TWIN SEEDS

WORK PACKAGE 1

Trends and drivers of global value chains and the role of MNEs in the recent wave of globalisation

Acknowledgements

This report is the first in the series of seven scientific deliverables of the TWIN SEEDS project, funded by Horizon Europe. The financial support of the European Union is gratefully acknowledged.

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Executive summary

While global value chains (GVCs) have played a crucial role in shaping international trade and production processes in this globalisation wave, recent developments suggest a potential slowdown or even a reversal in these integrative forces. Geopolitical shifts and technological transformations can be regarded as two core pillars shaping the remarkable rise and, today, the prospective restructuring of GVC-based production structures. In present days, there is a broad consensus that the COVID-19 pandemic and the Russian invasion of Ukraine have amplified and accelerated these technological and policy shifts that impact GVCs. Yet, while the immediate socio-economic effects are widely considered to be already evident, the long-term consequences on GVCs are still unfolding and require deep investigation.

This report analyses the long-term dynamics in EU-centred GVCs over the globalisation era, i.e. the period that commenced at the end of the last century and up to the COVID-19 pandemic. We provide new empirical evidence on EU's competitiveness and specialisations in GVCs over this period, assess the impacts of changing trade and investment policies on the evolution of GVCs and MNEs, as well as examine the effects of technological advances on the organisation of production and knowledge creation in GVCs.

The key messages of the report can be summarised as:

- GVCs have created a fierce competition between firms and countries to capture jobs and income, influenced by evolving trade policies and new technologies. It is essential for the EU to maintain a firm grip on strategic activities within GVCs to stay at the forefront of technological development and effectively compete with other global superpowers. At the global level, the EU has so far relatively successfully retained a strong hold both in terms of shares of income and high-quality jobs. The share of the EU in GVC income has stabilised at around 18% since 2012, falling from a higher level maintained for two decades up to the global financial crisis. All Eastern European countries have increased their share of GVC income over time, at the expense of Western European countries. Still, Eastern European shares remain much smaller than those of Western European countries.

- It is crucial to look at GVCs more broadly, as a sequence of, not only goods and services, but of activities. From this perspective, there is a regional division of labour within the EU: Western EU countries specialise in pre- and post-production functions, whereas Southern and Eastern EU countries specialise in production. Given R&D activities are presently a prerogative of the old member states, less advanced member states stand to gain by upgrading towards R&D-intensive activities within GVCs. While the new data gathered in this report show some dynamism in new member states in terms of higher income shares from GVCs through industrial convergence, high growth of domestic business R&D expenditures (BERD), and shrinking dependence on foreign R&D, more efforts are needed if they are to catch-up with old member states in virtually all these dimensions. Crucially, this also calls for a clear industrial strategy in new member states to tackle the functional divergence that has emerged in the EU.

- Specialisations across different value chain functions appear to be driven by different forces. For countries to specialise more heavily in R&D activities, investments in new digital technologies and domestic knowledge creation can pave the way forward. In particular, the adoption of intangible ICT assets such as statistical computing software, databases and database management systems can help spur R&D specialisations. At the same time, the positive impact of business R&D expenditures highlights the role of innovation policies for smarter integration in GVCs. These results hold particularly strongly for the less advanced economies of the EU, suggesting ICTs and innovation policies offer a valuable means of breaking away from path dependencies.

- The trade policy regime in which the EU operates has changed quite significantly, especially following the Global Financial Crisis of 2008/09. Even prior to that, the failure of the Doha Round and the rise of China also indicates more fundamental long-run structural changes in the global trade and investment regimes. The EU – in line with other main global actors – has moved much more strongly in the direction of bilateral and unilateral agreements, widened its portfolio of trade policy measures and increased its strategic leveraging of trade and investment in a rapidly changing geo-political and geo-economic environment. The EU will have to tread a fine line between attempting to keep global international trade and production relations rules-based and relatively open, while also pursuing its own strategic goals in terms of strengthening its technological and industrial capabilities and defending its interests.

- International production networks (IPNs) are overwhelmingly organised by multinational enterprises (MNEs). Hence the impact of changing trade policy environments on MNEs production and trading activities are an important aspect of studying developments of global production integration. A detailed study in this report of the impact of tariff and non-tariff measures (NTMs) showed that NTMs pose a higher challenge to MNEs' subsidiaries' activity and performance than tariffs. High-tech manufacturing subsidiaries are particularly vulnerable to these NTMs, as they suffer higher regulatory losses. However, multinational affiliates that have higher productivity, are under full foreign ownership, and those that are embedded within a larger international network of subsidiaries are better equipped to counter and even utilize the challenges posed by NTMs. Furthermore, Preferential Trade Agreements (PTAs) are very important to counteract the possible negative impact of NTMs on production and export activities of subsidiaries. For EU policies this is important, as including a wider set of economies within a common regulatory context will encourage trade and production linkages within the PTA region.

- Our research on the impact of Bilateral Investment Treaties (BITs) suggests that an improved foreign investment environment together with a credible commitment to a high level of investor protection are important to stimulate the formation and consolidation of IPNs driven by EU multinational companies. Hence, the creation of a sound investment environment is a key factor to achieve the so-called Open Strategic Autonomy, which has become one of the priorities of the EU. Indeed, investment liberalisation, mainly if combined with trade liberalisation, makes IPNs not only more efficient (by reducing the costs of doing business abroad and improving EU firms' competitiveness in international markets), but also more resilient to policy risks and other non-economic shocks. Furthermore, through the implementation of more BITs, the EU can contribute to shaping global rules for a more sustainable and fairer globalisation. At the sub-national, regional level, the impact of BITs is positive and significant in low and medium-high income regions but insignificant in medium-low income regions. This calls for policy interventions designed to promote and support the internationalisation of local firms in EU regions which host no or few MNEs.

- R&D and innovation are increasingly traded within GVCs. From 2010 to 2019, there was an increase in imported R&D across all regions of the globe. In all advanced economies, including the EU27 (and in contrast to China), imported R&D grew faster than domestic R&D. This shows that world economies are highly interlinked when it comes to new knowledge production and China is becoming an increasingly important player, ramping up its R&D efforts.

- The dependence on foreign R&D for the EU27 is slightly higher than for the US and Japan. By contrast, newly emerging superpowers, notably China and India, reduced their dependence on imported R&D by almost the same amount as the developed countries. Looking inside the EU27, we find that dependence increased in Finland, the Netherlands, and France. By contrast, some member states in Central and Eastern Europe, most notably Bulgaria and Poland, experienced the largest drops in dependence.

- The largest foreign R&D dependencies of the EU27 on imported R&D are in computer, electronic and optical products, and pharmaceuticals. Despite these dependencies, the US and the EU still contribute the most to global knowledge production, with about 30% each of global knowledge production. The share of China is considerably smaller, albeit increasing (from 8% in 2010 to 14% in 2019). Zooming in on the dependencies of the EU on China, we uncover strong technological dependencies in the EU factory economies of Central and Eastern Europe, in particular in Hungary and Czechia.

- Some digital technologies, and especially logistics technologies and robots, positively contribute to firms' productivity and export performance. More specifically, an increase in one unit of the score of logistics technologies (indicating an increase in the adoption of logistics technologies within firms) increases turnover per employee by 13%, while a one-unit increase in the score of robots rises the same indicator by 7.4%. By making firms more productive, digital technologies also spur firms' exports. This is particularly true for logistics technologies. The effect for robots is slightly smaller, but is still significant and positive. Some digital technologies, and in particular logistic technologies and additive manufacturing, also contribute to higher servitisation, and through that, to exports. These results suggest that a digitalisation strategy may have different impacts depending on the adopted technology. For example, a firm that invests in robots pursues a different strategy to a firm which employs logistic technologies. The former will become more productive in its manufacturing activities, while the latter is likely to be better able to increase its turnover by adding a service component to its physical production. These results also indicate that digital technologies have a strong role to play in stimulating exports by facilitating the introduction of new service innovations.

- Digital technologies are also positively associated with embeddedness in GVCs. We find a positive and significant relationship between participation in GVCs and the adoption of robots and data analytics. Results are particularly strong when we measure GVC participation via a measure of forward linkages (as compared to backward linkages). This might suggest that pressure from buyers abroad incentivises the adoption of these technologies, or that these technologies assist organizations in being able to produce for foreign markets. From these findings, it could also be evinced that innovation performance within GVCs is less a matter of incorporating knowledge from suppliers via imports and more of upgrading through exporting. Our analysis also shows that the relationship between GVC embeddedness and innovation performance is mediated by the governance structure chosen, with internalisation of production and development being the only governance mode contributing positively to new innovations. In particular, we provide evidence that when organisations internalise their production and development processes, while remaining open to GVCs, they are likely to benefit more from this engagement and boost their innovation performance. Their integration into GVCs remains a positive influence on their innovation performance, but these benefits are smaller when they engage in internal or external collaborations or outsource production and development activities. Therefore, GVC governance is an essential factor mediating these relationships and it is vital that organisations develop internal mechanisms (resources and capabilities) to reap the benefit of GVC integration.

1. Introduction

As the present wave of globalisation gained momentum around the 1980's (Antrás, 2020; Baldwin, 2016), firms began to geographically disperse stages of production, following locational advantages tied to a particular destination. The resultant production structures came to be known as global value chains (GVCs). Within GVCs, production processes are organised into networks of different firms and countries, whereby each participant adds a portion of the value to the final product, and captures the gains accruing to that portion (e.g. Antràs and Chor, 2022; De Backer and Miroudot, 2014; Gereffi et al., 2001; Gereffi, 2011, 2014). While GVCs have played a crucial role in shaping international trade and production processes in this globalisation wave, recent developments particularly after the global financial crisis of 2008/09, suggest a potential slowdown- (Timmer et al. 2021) or even a reversal in these integrative forces (Antràs, 2020; Javorcik, 2020; Miroudot and Nordström, 2019).

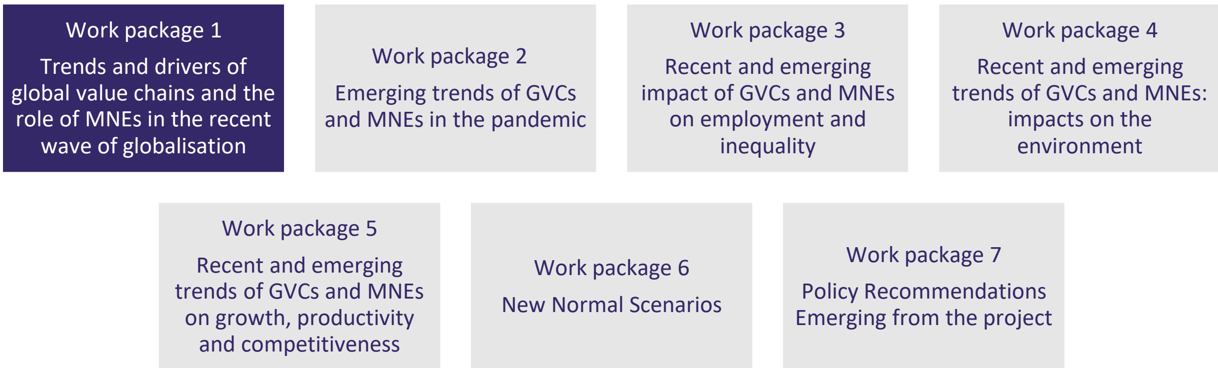
Geopolitical shifts and technological transformations can be regarded as two core pillars shaping the remarkable rise and, today, the prospective restructuring of GVC-based production structures. With the fall of the iron curtain, China's accession into the World Trade Organisation (WTO), and the waves of enlargements in the European Union (EU), the mid-1980's to the end of the first decade of the 21st century witnessed a wave of global integration and trade liberalisation (Antràs, 2020). However, in the most recent years, geopolitical tensions and the assertion of national interests from different parts of the world have led to increasing concerns regarding the global interdependencies arising from GVCs. Consequently, the narrative of bringing jobs back home and strengthening domestic manufacturing came to the forefront of policy debates, translating to new directions in trade, investment and industrial policies.

Moreover, technological advancements, most notably in information and communication technologies (ICT), eased the coordination of production across borders, facilitating the consolidation of GVCs (Baldwin, 2006). At the micro-level, ICT changed the ways firms do business and influenced their ability to participate in and benefit from GVCs (e.g. Butollo et al., 2022; Strange and Zucchella, 2017; UNIDO, 2019). Today, some observers believe that the latest technological breakthroughs in areas such as advanced manufacturing or artificial intelligence, are likely to enhance efficiency and flexibility within domestic settings. If these gains were to materialise, these new digital technologies would potentially shorten value chains into more regional structures (Faber, 2020; Krenz et al., 2021). At the same time, there are growing concerns regarding dependencies in critical technologies arising from GVCs (e.g. Edler et al., 2020; European Commission, 2021). With these discussions gaining momentum also within policy cycles (e.g. Raza et al., 2021), the assessment of how state-of-the-art technologies interact with GVCs and impact firms' performance becomes paramount.

In present days, there is a broad consensus that the COVID-19 pandemic and the Russian invasion of Ukraine have amplified and accelerated these technological and policy shifts that impact GVCs. Yet, while the immediate socio-economic effects are widely considered to be already evident, the long-term consequences on GVCs are still unfolding and require deep investigation.

Against this background, the aim of the TWIN SEEDS project is to bring solid empirical evidence on the consequences of the past as well as the most recent events on GVCs, and explore trends in international trade, multinational enterprise (MNE) behaviour, and production organisation as they relate to the changing policy environment and new technologies ('twin seeds'). This report - the first in the series of seven reports (see Figure 1 below)- provides a foundation for the subsequent analyses to be undertaken over the course of the TWIN SEEDS project. It analyses the long-term dynamics in EU-centred GVCs over the globalisation era, i.e. the period that commenced at the end of the last century and up to the COVID-19 pandemic. To this end, we provide new empirical evidence on EU's competitiveness and specialisations in GVCs over this period, assess impacts of changing trade and investment policies on the evolution of GVCs and MNEs, as well as examine the effects of technological advances on the organisation of production and knowledge creation in GVCs.

Figure 1: Summary of the TWIN SEEDS project and its Work Packages



Source: Authors' elaboration.

