,147
R-squared	0.151	-0.259	0.109	0.301

IV-2SLS estimations. Alternative Bartik IV based on the country-level share of (real) capital in Innovative Property (share), and ICT- and AI-related world stock of patents as defined by OECD (shift). All the explanatory variables are expressed in natural logarithm. Country-sector fixed effects always included. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A 7: Main results by Pooled OLS and Panel FE estimators

	(ln) GVC				Regionalization			
	Participation		Regionalization		(ln) Intra-EU VA		(ln) Extra-EU VA	
	Pooled OLS	Panel FE	Pooled OLS	Panel FE	Pooled OLS	Panel FE	Pooled OLS	Panel FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital capital, t-1	0.041**	0.081***	-0.027	-0.008	0.149*	0.231***	0.176	0.239***
	0.019	0.014	0.055	0.016	0.086	0.022	0.114	0.025
Non-digital capital, t-1	0.006	0.041	-0.033	0.066**	0.026	0.185***	0.059	0.119**
	0.033	0.027	0.144	0.033	0.147	0.045	0.185	0.049
Employees, t-1	-0.206***	-0.390***	0.168**	-0.072*	0.245**	0.167***	0.077	0.240***
	0.022	0.034	0.076	0.041	0.109	0.056	0.140	0.062
Value Added, t-1	0.020	-0.010	0.025	0.000	0.104	0.069***	0.079	0.069***
	0.031	0.011	0.173	0.013	0.149	0.018	0.200	0.020
Year 2009	-0.129***	-0.111***	-0.017	-0.005	-0.322***	-0.323***	-0.306***	-0.318***
	0.007	0.011	0.013	0.013	0.016	0.017	0.018	0.019
Year 2012	0.013*	0.010	-0.121***	-0.118***	0.003	0.009	0.124***	0.127***
	0.008	0.010	0.012	0.012	0.012	0.017	0.014	0.019
Country-sector FE	No	Yes	No	Yes	No	Yes	No	Yes
Constant	-0.390**	0.129	0.109	0.341	4.852***	3.483***	4.744***	3.141***
	0.151	0.242	0.411	0.291	0.767	0.395	1.003	0.439
Observations	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398
R-squared	0.502	0.221	0.135	0.068	0.380	0.307	0.195	0.283

Pooled OLS and Panel FE (within) estimations. All the explanatory variables are expressed in natural logarithm. Bartik IVs based on ICT- and AI-related world stock of patents (OECD). Country-sector fixed effects always included. * p < 0.10, ** p < 0.05, *** p < 0.01

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