The report is organised in the following way: after this introductory chapter, three analytical chapters follow. In Chapter 2, we assess the EU's competitiveness in GVCs and study EU specialisations in the different stages of the value chain. In doing so, we document important trends at the global level over the past two decades, comparing the performance of the EU with that of other global players, as well as the positioning of member states inside the EU. Acknowledging the functional divergence that emerged in the EU, with more advanced countries specialising in research and development (R&D) and less advanced ones focusing on production, we analyse the ways in which industrial policies and ICT assets influence specialisations in the R&D stages of the value chain. In Chapter 3, we focus on the policy dimension, by studying shifting trade policies at multilateral, bilateral and unilateral level. We explore the ways in which these policies have shaped EU-centred GVCs, and how they have impacted the performance of MNEs. As GVCs are structured around not only trade, but also investment and production, we also consider the role of bilateral investment treaties (BITs) in the formation and expansion of international production. Chapter 4 zooms in on technological change: first, it shows new data on how and by whom R&D and innovation are undertaken in GVCs. It then analyses how different digital technologies affect trade, and how these technologies matter in explaining the benefits of GVC insertion, depending also on the governance of value chains. Chapter 5 summarises the key findings stemming from our analyses, while Chapter 6 concludes the report and provides some policy implications.

2. Competitiveness in GVCs and specialisations in the EU

Contextual background and research objectives

As trade barriers were lifted, and as ICT eased coordination of activities and expanded the tradability of services, conducting different steps of production in different locations began to represent an attractive way of organising the production process (Baldwin, 2016). Under this setting, global competition became increasingly about *who does what* and *where*, rather than solely about the products that are being produced.

Within this framework, an analysis of international competitiveness requires an understanding of how value is created in the production process and how these gains are distributed across different actors (Gereffi, 2023). In this sense, mapping the distribution of rents (or 'value added') along GVCs can offer insight regarding an economy's competitiveness in GVCs. Such a GVC perspective makes it evident that increasingly granular specialisation possibilities for economies exist in the present age (Baldwin and Evenett, 2012). This is because countries compete with each other ever more fiercely not only at a highly detailed level of intermediate products feeding into the production of a final good, but also at the level of specific activities ('stages') involved in the production process (Baldwin and Lopez-Gonzalez, 2015; Stöllinger, 2021; Timmer et al., 2019).

One can easily imagine that the ability of countries to occupy different stages of the production process goes hand-in-hand with certain asymmetries present in the global economy (Baldwin and Lopez-Gonzalez, 2015). Countries with superior capabilities are presumed to occupy the more knowledge-intensive functions of the production process, such as R&D. By contrast, less developed countries are more likely to provide the 'muscle-power', specialising in the relatively less knowledge-intensive activities, most notably production and assembly. In this sense, GVC integration has been postulated to create labour divisions between *headquarter* economies and *factory* economies in the global economy (Baldwin and Lopez-Gonzalez, 2015), in turn having implications for countries' socioeconomic development prospects (Stöllinger, 2021; Stöllinger et al., 2023). At the same time, certain activities of the value chain are not just more remunerative in terms of value added, but also carry strategic importance. The R&D function is a case in point: as international competitiveness places growing emphasis on the control of new technologies, it becomes crucial to ensure the expansion and enhancement of innovative R&D activities across industries in the EU. The less proactive approach of the EU towards industrial policy in the 1990's contributed to the relocation of important sectors and economic activities (primarily R&D) outside the EU (Aiginger, 2007; European Commission, 2002, 2005; Landesmann and Stöllinger, 2020; Pellegrin et al., 2019), after which point EU policy documents started to put a much stronger emphasis on knowledge creation and innovation as the cornerstones of international competitiveness (e.g. European Commission, 2005). In this sense, understanding how the '*twin seeds'* megatrends of the present age (trade and investment policies on the one hand and digital technologies on the other hand), can stimulate participation in strategic GVC functions is crucial for guiding policies aimed at enhanced competitiveness and resilience in the EU going forward.

Still, even in the age of global production, it needs to be noted that value chains tend to have a strong regional bias (Baldwin and Lopez-Gonzalez, 2015). This regional orientation can be deemed particularly relevant in the case of Europe, as the period of globalisation expansion of the late 20th century and the early 2000's coincided with a deep integration of Eastern Europe with Western Europe, to form the enlarged EU. Therefore, while it is necessary to understand the external competitive position of the EU with respect to the rest of the world in the context of GVCs (especially as new global players come to the forefront), it proves no less important to gain an in-depth insight regarding points of convergence and divergence of individual economies within the EU. Indeed, any imbalances within the EU need to be carefully considered and tackled, as they may hinder EU cohesion and contribute to the distributional discontent that has fuelled a de-globalisation sentiment in recent times (Rodrik, 2019).

Against this background, the objective of this chapter is to provide a framework for describing how EU GVC organisation has evolved, and what implications arise from the point of view of international competitiveness. It aims to do so by analysing the main trends in GVC-based competition, considering the ability of the EU, as well as its individual member states, to capture jobs and income vis-á-vis other regions of the world. We emphasise the importance of looking at GVCs more broadly, as a sequence of, not only goods and services, but of activities. To this end, we provide new evidence on trends of EU competitiveness in different sectors and activities by introducing the concept of *functional specialisation* (Stöllinger, 2021; Timmer et al., 2019) looking at GVC income divided across different business functions (i.e. activities involved in producing a final good). Recognising the role of MNEs and the significance of foreign direct investment (FDI) in facilitating GVCs, we also provide novel evidence with respect to greenfield FDI inflows in the EU, and how these shape functional specialisation patterns of economies. Finally, we analyse the impact of ICT and of policy contexts (especially those affecting trade and FDI) on the countries' competitive standing in GVCs from the perspective of functions, focusing on the most strategic and remunerative stage of the value chain, namely R&D.

The main research questions we pose in this chapter are the following:

- How has EU's competitiveness in manufactures GVCs evolved over the past three decades?
- How has the competitiveness of EU member states in manufactures GVCs evolved over the past three decades?
- In which sectors and business functions do EU countries specialise when contributing to GVCs?

- Which functional specialisations emerge from FDI flowing into EU countries?
- How do ICT and policy factors impact the ability of EU countries to specialise more deeply in R&D activities?

Methods of analysis and data

To shed light on the above questions, we apply analytical approaches pioneered within the consortium (Stöllinger, 2021; Timmer et al., 2013; Timmer et al., 2019) which allow us to measure incomes and jobs generated by the EU in GVCs of manufactured goods, and to identify more accurately the specialisations of EU countries in GVCs.

As a first step, we quantify GVC income and jobs, that is, the value added and number of workers, respectively, that countries capture from their direct or indirect involvement in GVCs. To this end, we make use of the accounting framework introduced by Timmer et al. (2013) and measure the incomes and jobs attributable to countries in GVCs of manufactured final goods. We update this framework to encompass also latest developments up to 2018, starting from 1995. Previous studies have only considered the period up to 2008[1], calling for a more recent perspective on the issues at hand. The calculation entails the decomposition of the value of a final product into the value added by labour and capital inputs that go into each stage of production. Note that by considering each cell depicted on Figure 2, it becomes possible to trace the origin of all value added across all participating countries and industries for the production of a given final manufactured good. It is through this procedure that we are able to identify how EU countries are performing against other parts of the world in adding value and generating jobs in the GVCs of manufactured products[2].

Figure 2: An accounting framework for GVCs

<table>
<tr><td colspan="3" rowspan="3"></td><td colspan="7">Final products of a global value chain, identified by country and industry of completion</td><td rowspan="3">Value added</td></tr>
<tr><td colspan="3">Country 1</td><td rowspan="2">...</td><td colspan="3">Country M</td></tr>
<tr><td>Industry 1</td><td>...</td><td>Industry N</td><td>Industry 1</td><td>...</td><td>Industry N</td></tr>
<tr><td rowspan="7">Value added from country-industries participating in global value chains</td><td rowspan="3">Country 1</td><td>Industry 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="3">Country M</td><td>Industry 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Industry N</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Total final output value</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>World GDP</td></tr>
</table>

Note: Cell values represent the value added generated in the country-industry given in the row, within the global value chain corresponding to the country-industry of completion given by the column.
Source: Timmer et al. (2014).

[1] See Timmer et al., 2013.
[2] Because manufacturing can be deemed as particularly prone to global fragmentation, the core focus of our analysis here is on final manufactured goods.

Subsequently, we extend our analysis by subdividing the value added by activities ('functions') that make up the value chain, such as R&D, production, or marketing. The value added of a particular function is proxied by the income of workers that perform the activity. On this basis, we calculate revealed comparative advantages (RCA) by functions ('functional specialisations') based on trade and occupation (see Technical Appendix A for details). The main input data is the OECD's November 2021 edition of the Inter-Country Input-Output (ICIO) database, combined with industry-level occupation and wage data to obtain job and incomes shares by activities in GVC. The occupations dataset is derived from the European Labor Force Survey (LFS), while the relative wage data by 2-digit occupations for EU countries is constructed from the microdata underlying the Structure of Earnings Surveys (SES). Through this approach, we are able to obtain new insights about the different roles EU countries play in production networks, and also make comparisons with key EU competitors: China, Japan, the Republic of Korea, and the United States (US).

As a next step in our analysis, we calculate functional specialisations based on greenfield FDI projects. This allows us to complement the above-described trade-based approach, by identifying the specialisations that emerge from the FDI channel. In the last decades, MNEs have heavily used FDI to spread out activities of the production process across different locations, maximising locational advantages tied to a given economy. Consequently, global FDI activity has grown more than five-fold in the last 20 years[3], increasingly encompassing also emerging parts of the world, which can undertake certain activities at a significantly lower cost. Hence, it becomes particularly interesting to also consider task divisions that arise out of this channel. To this end, we draw on the fDiMarkets database, which provides detailed project-level information on greenfield FDI projects, including the activity which the established subsidiary intends to carry out. Applying the methodology proposed by Stöllinger (2021), we first group the activities as indicated in the dataset into five functions. Then, based on the number of jobs created in each function, we calculate an RCA-type functional specialisation measure at the country-industry level (see Technical Appendix B for details). These functional specialisations can be linked to measures of sectoral specialisations, giving us a more comprehensive image of the positioning of EU countries along GVCs.

Finally, we dive deeper into the study of the drivers of specialisations in one specific 'function' i.e. R&D, as representative of a highly strategic and remunerative function of the value chain (Mudambi, 2008; Shih, 1996). To better understand if and how ICT and policy impulses can help countries take on more deeply R&D activities of the value chain, we econometrically model specialisations in R&D as a function of ICT assets and industrial policy (state aid) efforts. The scope of our analysis is EU countries across 10 industries of the manufacturing sector over the period of 2003-2019[4]. Generalised Method of Moments (GMM) estimators are used for estimating the econometric model (see Technical Appendix C for the model specification).

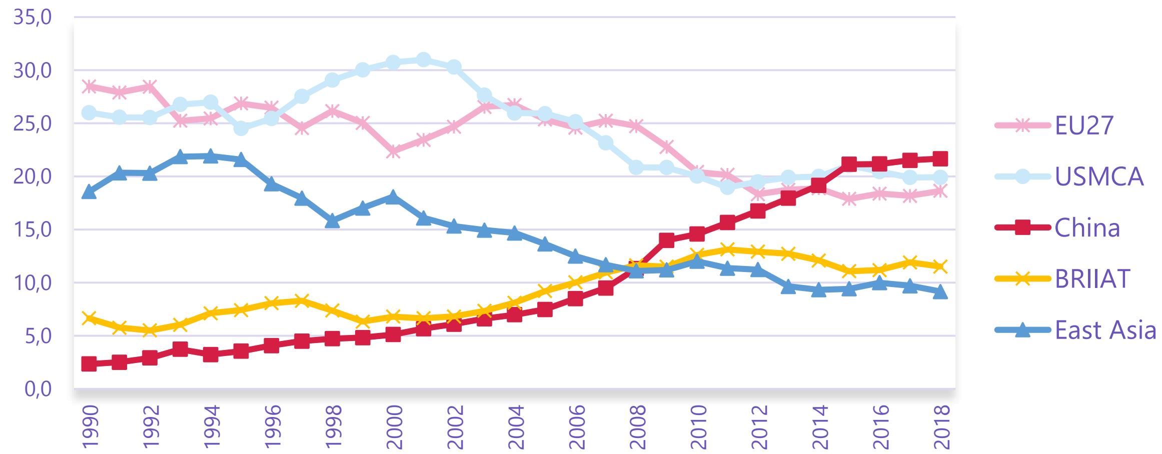
[3] Comparison of 1999 to 2019 data on FDI stocks in current US dollars, obtained from UNCTADStat.

[4] FDI-based functional specialisations. Malta, Cyprus and Croatia are excluded from the analysis due to data limitations.

Findings and discussion

There is a stabilisation in the GVC income shares claimed by world regions over the past decade (see Figure 3), suggesting that regional blocs are firmly holding on to their competitive position within GVCs. Indeed, following the rise of some emerging countries and the decline in the shares of the developed world that characterised GVCs in the early 2000's, the reorganisation of GVCs appears to have halted in the 2010's. China is the clear exception to this trend, seeing a continued increase in its share of world GVC income thereby overtaking all other regions. As can be seen, China's share in world GVC income rose from about 2% in 1990 to 11% by 2008 and its share continued to increase to 22% by 2018.

Figure 3: Regional shares in world GVC income for all manufactures (%)



Notes: Value added by regions in the production of final manufacturing goods. East Asia includes Japan, the Republic of Korea, and Taiwan. BRIIAT includes Brazil, Russia, India, Indonesia, Australia, and Turkey. EU27 includes all European countries that are part of the European Union as of January 2022. USMCA includes Canada, Mexico, and the US. Shares do not add up to 100% as the remainder is the share of all other countries in the world.
Source: Author's calculations based on the OECD ICIO Tables, release November 2021 for the period 1995-2018; extrapolated to 1990 using the trend in GVC income by region based on the long-run WIOD, release March 2022 (see also de Vries, forthcoming)

Zooming in on the EU, Figure 3 shows that the share of the EU in GVC income was holding up until the global financial crisis, with the share oscillating at around 25% for almost two decades since 1990. However, the global financial crisis of 2008/09 hit Europe particularly hard, after which its competitive position dropped notably. Yet from 2012 onwards, EU's share in GVC income has been again stable at about 18%. Still, the EU presently falls behind China and North America (USMCA) by a margin of around 5 percentage points.

At the same time, real GVC income for the EU as a whole decreased by 18% between 2008 and 2018. While the income generated from manufactures GVCs was increasing in absolute terms in all EU countries between 1995 and 2008, the period following the global financial crisis has seen a reversal of this growth (

Table 1). The stable share coupled with absolute decline in GVC income is suggestive of maintaining a competitive position while expenditure by advanced economies and China has been likely shifting towards services. Still, we find a continuously growing dependence of individual EU countries on foreign demand to generate GVC income in manufactures, implying that the EU member states remain tightly embedded in cross-border production networks, which also encompass intra-EU value chains.

Table 1: Real GVC income in selected EU countries, in constant $m, all manufactures.

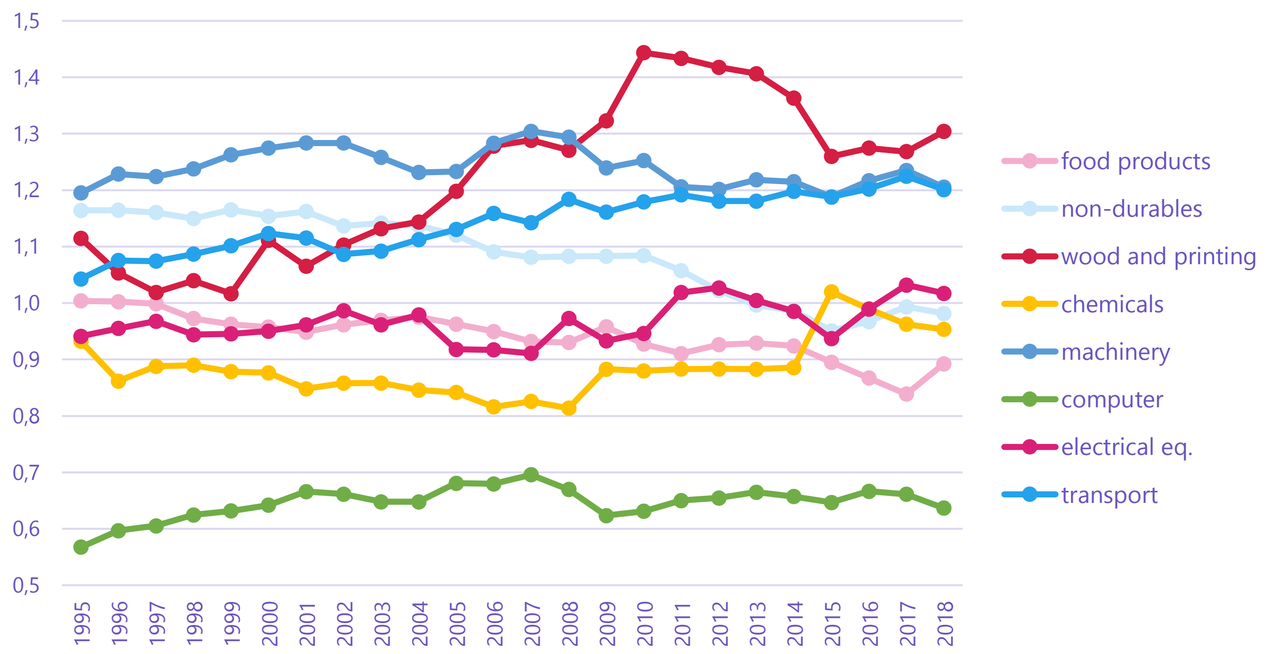
	Real GVC income (in constant $m)				Share in EU27 GVC income		Real GVC income due to foreign demand (%)	
	1995	2008	2011	2018	1995	2018	2008	2018
Germany	623,580	677,914	648,872	593,680	34.0	31.3	53.5	60.0
France	302,105	317,848	304,231	233,334	16.5	12.3	53.2	60.8
Italy	287,630	362,586	347,052	261,766	15.7	13.8	45.1	52.5
Spain	124,911	174,043	166,587	138,038	6.8	7.3	47.2	57.5
Netherlands	94,718	121,980	116,754	99,835	5.2	5.3	71.1	82.5
Belgium	66,846	70,690	67,662	58,372	3.6	3.1	70.8	76.1
Sweden	56,567	70,076	67,074	53,062	3.1	2.8	69.8	71.7
Austria	50,395	64,265	61,512	57,472	2.7	3.0	63.9	71.0
Denmark	35,149	39,307	37,623	33,446	1.9	1.8	71.7	76.4
Poland	34,287	78,995	75,611	80,379	1.9	4.2	53.8	64.8
Finland	28,835	41,419	39,645	25,839	1.6	1.4	66.7	63.4
Portugal	23,650	27,363	26,191	22,472	1.3	1.2	48.7	63.3
Greece	20,997	26,445	25,312	15,365	1.1	0.8	45.7	55.9
Ireland	18,181	39,323	37,639	71,056	1.0	3.7	84.6	93.2
Czechia	14,902	43,284	41,430	40,148	0.8	2.1	67.9	77.1
Romania	12,605	34,557	33,077	34,508	0.7	1.8	35.1	49.6
Hungary	10,761	25,549	24,455	21,498	0.6	1.1	75.2	80.3
Slovenia	4,898	8,242	7,889	7,247	0.3	0.4	79.0	82.1
Croatia	4,733	8,212	7,860	5,625	0.3	0.3	38.5	47.7
Slovakia	4,356	16,855	16,133	15,665	0.2	0.8	74.2	82.6
Luxembourg	3,990	6,065	5,805	6,263	0.2	0.3	101.2	90.3
Bulgaria	3,635	6,750	6,461	7,899	0.2	0.4	54.2	71.5
Cyprus	1,492	2,037	1,949	1,396	0.1	0.1	54.0	63.2
Lithuania	1,468	7,046	6,744	7,188	0.1	0.4	55.7	67.0
Latvia	1,076	3,470	3,322	2,880	0.1	0.2	54.7	72.6
Malta	972	1,020	976	964	0.1	0.1	71.0	81.6
Estonia	818	2,903	2,778	2,974	0.0	0.2	73.0	76.5
EU27	1,833,558	2,278,246	2,180,644	1,898,373	100	100		

Notes: Real GVC income for all manufactures and in constant 1995 prices using US CPI as deflator. US CPI is 1.41 in 2008, 1.48 in 2011, and 1.65 in 2018.

Source: Author's calculations based on the OECD Inter-Country Input-Output Tables, release November 2021 (see also de Vries, forthcoming).

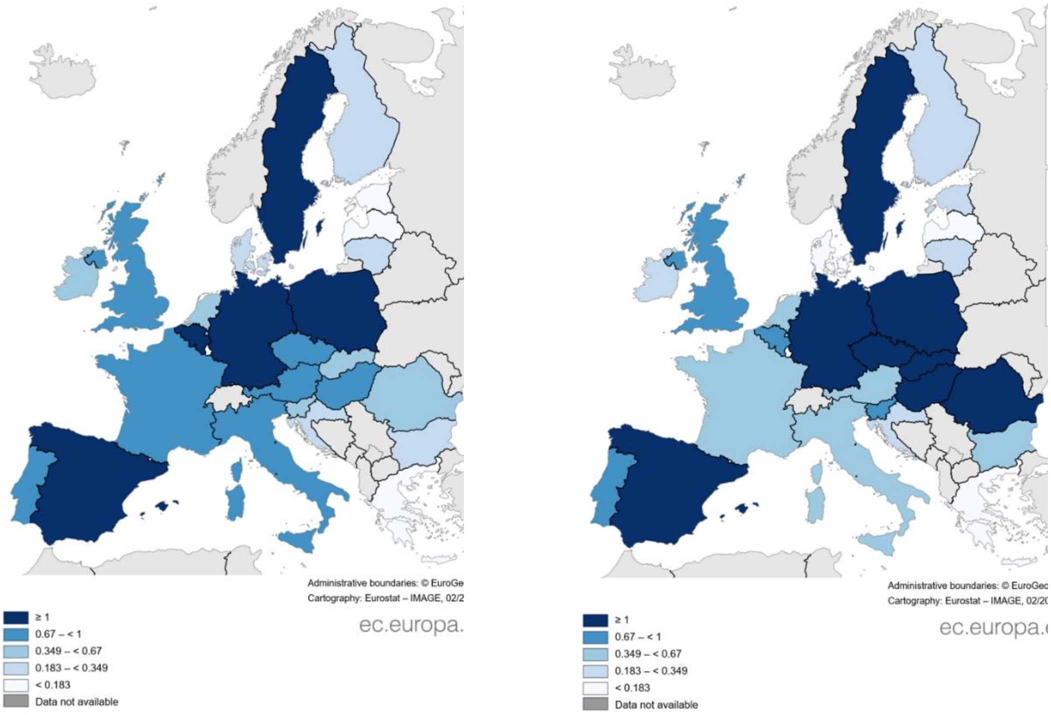
Indeed, over the past three decades, the EU has been specialising ever more deeply in vehicles and transport equipment as well as in machinery (Figure 4). Looking inside the EU, the deepened specialisation is driven in most part by the heightened participation of EU's new member states in these value chains (Figure 5), as these countries were able to relatively successfully close the gaps with Western Europe, to concentrate growing shares of their labour in high to medium-high technology manufacturing industries. With such industrial convergence, all Eastern European countries have been able to capture a larger share of GVC income over time— between 1995 and 2018, Poland's share of GVC income has grown from 1.9% to 4.2%, Czechia from 0.9% to 2.1%, and Romania from 0.7% to 1.8%. Nonetheless, these figures are dwarfed by those of Western European nations, which capture the lion's share of the EU's GVC income (
Table 1). Indeed, Germany still captures over 30% of GVC income, though the shares of the EU's three largest GVC players (namely, Germany, France and Italy) have been declining over time.

Figure 4: Revealed comparative advantage of EU27, by group of final manufactures (%)



Notes: Revealed comparative advantage calculated as EU 27 share in world GVC income for a group of manufactures divided by same ratio for all manufactures. Food manufacturing products (Food: produced in ISIC rev. 4 industries 10 to 12), Other non-durable products (Tex: 13 to 15, 31 to 33), Chemical products (Chem: 19 to 24), Machinery and metal products (Mach: 25 and 28), Computer equipment (Comp: 26), Electrical machinery products (Elec: 27) and Transport equipment (Tra: 29, 30). Source: Authors' calculations based on the OECD ICIO Tables, release November 2021 (see also de Vries, forthcoming).

Figure 5: Specialisations in vehicles and transport equipment, 1995-1998 vs. 2016-2018



Note: Calculated as RCA based on average persons employed over the respective period. Values above 1 represent relative specialisations against the EU benchmark. Maps created using the IMAGE tool of the European Commission. Source: Authors' calculations based on data from Eurostat.

Looking at trends in the number of workers by different GVC functions, we find that during 2011-2018 the growth in engineering and support workers was higher than the growth in production workers in most countries of the EU (Table 2), meaning an expansion in business functions that are relatively well-paid. This suggests a clear but gradual specialisation pattern away from production and towards the upstream and downstream end of GVCs. In countries such as Austria, Poland, Portugal, and Sweden, the growth in engineering jobs was particularly high in recent years. In other countries such as Germany, Luxembourg, and Romania, support jobs expanded most rapidly. Still, the expansion of production jobs is observed in many Eastern European countries, most notably in Hungary, Slovenia, Czechia and Slovakia. Presently, about 55% of EU jobs in manufactures GVCs come from pre- and post-production activities. By contrast, production accounts for the majority of manufactures GVC jobs in China, at about 69 percent. However, we observe a rapid increase in engineering jobs in China between 2011 and 2018. Similarly, the number of engineering jobs in manufactures GVCs grew strongly in the US, though interestingly so did production jobs.

Table 2: Growth in manufactures GVC workers by business function, 2011 and 2018

	Engineering			Production			Support			Management			Other		
	2011	2018	change	2011	2018	change	2011	2018	change	2011	2018	change	2011	2018	change
Germany	1,337	1,311	-1.9	3,906	3,889	-0.4	3447.6	3886.0	12.7	571.5	551.6	-3.5	926.1	994.2	7.4
France	616	523	-15.0	1,521	1,495	-1.7	1256.9	1256.5	0.0	337.3	347.8	3.1	471.1	536.2	13.8
Italy	436	550	26.1	2,544	2,345	-7.8	1916.9	1949.4	1.7	213.3	191.9	-10.0	469.4	625.7	33.3
Spain	210	246	16.9	1,496	1,544	3.2	898.9	934.1	3.9	175.6	158.9	-9.5	384.9	460.7	19.7
Netherlands	132	133	1.2	504	502	-0.4	611.6	676.5	10.6	113.4	95.0	-16.2	240.7	282.0	17.2
Belgium	100	85	-15.2	285	289	1.4	300.9	299.1	-0.6	70.1	80.5	14.8	101.1	123.0	21.7
Sweden	85	121	42.0	327	258	-21.0	226.4	255.1	12.7	45.6	54.5	19.7	75.1	71.3	-5.1
Austria	87	110	27.2	387	379	-2.1	280.7	316.3	12.7	46.7	44.8	-4.1	85.6	99.6	16.3
Denmark	42	59	40.3	156	160	2.1	154.4	149.4	-3.2	10.7	7.2	-33.1	54.4	58.9	8.2
Poland	245	447	82.6	2,469	2,469	0.0	880.6	1063.6	20.8	228.5	248.7	8.8	249.8	275.3	10.2
Finland	59	60	2.1	198	170	-13.9	125.2	132.2	5.6	29.3	14.3	-51.2	47.0	45.6	-3.0
Portugal	49	74	49.0	639	610	-4.5	176.6	218.2	23.6	58.5	54.5	-6.9	96.7	105.8	9.4
Greece	36	31	-14.2	391	321	-17.9	182.0	212.1	16.5	21.5	18.6	-13.3	33.3	39.0	17.2
Ireland	20	29	44.7	154	172	12.3	103.6	117.9	13.8	25.6	39.4	54.0	29.3	42.0	43.5
Czechia	144	173	20.5	794	869	9.5	397.6	438.3	10.2	62.1	75.9	22.2	101.7	114.6	12.7
Romania	119	132	10.4	1,919	1,819	-5.2	294.8	360.0	22.1	38.8	32.5	-16.3	161.0	177.9	10.5
Hungary	69	82	19.2	557	636	14.1	248.9	292.6	17.6	50.4	42.9	-14.9	91.7	95.6	4.3
Slovenia	21	24	14.9	110	121	10.0	58.5	68.7	17.4	19.1	20.7	8.6	17.7	21.1	19.0
Croatia	28	33	19.0	213	180	-15.5	82.7	86.3	4.3	14.8	14.8	0.2	25.4	25.6	0.9
Slovakia	49	54	11.3	321	349	8.7	166.7	180.9	8.6	31.3	29.1	-7.1	45.4	59.4	30.6
Luxembourg	7	6	-10.7	24	24	-0.6	27.8	37.2	33.7	3.4	2.8	-17.6	8.3	10.6	27.2
Bulgaria	41	49	19.6	607	577	-4.9	182.9	205.7	12.5	51.3	54.8	6.8	95.9	77.1	-19.6

Lithuania	16	18	16.6	161	167	3.6	71.6	69.6	-2.8	23.5	24.3	3.6	22.3	25.2	13.1
Cyprus	2	3	38.8	22	23	4.8	18.8	17.6	-6.6	2.7	2.4	-10.7	6.4	5.2	-18.3
Latvia	10	10	2.8	87	83	-4.7	38.0	38.5	1.2	15.9	14.1	-11.4	13.1	12.3	-6.1
Malta	2	3	19.7	11	12	4.8	6.3	9.8	57.0	2.1	3.0	42.2	3.6	4.2	13.9
Estonia	9	10	15.9	66	63	-3.6	27.6	29.4	6.6	10.2	15.2	48.4	9.6	9.4	-1.4
EU27	3,969	4,377	10.3	19,868	19,530	-1.7	12,185	13,301	9.2	2,273	2,240	-1.4	3,867	4,398	13.7
China	6,734	9,293	38.0	197,829	156,188	-21.0	41,087	45,355	10.4	5,062	4,897	-3.3	9,599	9,550	-0.5
Japan	1,119	1,198	7.0	6,585	6,215	-5.6	4,245	4,019	-5.3	485	457	-5.8	843	855	1.4
Rep. of Korea	444	394	-11.1	2,814	2,523	-10.4	2,178	2,174	-0.2	95	87	-8.5	630	808	28.3
United States	1,331	1,951	46.6	6,613	6,976	5.5	5,581	5,323	-4.6	1,949	1,510	-22.5	2,486	2,995	20.5

Notes: Manufactures GVC workers are workers directly and indirectly involved in the production of final manufacturing goods. Change is the (log) growth rate between 2011 and 2018.

Source: Author's calculations based on the OECD Inter-Country Input-Output Tables, release November 2021, OECD TiM, release 2021, and the Occupation Database (see also de Vries, forthcoming).

As can be inferred from Table 2, there are clear differences in the participation of countries in different stages of the production process, which in turn translates to differing functional specialisations. Taking the perspective of GVCs as a sequence of tasks, we observe strong functional specialisation in engineering in Finland, Germany and Sweden, in management in France and Belgium, in support activities in Italy and Luxembourg (Table 3). In general, we find that Western EU countries tend to specialise in pre- and post-production functions in GVCs, whereas Southern and Eastern EU countries specialise in production, suggestive of a regional division of labor within the EU, with typically Western EU countries orchestrating production networks that reach deep into the region. Unsurprisingly, China specialises in production activities in GVCs, while the US and the Republic of Korea are more heavily involved in pre- and post-production functions. At the same time, we find that the majority of countries continue to exhibit their strongest specialisations in the same functions in 2018 as they did in 2011, pointing to the rather slow-moving nature of structural change from a functional perspective.

Table 3: Functional specialisations in GVCs, 2011 and 2018

	Engineering	Production	Support	Management	Other	Engineering	Production	Support	Management	Other
	2018	2018	2018	2018	2018	2011	2011	2011	2011	2011
Specialised in engineering										
Germany	**1.34**	0.73	**1.22**	**1.12**	0.92	**1.62**	0.75	**1.14**	0.95	0.97
Sweden	**1.60**	0.71	**1.12**	**1.14**	0.94	**1.30**	0.92	**1.04**	0.81	**1.17**
Austria	**1.30**	0.80	**1.11**	**1.03**	**1.17**	**1.24**	0.83	**1.12**	0.99	**1.20**
Denmark	**1.67**	0.71	**1.22**	0.31	**1.56**	**1.39**	0.76	**1.27**	0.41	**1.73**
Finland	**1.46**	0.82	**1.10**	0.72	**1.19**	**1.50**	0.83	0.94	**1.15**	**1.20**
Ireland	**1.53**	0.76	0.92	**1.48**	**1.14**	**1.22**	0.88	**1.06**	0.95	**1.27**
Specialised in management										
France	**1.35**	0.68	**1.02**	**1.61**	**1.39**	**1.76**	0.67	0.99	**1.27**	**1.34**
Belgium	0.99	0.61	**1.17**	**1.93**	**1.37**	**1.29**	0.62	**1.21**	**1.37**	**1.37**
Portugal	0.97	0.91	0.89	**1.58**	**1.25**	0.88	0.89	0.88	**1.63**	**1.33**
Slovenia	1.00	0.90	0.99	**1.54**	0.93	**1.15**	0.84	0.99	**1.46**	**1.01**
Malta	0.89	0.76	**1.13**	**1.51**	**1.42**	**1.13**	0.92	0.88	**1.14**	**1.61**
Estonia	0.73	0.94	0.90	**1.96**	0.88	0.82	**1.03**	0.92	**1.30**	0.98
Bulgaria	0.78	0.99	0.98	**1.43**	0.96	0.76	**1.07**	0.90	**1.12**	**1.22**
Lithuania	0.70	**1.09**	0.87	**1.48**	0.92	0.84	**1.03**	0.92	**1.28**	0.90
Latvia	0.70	**1.03**	0.92	**1.59**	0.88	0.73	**1.04**	0.90	**1.38**	**1.03**
Poland	**1.01**	0.96	**1.04**	**1.14**	0.84	0.81	**1.06**	0.98	**1.08**	0.87
Specialised in support										
Italy	0.95	0.81	**1.25**	**1.06**	**1.17**	0.86	0.85	**1.30**	0.90	**1.08**
Luxembourg	0.69	0.44	**2.01**	0.74	**1.09**	0.92	0.43	**1.88**	0.91	**1.10**
Cyprus	0.71	0.68	**1.43**	**1.42**	**1.09**	0.56	0.59	**1.54**	**1.41**	**1.36**
Greece	0.57	0.99	**1.32**	0.75	0.81	0.77	**1.11**	**1.13**	0.59	0.81
Croatia	**1.07**	0.93	**1.14**	0.77	**1.05**	**1.16**	0.92	**1.12**	0.76	**1.12**
Specialised in other										

Netherlands	**1.02**	0.58	**1.44**	**1.06**	**1.58**	**1.25**	0.60	**1.40**	**1.01**	**1.41**
Spain	0.93	0.97	0.94	**1.08**	**1.48**	0.93	0.96	0.94	**1.15**	**1.38**
Specialised in production										
Czechia	**1.04**	**1.09**	0.95	0.87	0.75	**1.12**	**1.10**	0.97	0.69	0.80
Romania	0.97	**1.26**	0.82	0.38	**1.08**	**1.17**	**1.40**	0.62	0.42	0.80
Only specialised in production										
Hungary	0.86	**1.20**	0.89	0.64	0.97	**1.02**	**1.11**	0.89	0.83	**1.06**
Slovakia	0.87	**1.15**	0.91	0.83	0.97	0.97	**1.08**	0.99	0.84	0.88
Specialisation in other major economies										
China	0.52	**1.41**	0.86	0.40	0.82	0.44	**1.49**	0.80	0.37	0.81
Japan	**1.10**	**1.13**	**1.04**	0.40	0.65	**1.10**	**1.14**	**1.08**	0.36	0.70
Rep. of Korea	**1.30**	0.84	**1.10**	0.75	**1.40**	**1.22**	0.84	**1.13**	0.72	**1.59**
United States	**1.33**	0.69	0.99	**1.84**	**1.14**	**1.07**	0.69	0.99	**2.03**	**1.08**

Notes: GVC income share by business function of a country relative to GVC income share of business function in EU 27, China, Japan, the Republic of Korea, and the United States. Entries bigger than one in bold. Allocation of countries to a particular group are based on the highest functional specialization index of the country in 2018.
Source: Author's calculations based on the OECD ICIO Tables, release November 2021, and the Occupation Database (see also de Vries, forthcoming).

Shifting the focus to greenfield FDI, through which MNEs disperse their production processes across borders and integrate countries into GVCs, we observe the largest number of FDI jobs overall created in Poland, followed by Spain, Germany and France (Table 4). Taking into account the population size, Ireland and Eastern European countries stand out as particularly FDI-oriented economies, though as Table 4 makes evident, the incoming FDI projects in Eastern Europe are mostly confined to production activities. Indeed, in line with the above-mentioned trade-based specialisations and extant literature on the topic (e.g. Kordalska et al., 2022; Stöllinger, 2021), we find a dichotomy between Eastern and Western European economies in functional specialisations also arising from FDI projects (Figure 6).

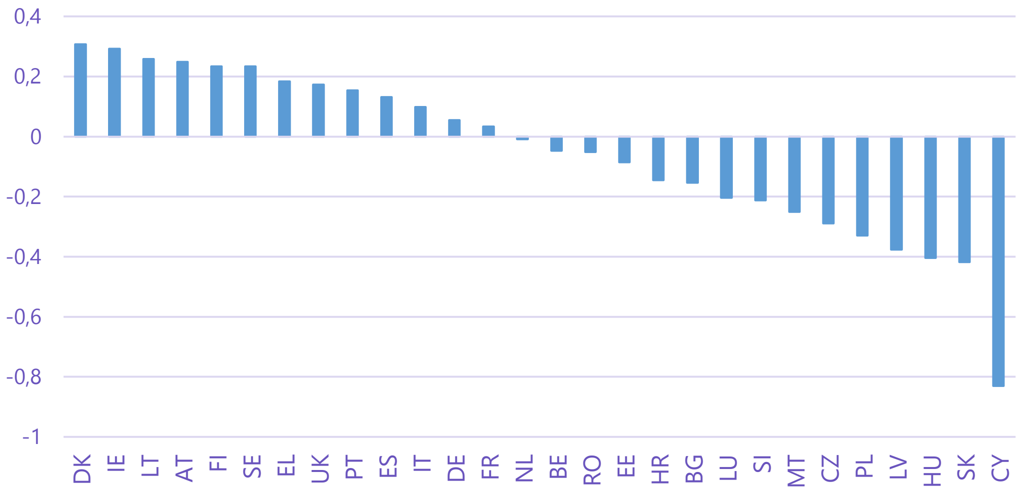
Table 4: Number of jobs created from greenfield FDI projects by function, cumulative for 2003-2021

	Headquarters	Production	R&D	Sales	Technical support	Total
Poland	6,048	34,7522	25,846	198,995	16,751	595,162
Spain	24,342	13,4368	40,487	148,868	12,522	360,587
Germany	31,982	13,7187	34,082	135,632	15,575	354,458
France	15,254	11,3476	30,294	158,544	11,226	328,794
Romania	4,458	21,7871	24,491	57,892	10,809	315,521
Hungary	1,688	23,5507	11,181	48,483	9,669	306,528
Czechia	1,735	19,8111	12,191	39,323	5,824	257,184
Slovakia	944	15,8247	6,846	24,955	2,939	193,931
Ireland	29,903	42,709	28,707	72,494	8,527	182,340
Netherlands	25,650	23,241	12,188	77,168	5,949	144,196
Bulgaria	486	88,422	8,208	28,795	4,020	129,931
Belgium	7,838	53,809	10,125	53,954	3,485	129,211
Italy	4,244	43,337	11,634	49,405	2,312	110,932
Austria	6,639	33,337	10,137	19,292	1,378	70,783
Portugal	936	26,927	8,212	31,159	2,635	69,869
Lithuania	379	25,273	7,497	14,282	3,871	51,302
Sweden	2,507	17,660	6,853	20,749	1,626	49,395
Finland	1,865	11,310	5,073	17,087	1,224	36,559
Denmark	3,650	6,164	4,573	11,917	1,853	28,157
Estonia	412	14,207	1,707	6,418	823	23,567
Croatia	240	10,104	1,329	8,688	333	20,694
Latvia	182	10,407	763	7,612	598	19,562
Slovenia	350	11,565	941	3,355	626	16,837
Greece	494	1,321	1,972	11,619	396	15,802
Luxembourg	982	1,876	474	4,690	313	8,335
Malta	270	2,912	383	2,080	1,779	7,424
Cyprus	275	818	25	2,026	0	3,144

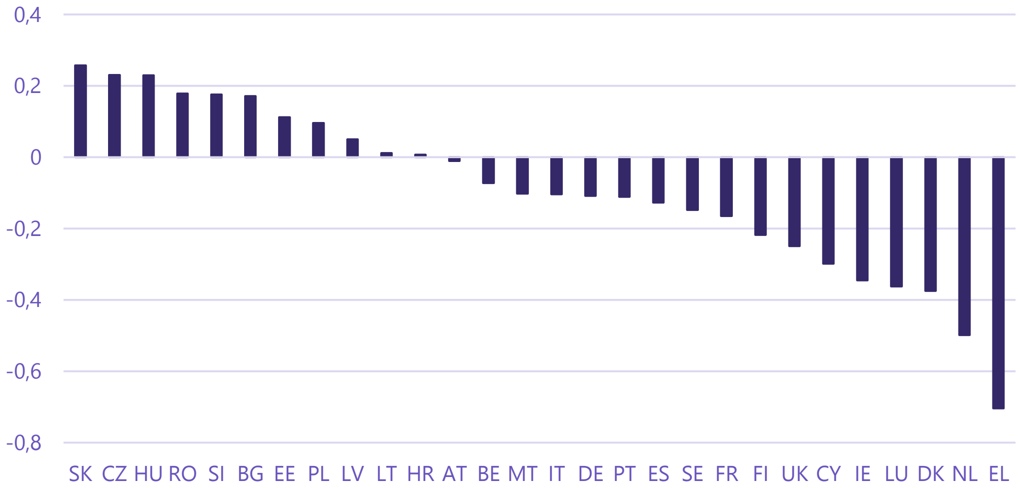
Note: Only projects within the manufacturing sector are included. Classifications of functions based on Stöllinger (2021).
Source: Authors' calculations based on fDiMarkets.

Figure 6: FDI-based functional specialisations in the R&D and Production functions, 2003-2021

A. FDI-based functional specialisations in R&D



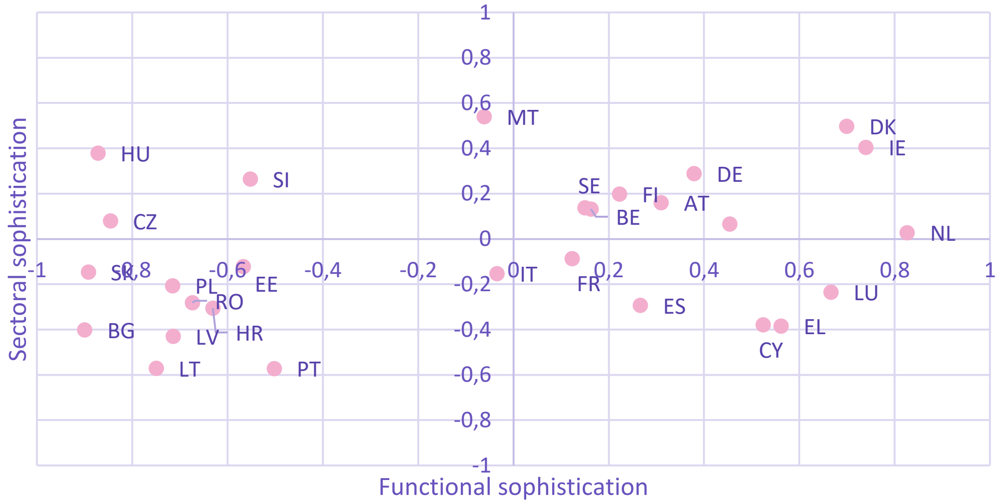
B. FDI-based functional specialisations in Production



Note: Values above 0 represent relative specialisation in the given function against the EU.
Source: Authors' calculations based fDiMarkets following the methodology of Stöllinger (2021); a replication of Kordalska et al. (2022)

Mapping EU countries based on their relative industrial sophistication, considering both the sectoral and the functional lens (Figure 7), highlights that the integration of new EU member states witnessed at the sectoral level (as demonstrated on Figure 5) needs to be contrasted with a divergence at the functional level. The countries in the top-right quadrant of Figure 7 are heavily oriented towards both high-technology sectors as well as sophisticated value chain functions, and hence can be deemed as having the most competitive industrial structures. Countries such as Denmark, Germany, Austria and Ireland fall into this frontier category. In the top-left quadrant, one finds countries which complement the first group by specialising in similarly advanced industries, yet taking care of production activities within these values chains. This quadrant is the domain of the most developed Eastern European countries (Hungary, Czechia and Slovenia), which though relatively specialised in high-technology manufacturing, tend to be far less active in carrying out sophisticated functions. Such a pattern can be defined as one where sectoral convergence is accompanied by functional divergence. The bottom-left quadrant is virtually entirely made up of 'factory' Eastern European countries, which represent varying degrees of under-specialisation in sophisticated manufacturing sectors and heavy under-specialisation in sophisticated functions. In other words, in this quadrant, we find economies that are specialised in low-tech or medium-tech manufacturing industries and within these GVCs they are mostly in charge of simple production activities. Finally, the bottom-right quadrant shows typical 'headquarter' economies (i.e. economies specialised in headquarter business activities within GVCs), but which do not occupy high-technology manufacturing sectors to the same extent as others. More services-oriented economies such as Luxembourg, as well as multiple Southern European economies, are in this group.

Figure 7: Relative specialisations of EU countries by functional and sectoral sophistication

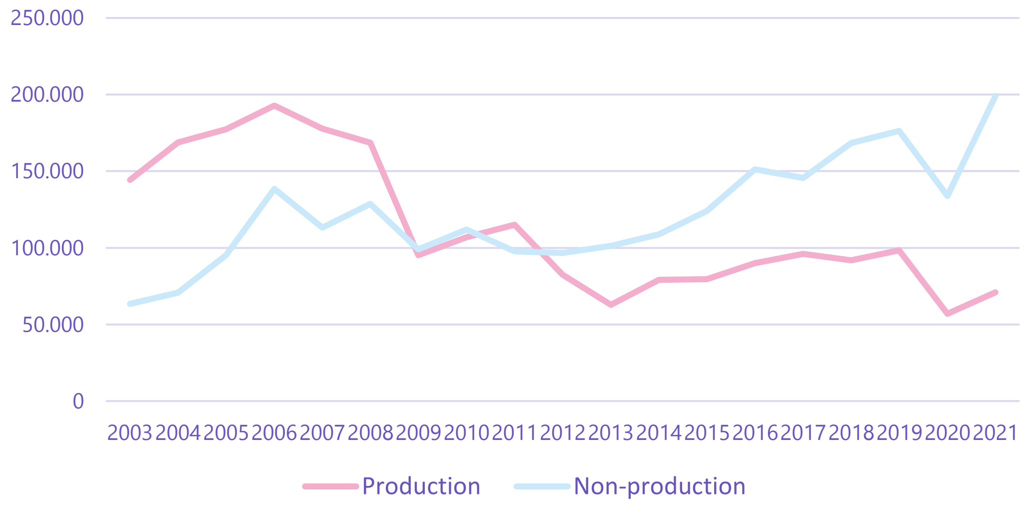


Note: Sectoral sophistication is calculated as the ratio of RCA based on employment in high-technology sectors to low-technology sectors[5], with values normalised so that 1 represents highest specialisation in high-tech and de-specialisation in low-tech sectors. Average employment for the period 2016-2018 is taken. Functional sophistication is calculated as the ratio of functional specialisation in R&D to functional specialisation in production, with values normalised so that 1 represents highest specialisation in R&D and de-specialisation in production. The methodology of functional specialisation calculation follows Stöllinger (2021).
Source: Authors' calculations based on fDiMarkets and OECD Trade in Employment database.

Following trends in greenfield FDI, one can see that while the offshoring of production activities dominated greenfield FDI activity in the EU in the early 2000's, in recent times, it has been shifting more prominently towards the offshoring of non-production functions (headquarters, R&D, technical support, marketing) As Figure 8 indicates, the EU appears to be becoming a more attractive FDI destination for such higher value functions. Yet competition from (old and newly emerging) global powers creates pressures for the offshoring of not just production, but also for higher value-added activities. In this context, conserving and possibly deepening EU industries' specialisations in R&D is critical to remain international competitive.

[5] Following Eurostat's Aggregations of manufacturing based on NACE Rev. 2

Figure 8: Number of greenfield FDI jobs created in the EU by type of activity



Note: Only projects within the manufacturing sector are included.
Source: Authors' calculations based on fDiMarkets.

So how can a country strengthen international competitiveness in the most sophisticated functions of the value chain? Our analysis finds that ICT assets and business R&D expenditures (BERD) can contribute to the abilities of countries to specialise in the most knowledge- and innovation-intensive activities of the value chain, namely R&D activities. However, this effect does not hold unilaterally for both tangible and intangible ICT technologies. It is rather confined to the size of intangible ICT assets (as measured by investment stocks in software and databases)[6]. In other words, the widespread adoption of various ICT tools, such as statistical computing software, databases and database management systems, can help spur R&D specialisations. At the same time, the positive role of business R&D expenditures highlights the role of innovation policies for smarter integration into GVCs[7]. These results hold particularly strongly in the case of the less advanced economies of the EU (See Technical Appendix C), suggesting the accumulation of ICT capacities and innovation-oriented policies offer a valuable means of breaking away from existing path dependencies determining functional specialisation. To our surprise, we do not find support that industrial policy, as measured by state aid expenditures, promotes relative specialisations in R&D. Still, given that EU industrial policy over the period has essentially been an industrial innovation policy (Aiginger, 2007; Soete, 2007), the strong significance of business R&D indirectly underscores the importance of an industrial policy that promotes R&D and innovation within the EU context. Yet, at the same time, these findings stress the pressing need for more comprehensive data on industrial policy tools, while questioning the strategic thinking in the utilisation of state aid by EU member states.

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[6] See Technical Appendix C for the results of the econometric analysis.
[7] The issue of endogeneity is addressed by relying on GMM estimators.

3. Policy shifts: Impact on the evolution of GVCs

Contextual background and research objectives

This chapter addresses the question of how shifting trade policies at multilateral, bilateral and unilateral level have shaped EU-centred GVCs and whether trade liberalisation affects GVC trade differently from traditional trade. As GVCs are structured around not only trade, but also investment and production, this task also studies the role of bilateral investment treaties (BITs) in the formation and expansion of international production.

TWIN SEEDS defines two ‘forces’ as shaping GVCs over the pre- and post-Covid eras: one such force is technological developments (to be covered in Chapter 4), the other is changes in policy regimes. In this chapter we summarise TWIN SEEDS research in the policy field, particularly in the field of trade policy. In this context, WP1 covers the pre-Covid era, while WP2 will follow the analysis beyond the Covid crisis. Trade policy has many dimensions affecting trade in goods and services, but also international production and investment decisions, and covers policy agreements and policy shifts at the multilateral, bilateral and unilateral levels. Furthermore, the reach of trade policy regimes and trade policy instruments has widened significantly, reflecting geo-political and geo-economic changes.

Since the 1980s, trade policy regimes at the global level have gone through distinct phases: from a strong push towards global liberalisation, towards more complex patterns, where multilateral initiatives such as the Doha Round failed, and agreements were increasingly pursued at the bilateral and regional levels. Finally, several unilateral steps were taken by some of the main actors attempting to support their strategic positions in global economic relations.

At its basic level, trade policy decides whether and how taxes (or other costs) will be applied to imports (and sometimes exports), which trade partners are subject to them under various trade regimes and under what conditions. It is precisely because most countries provide preferential access to certain suppliers that trade regimes and their attendant rules are relevant to shaping GVC structures.

Curran et al. (2019) provides a useful framework (reproduced in Figure 9 for analyzing where and how trade regimes should be taken into account in GVC analysis. The key factors of importance that they underline are:

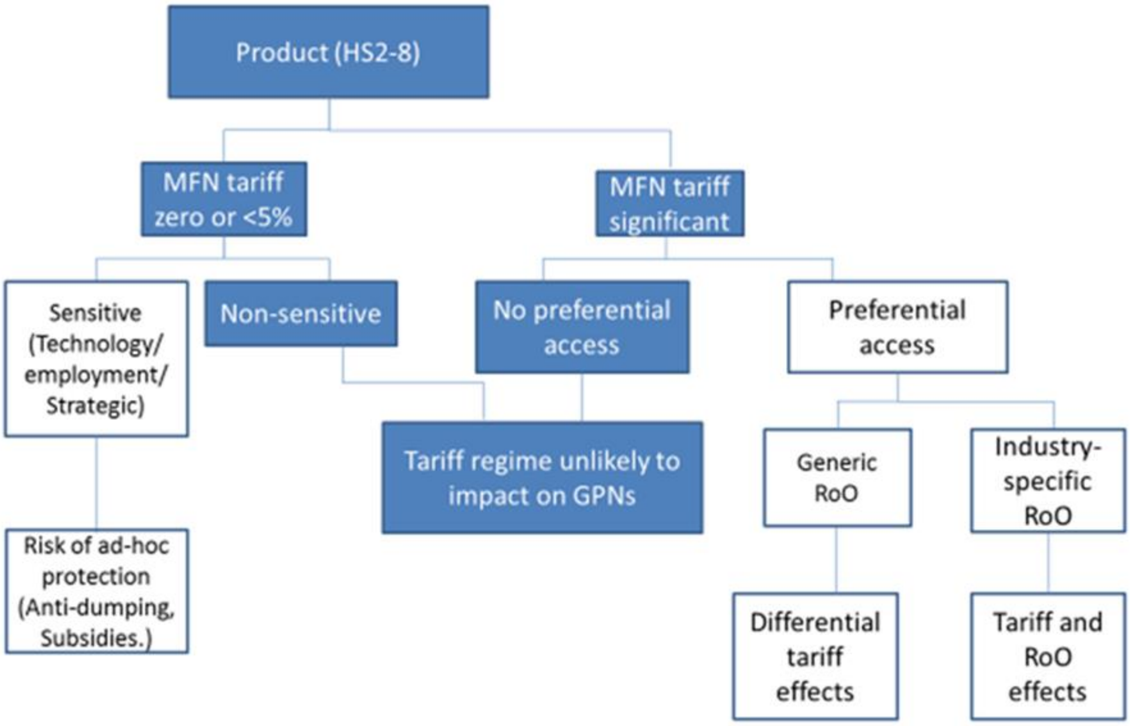
The level of the Most Favoured Nation (MFN) tariff - This is the standard tariff applied to all trade partners (or at least those which are members of the WTO. If MFN tariffs are zero or very low, then the difference between trade costs for preferential and standard suppliers is limited and therefore trade regimes are unlikely to be core factors in relative competitiveness. In this case, the main case where trade policy may become relevant is if products become sensitive for political reasons, or because of rapidly growing competition (e.g. steel, renewable energy products), such that contingent measures such as anti-dumping duties provide temporary protection and distort trade flows (Curran, 2015).

The extent of preferential access - For products where the MFN tariff is significant (more than 5%) this increases trade costs and thus makes those suppliers subject to the tariff less competitive. If some suppliers benefit from tariff reductions, or don't pay any tariffs, trade regimes are likely to impact on GVCs. The greater the number of suppliers subject to preferential access, the lower the effect. Thus, for example, if all developing countries were accorded zero tariff access to the EU market for a certain good, the trade regime would be less impactful than if only Least Developed Countries (LDCs) benefited from preferential access.

The Rules of Origin (RoO) applied to the preferential tariff – All trade preferences are subject to certain conditions. Most notably preferential tariffs are only applied to goods 'made in' the country subject to the preferences. The definition of 'made in' varies by trade regime and sector, sometimes significantly, but generally the RoO define the origin of a product in terms of a fundamental change in the nature of the product in a given country *or* the source of the intermediate products incorporated into the good *or* whether certain production processes are undertaken in the country *or* a combination of two of these. Almost by definition, regulations which require a certain set of production processes (or a certain percentage of the value-added of a product) to be undertaken in a given country impact on GVC structures by providing tariff advantages to products made in certain ways or using certain inputs compared to others.

Non-tariff measures - tariffs are not the only aspects of trade regimes and policy which impact on GVC choices. Non-tariff measures (NTMs) also increase trade costs and therefore agreements which reduce these barriers (such as mutual recognition agreements, or harmonized standards) can also favour certain sources over others. This is particularly the case in some of the EU's recent Free Trade Agreements (FTAs). Within WP1, a specific effort has been devoted to analyzing the impact of NTMs on EU MNEs and international production decisions, which will be reported below.

Figure 9: A framework for integrating trade regimes into GVC analysis



Source: Curran et al. (2019)

In the current research, we sought to expand this framework, in order to support TWINSEEDS analysis of shifting trade regimes and EU-centered GVCs and anticipate the impact of recent and future policy shifts (to be further analysed in WP2). In this context, we propose to take into account a wider range of trade (and related) policy instruments We shall return to the expanded framework in the section on 'Findings and discussion' below.

The research objectives of the studies undertaken in the TWIN SEEDS project covered in this chapter are the following:

- cover developments in the global trade policy environment pre-Covid with a focus on the adjustments and developments of EU policies in the light of the changing geo-economic and geo-political context;
- undertake specific in-depth studies of the impact of trade policies in less well researched areas of international trade and investment policies. This includes:
  - firstly, the impact of tariff- and, specifically, non-tariff measures (NTMs) on the output/sales and productivity performances of the subsidiaries of EU-headquartered companies in global destination countries; this reveals important aspects of how trade policies affect international production networks of EU-companies;
  - secondly, the impact of Bilateral Investment Treaties (BITs) on EU multinational companies' location decisions and investment activities in different locations across the globe. This analysis goes beyond the EU-country level impacts and also captures

the impact of the development of EU multinational global networks on EU regions at the sub-national level.

Methods of analysis and data

The topic covered in this part of the research has been approached in three ways:

Firstly, we cover the development of trade policy regimes over the pre-Covid period, especially the changes brought about by the Global Financial Crisis (GFC). This covers the period in which international trade and investment experienced what has been called 'slowbalisation', with direct effects on GVCs (Aiyar et al, 2023; Antras, 2020; Linsi, 2021). This pre-dated the disruption of international production linkages during the Covid crisis. We undertook a deep examination of trade policy changes at the multilateral, bilateral and unilateral levels using our analytical framework (see schemes 1 above and 2 below) to consider how these changes affected GVCs. This analysis has been undertaken through the careful analysis of trade policy documents and academic analysis.

The next two lines of research involve the compilation of comprehensive datasets used in detailed econometric studies:

Thus, the second line of research pertains to a thorough examination how tariff and NTMs affect production decisions and performance characteristics of multinational enterprises' subsidiaries located in different ('host') countries. The regulatory environment in both the home and host countries, along with sector-specific factors, plays a crucial role in determining the location choices and investment intensity of parent companies in their subsidiaries, which then translates into the performance of their subsidiaries. Regulatory NTMs such as technical barriers to trade (TBTs), and sanitary and phytosanitary (SPS) measures are the most commonly used NTMs. These regulatory NTMs have heterogenous effects on trade of goods at the detailed six-digit level of the Harmonised System (HS). Sometimes they can even stimulate trade as they provide better information to consumers, improving demand. While NTMs impose additional costs on producers, as they incur variable compliance costs or fixed costs of investing in better production procedures, they may also enforce product quality and compliance with environmental standards, which can stimulate demand. Therefore, their effects on trade costs in any direction could substantially affect GVC patterns, and thus the performance of subsidiaries of MNEs. Consequently, the specific nature of NTMs and their associated costs could influence the decisions of MNEs regarding country and sector allocation, as well as production, export, and import choices. Thus, this research analyses how the trade costs associated with the regulatory NTMs affect the output and (productivity) performance of foreign subsidiaries of MNEs.

The third line of research studies the impact of Bilateral Investment Treaties (BITs) on the development of EU-centred Global Production Networks (GPNs) [8]. BITs are one of the most

[8] In line with the literature, we define GPNs as those segments of GVCs that are organised by the network of multinational enterprises' activities in different parts of the world through their network of subsidiaries. Such networks define as 'Global Ultimate Owners' (GUOs) the headquarter of that MNE located in a particular ('home') country and a 'subsidiary' located in another ('host') country.

important policy instruments to protect and promote investments by companies of one country in the territory of the partner country. BITs aim at generating investor confidence that the regulatory framework of the host state guarantees the stability and the predictability of the investment, protecting it from arbitrary legislative or administrative actions. Although BITs vary across countries, they cover three main areas: admission of foreign investments, national treatment, and dispute settlement procedures. BITs may also include provisions dealing with the free transfer of payments, conditions under which expropriation is allowed and compensations occur, exceptions to the MFN standard, as well as a potential denial of benefits granted to third parties (e.g. Egger, Merlo, 2012; Berger et al., 2013; Chaisse and Bellak, 2011). Since GPNs encompass firms repeatedly exchanging goods and services, financial capital, personnel, and knowledge and technologies, and by relation-specific investments, BITs represent an important policy instrument to safeguard the investments made by MNEs belonging to a specific country in the territory of another state and hence may encourage the formation and the development of GPNs.

In the following we shall discuss in more detail the methodological approach taken by the econometric studies which in a number of ways have made important original contributions to the field of GVC/GPN analysis. We start with the compilation of some new datasets.

(i) *The compilation of ad valorem equivalents (AVEs) of NTMs*: What matters for MNEs that are heavily involved in the global value chains (GVCs) are the trade costs associated to these regulatory measures rather than their mere existence of proliferation. Thus, one needs to include a measurement on the trade costs that could vary bilaterally over years in each sector. One main way to do this is to estimate these time-varying bilateral AVEs of NTMs, which could differ not only across sectors and importers but also across exporters and years. For the purposes of the research undertaken for WP1, annual bilateral AVEs of regulatory NTMs (specifically TBTs and SPS measures) were estimated at the six-digit product level of the HS, over the period 1996-2021. Detailed information regarding the estimation procedures of such AVEs is provided in Appendix D.1.

(ii) *The impact of BITs on EU-centred GPNs*: Information on BITs signed by EU countries and entered into force in the sample period (2007-2017) has been drawn from the EDIT database (Alschner et al., 2021), a comprehensive full-text database of international investment agreements provided by the World Trade Institute – University of Bern. It includes 2,549 treaties in force, of which 1,170 involve at least one EU country. Only 207 of these BITs entered into force in the sample period. The study focuses on BITs in force since this is the only status that ensures the full enjoyment of benefits granted by the treaty (Busse et al., 2010; Sirr et al., 2017).

The distribution of BITs entered into force by EU country and destination areas reveals that 125 BITs (48% of the sample) have been signed with MENA (Middle East and North Africa) or Sub-Saharan countries. In contrast, only 4% of these BITs involve other EU or North American countries.[9]

[9] Intra-EU BITs amounted to about 200. Most of them were agreed upon in the 1990s, before the latest EU enlargements (2004, 2007, and 2013). Only one of them, i.e. the Croatia-Lithuania BIT signed in 2008, entered into force in the sample period. All these BITs are terminated since they were mainly signed between existing members of the EU and prospective members. Indeed, all Member States are subject to the same EU rules, and all EU investors benefit from the same protection thanks to EU rules (e.g. non-discrimination on grounds of nationality). The United States of America signed BITs with 9 Central and Eastern EU member states. All of them entered into force before 2004. Canada signed BITs with 11 Central and Eastern EU member states, but only four of which entered into force during the sample period.

These figures suggest that, at least in the sample period, EU member states used BITs to incentivize investments in geographical areas that are not among the preferred locations for EU MNEs. Hence, we can conclude that BITs signed by EU countries aimed at strengthening investors' protection against political risks and arbitrary administrative decisions in countries poorly endowed with sound institutional settings. Further details regarding the compilation of the BITs database suitable for the analysis of this line of research is provided in Annex E.1.

(iii) *MNEs and IPNs*: For both exercises, the analysis of the impact of NTMs and of BITs, information on EU-MNEs and their foreign subsidiaries has been drawn from Amadeus and Orbis, both datasets provided by Bureau van Dijk, which include comprehensive information on financials and detailed corporate structure of about 21 million companies across Europe (Amadeus) and across the world (Orbis). The Orbis database was used for the NTM analysis and Amadeus for the BITs analysis. In each case, one can capture the ownership relationship between the 'Global Ultimate Owner' (GUO) and their foreign subsidiaries. For the NTM analysis a dataset was compiled that included firm/subsidiary-level characteristics such as total assets, number of employees, revenue and turnover, spanning the period 1996 to 2020. There was also a focus on high-tech sectors[10], which rely heavily on FDI for global production efficiency. For the BITs analysis, the compilation of the data included the sub-national (NUTS-2) regional level of the EU regions hosting the MNE's headquarters, covering sector of activity and the destination countries of their foreign subsidiaries. 281 European regions were considered, along with 226 destination countries, 6 sectors of economic activity,[11] and 3 years (2007, 2014, and 2018), i.e. approximately 1.15 million possible observations.

Findings and discussion

As discussed above the research covered in this chapter included three areas:

(i) How has shifting EU and international trade policy in multilateral, bilateral and unilateral contexts shaped EU-centered GVCs?

To understand recent shifts in the EU's trade regime, as well as how the use of trade policy instruments has changed, it is important to put them into context. The first two decades of the 21st century have seen quite diverse trends. Strong integrationist trends dominated prior to the GFC in 2008/09. This was followed by a period of economic instability, especially in Europe and the emergence of a less dynamic, more skeptical context, with rising protectionism towards the end of the 2010s. During this period, the EU has remained a defender of the international trading system, while simultaneously pursuing its interests in its bilateral and unilateral relations with the rest of the world.

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[10] The industries defined as 'high-tech' in this part of the analysis are: 'Manufacture of basic pharmaceutical products and pharmaceutical preparations', 'Manufacture of computer, electronic and optical products' as well as 'Manufacture of air and spacecraft and related machinery'.

[11] Following Eurostat classification, we considered: the primary sector (PRI), the manufacturing sector disaggregated in high-tech manufacturing sectors (H-TEC), low-tech manufacturing sectors (L-TEC), construction and Public Utility sectors (PU), and the services sector disaggregated in knowledge-intensive services (KIS), and no-knowledge intensive services (No-KIS).

Wider geopolitical realities have meant that, whereas at the beginning of the century, the EU was confident that further trade liberalization could be achieved at multilateral level through the WTO process (most notably the Doha Round launched in 2001), by the end, its primary focus for trade liberalization was through a series of bilateral agreements with favoured trading partners (Leblond and Viju-Miljusevic, 2019). At the same time, the growing economic and political importance of the emerging markets motivated a change in the EU's trade relations with the developing world. While it started the century with a new more generous trade regime for the poorest countries (the LDCs), its preferential access scheme for middle-income countries has become progressively more restricted. Thus, over time, certain countries have benefitted from more favourable access to the EU market, while others have seen their access reduced or removed, stimulating shifts in EU firm's sourcing patterns, especially in certain industries subject to high MFN tariffs (Curran et.al, 2019).

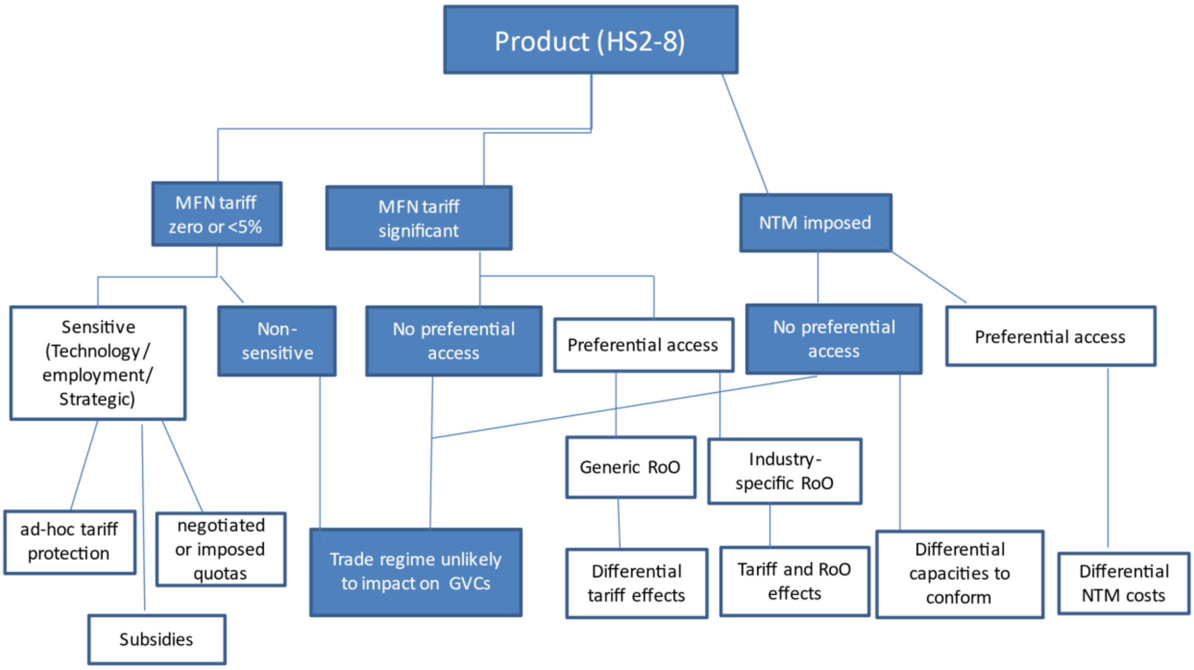
In terms of global trade trends, the context clearly shifted during the GFC. The shock created by the crisis was such that the upward trajectory which had characterized global trade at the beginning of the century abruptly halted. In the period following the GFC trade rebounded to some extent, but never recovered its prior dynamism. Thus, the growing integration of the global economy that had characterized the last decade of the 20th century and the first years of the 21st plateaued several years before the pandemic, with trade flows stagnating and GVC integration falling. This trend, which has been dubbed 'slowbalisation' or 'deglobalisation', reflects a variety of interconnected changes in geo-politics and technology (Aiyar et al. 2023; Antras, 2020; Linsi, 2021; The Economist, 2019).

Partly as a result of these global shifts, the nature and context of trade negotiations has changed over time. After an optimistic launch in 2001, the WTO multilateral negotiations - the 'Doha' round - ran into difficulties. Although the EU traditionally favored a multilateral approach, it began to look to other avenues for market opening and economic opportunities (Leblond and Viju-Mijusevic, 2019). At the same time the rise of the emerging economies, especially China, created new competitive threats and opportunities, that required coordinated responses. These evolutions have resulted in important changes in trade policy over the period, which have in turn encouraged the restructuring of the EU's GVCs.

In concert with these shifts, the internal policy context ihas become more complex, with an increasingly important role for the European Parliament and a rise in the salience of trade in public discourse (Meunier and Czesana, 2019). Added to this, the EU has both enlarged (through the access of the Central and Eastern European (CEE) countries) and reduced in size (with Brexit). These shifts impacted, not only the policy making process, but also the trade policy priorities of the EU.

Drawing on analysis of recent trade policy evolutions, this research underpins an extension of the above schema 1 to allow us to identify emerging shifts in trade policy regimes which affect GVC development (see schema depicted on Figure 10). This expanded approach will help us to better capture the impact of the changing trade policy context in which the EU operates in the 21st century.

Figure 10: A revised framework for assessing the impact of trade regimes on GVCs



Source: Authors' elaboration based on Curran et al. (2019)

The following are key issues highlighted in the schema:

- *Risk of intervention in industries considered sensitive* – while past sensitivities were often related to employment (which motivated the quotas in clothing and footwear), more recently technological sovereignty and capacities in leading edge technology (including digital and green technologies) have become very politically sensitive. The result has been increasing ad-hoc protection. On the import side this included EU and US anti-dumping actions on solar panels (Kolk and Curran, 2017). On the export side, there have been increasing restrictions on trade in leading edge electronics, especially in the US.

- *Preferential market access* – as highlighted above, the provision of market access through FTAs and unilateral schemes has a direct impact on relative competitiveness. Although there are not many significant new EU FTA negotiations, a key potential change in market access in the period of the TWIN SEEDS project would be the ratification of the agreement with Mercosur, which faces substantial barriers (Warborn et al. 2023). In terms of unilateral market access schemes, the key shifts will be related to the reform of the GSP. This process, and its potential impact on GVCs will be monitored within WP2 and WP6.

- *NTMs* – There is a large variety of NTMs that can impact on trade and GVCs, such that seeking to define how they impact on trade and GVCs is very difficult (Bown and Crawley, 2016). Although they vary over time and across sectors, common characteristics include potential discrimination against certain foreign producers, together with preferential treatment for others. Certain producers may be exempted, for example through mutual recognition agreements, while the capacity of certain suppliers to conform to the requirements of the NTM may vary widely. The EU is developing several NTMs in the post-COVID context, which will require analysis in terms of their impacts in GVCs. These include the Carbon Border Adjustment Mechanism (CBAM), the Due Diligence Directive and the Regulation on goods made by forced labour.

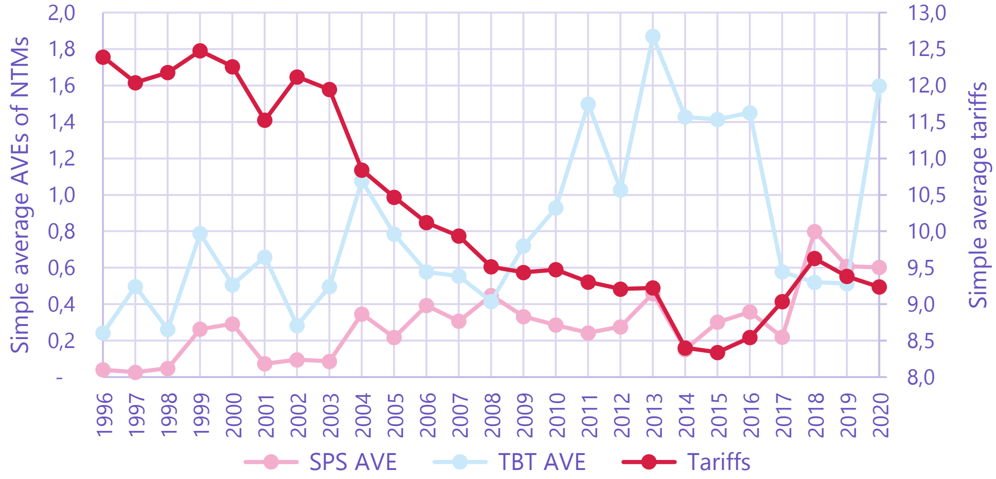
- *Trade Defence: Anti-Dumping (AD) and Anti-Subsidy (AS)* - Most research on trade defence has looked at AD. The impact of subsidies and reactions to them (AS duties) has been much less widely analysed. However, interest in the impact of subsidies on trade has increased in recent years, partly because of the widespread government support to industry during the GFC (Evenett and Jenny, 2009), but also because of their extensive use in large emerging markets, especially, but not only, China (Ambaw and Thangavelu, 2022). These latter subsidies have been blamed for global overcapacity and tumbling prices, especially in renewable energy sectors (Zhang et al. 2016) and steel (Wuttke, 2017), which in turn spilled over into the trade conflicts referenced above. Since the GFC, Evenett and his co-authors have been arguing that trade policy has increasingly been manifested through non-tariff measures including industrial policy in what they term 'murky protectionism' (Aggarwal and Evenett, 2013) and recently, academic interest in the impact of subsidies on trade has increased (Ambaw and Thangavelu, 2022; Kaplouptsidi, 2018).As pointed out in Curran (2015), and incorporated into Schema 1, industrial sectors which are important for employment and/or strategic objectives are particularly vulnerable to ad-hoc trade defence measures and subsequent impacts on GVCs. Given that the conception of strategic industries has recently expanded globally, both as a result of the COVID pandemic (Curran and Eckhardt, 2021) and the war in Ukraine, ad-hoc trade policy interventions seem likely to increase in the future.

(ii) How trade barriers (tariff and non-tariff measures) affect international production networks

In this part of the research we analysed how the performance of subsidiaries of MNEs responded to trade costs associated with different trade policy measures (tariffs and NTMs) affecting trade patterns between the home country ('home') of the MNE and the host country ('host') of its subsidiaries. Appendix D.2 gives the more technical details of how the analysis was conducted and Appendix D.3 presents detailed results from our econometric analysis. Here we summarise some of the main findings.

We start with some descriptive data: the following plots present the trade costs associated with NTMs (as calculated by AVE of NTMs) and tariffs over the period 1996-2020 (Figure 11) and across different non-service industries (Figure 12). These figures reveal that tariff measures were decreasing until the US-China trade war took off. On the other hand, TBTs and SPS measures have gained importance over time. These observations are in line with the conclusion of the latest trade (policy) report by UNCTAD (2022).

Figure 11: Simple average of tariffs and estimated AVEs of NTMs (across all trade flows including zero trade flows)



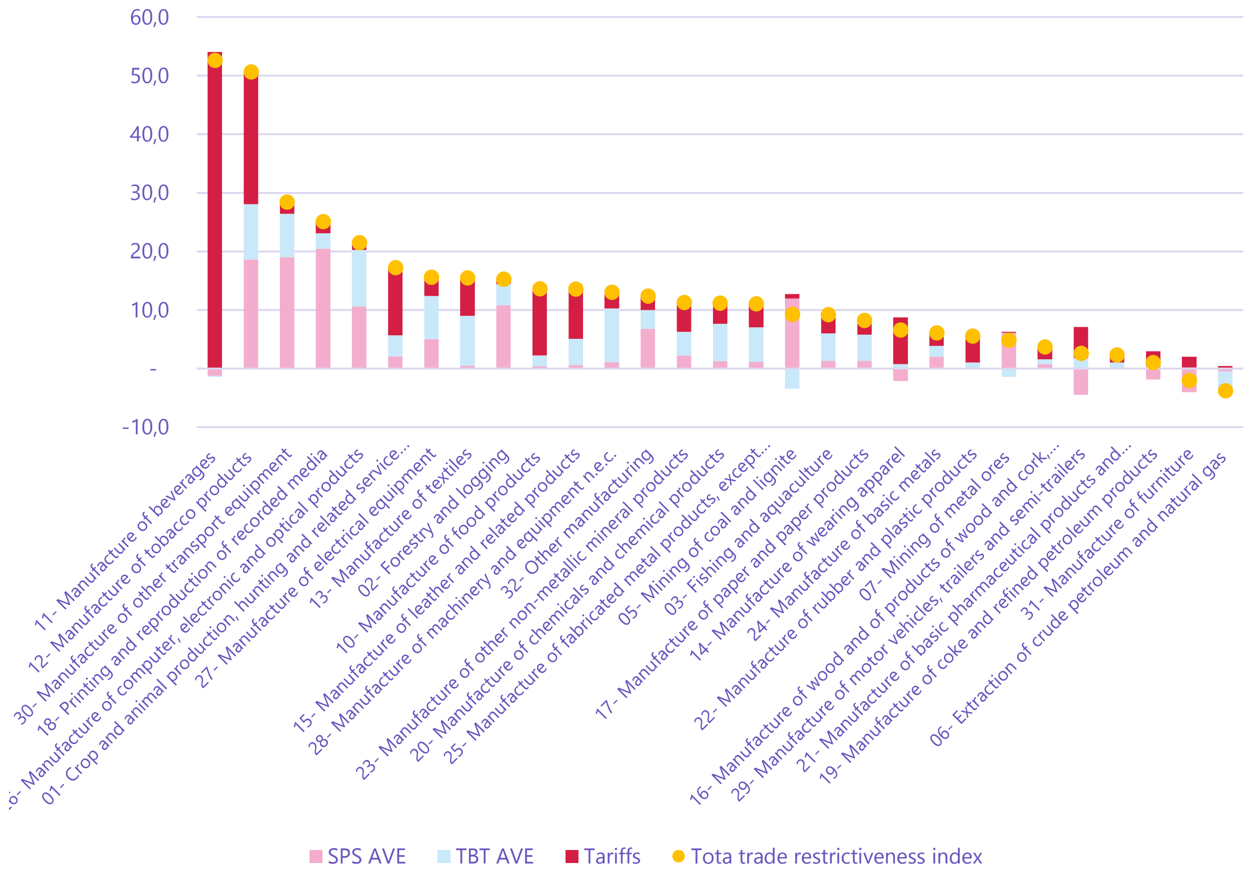
Source: WTO I-TIP, UN COMTRADE, WITS, authors' estimations.

Tariffs have been subject to a rather stable decreasing trend from the beginning of the period, owing to implementation of multilateral and unilateral tariff liberalization. This downward trend ended in 2015 when there was an upsurge due to tariffs imposed by the US on China and the latter's retaliation. As also pointed out by UNCTAD (2022), tariffs restrictiveness remains relatively high in developing economies.

Unlike tariffs, the trade costs related to TBTs and SPS measures have been on the rise since the beginning of the period. Figure 11 reveals that TBTs pose the highest trade costs, in comparison to SPS measures and tariffs. This could be due to the fact that TBTs are inherent to larger markets, such as that of the EU, China, Brazil, US and Australia, that account for a large share of global trade.

When various trade costs are analysed at the industry level (Figure 12), we see that beverages (NACE 11) are exposed to the largest barriers to trade, with a total restrictiveness index of about 52.6%.This is explained by very large protectionist tariffs (54%) imposed by many countries, while the trade-weighted average AVEs of TBTs and SPS measures is negative on this sector. Manufacture of tobacco (NACE 12) is the second most protected industry, with a total restrictive index of 50.7%, only 22.6% of which is determined by tariffs; the next industry with high exposure to trade costs (although stemming more from tariffs) is manufacturing of other transport equipment, followed by printing and reproduction of recorded media, and then by manufacture of computer, electronic and optical products.

Figure 12: Import-weighted trade restrictiveness index and its components by NACE two-digit sectors 1996-2020



Source: WTO I-TIP, UN COMTRADE, WITS, authors' estimations.

In general, we see that several industries are subject to higher tariffs, namely those related to agricultural production (animal production, etc.), tobacco manufacturing, food and beverages, and textile products. Although the results are an average over twenty-five years, the evidence indicates that food-related trade costs have also prevailed recently. According to WTO (2022), amidst economic uncertainty and multiple crises, trade costs have increased, mostly on food-related products. Significant costs associated with tariffs are noticeable in the manufacturing of intermediate products (e.g. motor vehicles, trailers, and semi-trailers; rubber and plastic products, etc.), while they are lower for high-tech products and for natural resources.

When it comes to TBTs and SPS measures, the industrial heterogeneity differs slightly. Of all the non-service industries, printing and reproduction of recorded media is the most exposed to TBTs. Furthermore, technical regulations, standards, and procedures strongly affect medium- to high-tech manufacturing (e.g., computer and electronics, machinery, and equipment) as well as tobacco manufacturing. This is unsurprising given the nature of the production in these sectors. Industries that are highly affected by SPS measures overlap with those industries that are highly affected by TBTs.[12] Additional industries that have to deal with high costs associated with SPS are those related to the trade of natural resources (forestry and logging, mining of coal and lignite, etc.).

[12] Industries related to mining, the tobacco industry, and forestry.

Coming now to an overview of the results from the econometric analysis, using the time-varying bilateral AVEs of NTMs, we examine the impact of NTM stringency imposed by the home and host countries on the performance indicators (revenue, turnover, and labour productivity) of foreign subsidiaries owned by MNEs. We also analyse how firm heterogeneity in terms of subsidiary's productivity could affect the impact of regulatory NTMs on subsidiary's output. In fact, it would be expected that firms with higher productivity are better equipped to circumvent the trade obstacles raised by regulatory NTMs, as the literature also suggests (Fontagné et al., 2015; Navaretti et al., 2018). Our findings confirm that NTMs have significant effects on subsidiary performance indicators. We observe diverse impacts resulting from measures imposed by the host and home countries, across sectors, and different types of NTMs (AVEs of TBTs and SPS measures). NTMs pose a greater challenge to MNE affiliates' activity and performance than tariffs. Particularly, high-tech manufacturing subsidiaries of foreign MNEs face heightened regulatory losses due to these NTMs. However, subsidiaries with higher productivity, full foreign ownership, and integration within a larger international network of subsidiaries can leverage these trade challenges to their advantage. Additionally, 'deep' Preferential Trade Agreements (PTAs) that include provisions for recognizing regulatory frameworks among trading partner countries can effectively mitigate the impact of stricter NTMs. This suggests that although trade costs associated to NTMs would have negative effects on the production of foreign subsidiaries as they disturb supply chains, such NTMs might not have strong disturbing impacts within deep PTAs. We also conduct an interesting analysis of the differentiated impact of NTMs on firm performance based on subsidiary productivity levels, which reveals that higher-productivity firms are more resilient to the negative effects of restrictive NTMs. A more detailed discussion of the results obtained is provided in Appendix D.3.

We would like to highlight the following implications of the results obtained:

- As there are important trends in the global economy towards increasingly using NTMs in shaping trade relationships between trading countries or trading blocs, the impact of NTMs on MNEs' production operations in different international locations is of particular interest.
- International production networks rely on the international flow of intermediate goods and services inputs across countries and trading blocs. Any impact which NTMs might have on such trade flows – in our case between the 'home' base of the MNE and its subsidiaries in 'host' countries - is important, as it impacts on the location decisions and production activities of MNEs and their subsidiary networks.
- The finding that deep PTAs can powerfully counteract the negative impact of NTMs on production (and implicitly export) activities of MNE subsidiaries is important, as it shows that by successfully including a wider set of economies within a common regulatory context, PTAs can encourage trade flows (and hence GPNs) within the PTA region. This amounts to 'trade diversion' and 'trade creation' effects of 'deep PTAs' (i.e. those that make provisions for regulatory alignment).
- The further results obtained regarding the impact of firm specific characteristics (such as the productivity level of the subsidiary, the network size of the MNE, and the ownership pattern of the MNE vis-à-vis its subsidiary) are interesting in the sense that high productivity subsidiaries and MNEs with a wider set of subsidiaries, or those with full ownership of their subsidiaries can withstand the negative impact of NTMs more easily. Hence in a world in which the incidence of such NTMs seems to be increasing, this would favour these types of firms which, in turn, has implications for industrial (market) structures at the global and regional levels.

- Finally, we found significantly higher sensitivity of MNEs in the high-tech sectors to the imposition of NTMs. This is particularly important as this group of industries is (and was) a driver of GPNs and international trade more generally.

(iii) The role of bilateral investment treaties (BITs) in the formation and expansion of international production

The analysis carried out in this line of research contributes to the literature in several dimensions. First, it adopts a regional-level approach, seeking to disentangle the potential heterogeneous effects that national policy aimed at promoting further integration at the world level may have at a sub-national level. Indeed, regions are not homogenous, in terms of both economic specialization and the number of MNEs they host. Thus, while investment, like trade liberalisation policies, may benefit all participants in the international economy, it is not clear yet whether the distribution of the advantages linked to these policies is uniform across space. This information is of particular interest to policymakers who may implement spatially targeted interventions to compensate for the potential adverse effects that deep integration into the global economy may have at the territorial level. This represents a true novelty in the current debate, mainly focused on the country- or at least firm-level analysis. Secondly, the focus is on GPNs, rather than on traditional FDI inflows or outflows. With the advent of GPNs, stand-alone MNEs do not exist anymore. What is observed today, instead, is a *network* of firms – made of a headquarter and many affiliates – performing different but strongly integrated tasks and functions aimed at producing the same final good that will be sold in the global market (Ascani et al. 2020; Bettarelli and Resmini, 2002). Lastly, in order to assess and compare the degree of protection granted by BITs signed by EU countries, textual overlaps between specific provisions included in the BITs have been thoroughly analysed with the help of learning machine techniques (for details see Appendix E.1). This strategy allows the clustering of treaties signed by different EU countries including the same provision in three homogenous categories, each offering a different degree of protection to foreign investors.

In order to achieve our main research objective – to investigate how and to what extent the policy shift towards more investment liberalisation has affected EU-centred GPNs – we addressed the following four questions:

1) What was the impact of BITs on GPNs led by EU-MNEs? In providing an answer to this question, we distinguished the ‘creation’ effect – i.e. whether BITs are able to incentivize new EU firms to become international and invest abroad – from the ‘development’ effect, i.e. the impact of BITs on the number of subsidiaries controlled by existing MNEs.
2) Do the substantive aspects of BITs matter for their effectiveness?
3) Is the effectiveness of BITs conditioned by the characteristics of the regions hosting the headquarters or by sector specificities? The answer to this question has relevant policy implications, since it may inform policymakers engaged in the implementation of investment liberation policies at the EU level about inequalities generated by further integration on a global scale.
4) Do BITs positively stimulate the formation and development of GPNs in all destination countries? Is their effectiveness determined or conditioned by the characteristics of the host countries?

The following is a summary of the results obtained from our analysis. Further details regarding the econometric estimates can be found in Annex E.3.

- *Ceteris paribus*, BITs have a positive effect on GPNs. This effect has two main components, i.e. the creation and the development effects. On average, both are positive and significant, with the latter larger than the former in magnitude. This implies that BITs are better designed to promote the expansion of existing networks rather than stimulate new firms to de-localise different stages of the production process abroad.
- MNEs are attracted by substantive provisions in treaties that provide greater investment protection, though no clause, *per se*, is able to condition the effectiveness of the entire treaty.
- BITs are a powerful instrument in promoting the expansion of MNEs' activities in less developed and emerging countries, not endowed with strong regulatory settings.
- BITs do not seem to be an effective instrument in promoting the internationalization of complex production processes, i.e. those characterising high-tech manufacturing products, and knowledge-intensive services, all else being equal.
- Within the country of origin, the impact of BITs is neither homogenous nor linear. Indeed, they positively affect the formation and development of GPNs originating in both low- and medium-high-income regions, with an impact that is slightly larger in the latter, but not in high-income regions where most GPNs originate. These non-linearities, make it difficult to understand whether BITs enhance convergence or divergent development trajectories. This ambiguity suggests the need to carefully monitor potential disparities over space.

Overall, these results confirm that a commitment to a liberal investment policy regime enhances the locational advantages of countries by improving the regulatory environment for investment, thereby incentivising EU firms to become international or to consolidate their foreign activities, though contingent on a set of specific factors. In particular, the research suggests that an improved foreign investment environment, together with a credible commitment to a high level of investor protection are important to stimulating the formation and consolidation of GPNs driven by EU multinational companies. Hence, the creation of a sound investment environment is a key factor to achieve the so-called Open Strategic Autonomy, which has become one of the priorities of the EU for the next years. Indeed, by reducing the costs of doing business abroad, investment liberalisation, if combined with trade liberalisation, makes GPNs not only more efficient (improving EU firms' competitiveness in international markets), but also more resilient to policy risks and other non-economic shocks. Furthermore, through the implementation of more EU-BITs, the EU may contribute to shaping global rules for a more sustainable and fairer globalisation.

Our findings also indicate that an open investment policy may have heterogeneous effects across regions within the same country, with different development levels. In particular, we found that BITs do not further stimulate the creation and development of GPNs originating from high-income regions. In contrast, our results indicate that the impact of BITs is U-shaped in the other three categories of regions, being positive and significant in low and medium-high income regions but insignificant in medium-low income regions. These non-linearities raise concerns about potential regional disparities.

4. Technological advances: organisation of production and knowledge creation in GVCs in the digital era

Contextual background and research objectives

At the global level, ICT transformed the way production and innovation processes are organised, enabling the emergence of global production networks (Antrás, 2020; Baldwin, 2016). In turn, GVC integration exposed economies to new technologies and knowledge, creating opportunities for the accumulation of capabilities and innovation (e.g. Lema et al., 2019; Pietrobelli and Rabellotti, 2011; Sturgeon, 2017). At the same time, continuously developing and adopting new technologies represent a means for defending and advancing one's position in GVCs, while new players start taking on strategic activities and capturing more value (see Chapter 2). Heightened competition, coupled with rising geopolitical tensions (see Chapter 3) and the supply chain disruptions due to the COVID-19 pandemic, contributed to a recent switch from a widespread positive perception of GVCs – GVCs as a source of growth and competitiveness – to a more critical view, emphasising job losses and technological dependencies. In the EU context too, 'technological sovereignty' and greater (strategic) autonomy in key technologies were reinforced as policy priorities in recent years (Edler et al., 2020; European Commission, 2021; Fabry and Veskoukis, 2021; Leonard and Shapiro, 2019). Hence, a deep understanding of the degree of dependence on foreign technologies becomes paramount to informing policymaking in the EU.

Beyond the macro-picture, it is clear that the internationalisation of R&D and innovation is a strategic choice of MNEs (Dachs and Zahradnik, 2022; Papanastassiou et al., 2020;). The literature, however, so far took only limited interest in the relationship between R&D internationalisation by MNEs and GVCs (Ambos et al., 2021). Even less attention was devoted to how internationalisation and integration within GVCs are affected by digitalisation, let alone by different digital technologies (Butollo et al., 2022).

Digitalisation changed the way firms do business (e.g. Brun et al., 2019; Schwab, 2016; UNIDO, 2019). These changes occur in many areas: from sourcing inputs to innovation, manufacturing, and the provision of services, to marketing and sales. Digitalisation also changes the ways firms expand internationally (Añón Higón and Bonvin, 2022; Gopalan et al., 2022; Strange and Zucchella, 2017). New technologies help firms to communicate with customers and suppliers abroad, connect their production activities to GVCs, and provide services over distance (Frank et al., 2019; OECD, 2017). Indeed, while product-related services already existed before digital technologies, digitalisation enhanced the scope and variety of such services (Ardolino et al., 2018; Dachs et al., 2020; Paschou et al., 2020).

While it may appear that the adoption of technologies takes place automatically, research shows that the absorption of digital technologies varies considerably across organisations (Delera et al., 2022; Muralidharan and Pathak, 2020). Varying degrees of adoption of new digital technologies - together with varying levels of productivity, competitiveness, and innovation - ultimately impact firms' opportunities to integrate into GVCs and benefit from them. In turn, whether firms are able to maximise the returns of their participation in GVCs crucially depends on the governance of their innovation processes. Indeed, outsourcing R&D and innovation activities might harm innovation performance, especially if excessively utilised or if their innovation capacities are already weak (Brancati et al., 2021; McWilliam et al., 2020; Steinberg et al., 2017).

This chapter touches upon several of these issues. It is dedicated to advancing the understanding of how and by whom R&D and innovation are undertaken in GVCs, by looking at the portion of R&D that is exchanged by countries within GVCs. This analysis helps identify the most important contributors to global R&D and innovation, as well as the degree of dependencies that the EU faces today (in comparison with 10 years ago) in different economic sectors. By tracing R&D within GVCs, we contribute to the recent debate on technology dependencies. Indeed, from a GVC perspective, technology dependency boils down to the question of how much foreign R&D is embodied in imports of intermediate products needed for domestic production (or exports). This chapter also pushes the empirical research frontier by studying how different digital technologies affect trade within GVCs. By considering eleven digital technologies, and exploring alternative channels of transmission, our research provides solid empirical evidence of the role of digital technologies in advancing EU MNEs' productivity and exports. Moreover, this chapter aims to shed light on how MNEs organise themselves within GVCs and, importantly, how digital technologies affect the governance of value chains and relationships therein. This is crucial for shaping trade and digitalisation policies, as well as MNEs' strategies concerning different digital technologies and insertion into GVCs.

The overarching research questions of this section are the following:

- How and by whom are R&D and innovation undertaken within GVCs?
- How do different digital technologies affect trade within GVCs?
- How do digital technologies affect the governance of GVCs and the relationships therein?

Methods of analysis and data

To answer the research questions of this chapter, a variety of analyses are performed.

For the first question, i.e. how and by whom are R&D and innovation undertaken within GVCs, we design a novel methodology to track the R&D produced and exchanged within GVCs. This consists of modelling R&D dependency in terms of the embodied R&D content of intermediate goods (see Appendix F for details). The basic idea behind this methodology is simple: each stage of a value chain creates inputs that become part of the final product. Production activities at each stage require R&D which then enters downstream stages of production by being embedded in the output of this stage. Consequently, we can consider the R&D content of a certain good as the sum of the R&D efforts in upstream sectors and the R&D efforts of the producing sector itself. Our approach builds on Papaconstantinou et al. (1996), Hauknes and Knell (2009), and Fusillo et al. (2021). While the idea that knowledge diffuses via GVCs has been used in models of greenhouse gas emissions in international trade (Yamano and Guilhoto, 2020), we are the first to apply this methodology to the question of technological dependencies.

We base our analysis on input-output-tables that trace the flows of goods for intermediate or final use throughout the economy and rely on annual inter-country input-output tables from FIGARO (Full International and Global Accounts for Research in input-Output analysis) provided by

EUROSTAT.[13] We complement input-output tables with data on BERD from a variety of data sources.[14] We then aggregate both FIGARO and BERD data to the NACE 2-digit industry level and country level, to allow for country- and industry-level comparisons.

The second research question, i.e. how do different digital technologies affect trade within GVCs, requires us to open the 'black box' of digital technologies and the channels through which these technologies can impact trade. To do so, we use advanced econometric techniques and examine two possible channels through which digital technologies may impact exports: i) via productivity, and ii) via servitisation, i.e. via the services that are enabled by ICT and can be offered together with the physical products. The econometric analysis employs structural equation modelling in the tradition of the Crépon, Duguet, and Mairesse (1998), or CDM, model. The CDM model has been widely used to study the effect of R&D on innovation and in turn the impact of innovation on productivity. We adapt this model to test if: i) digital technologies affect productivity, and, by increasing productivity, they affect exports (first channel); and/or ii) digital technologies help firms to provide services which in turn have an impact on exports (second channel).

To perform this analysis, we leverage a rich database, the European Manufacturing Survey (EMS). The EMS is a firm-level survey that targets manufacturing firms with 20 or more employees and investigates product, process, service, and organizational innovation. A harmonized questionnaire allows the analysis relationships between variables across countries. Data were collected in the spring and summer of 2018 and refer to the year 2017. The database includes 2,033 observations of Austrian, German, Croatian, and Swiss manufacturing firms and is representative at the country and sectoral levels. The EMS provides most variables for the analysis (for details on this analysis, see Appendix G).[15]

The third research question, i.e. how digital technologies affect the governance of GVCs and the relationships therein, also explores the role of different digital technologies focusing on robots, data analytics to improve the processes of production or service delivery, and data analytics to monitor employee performance. Looking at these three technologies, we explore: i) whether GVC embeddedness is positively related to the use of digital technologies within firms; and ii) if GVCs help foster product, process, and marketing innovations, and if this depends on the governance of production and development processes adopted within firms. In doing so, we contribute to the literature on GVCs and governance, by investigating the role of different digital technologies and different governance modes at the firm and sectoral levels.

For this analysis, we combine firm-level data on firms' decisions related to technology adoption from the European Company Survey with meso-level data on GVC embeddedness from the OECD Trade in Value Added (TiVA) dataset. In particular, the 2019 European Company Survey collects information on more than 19 thousand firms that were asked about their adoption of robots and data analytics tools. These variables proxy the level of digitalisation of firms and allow

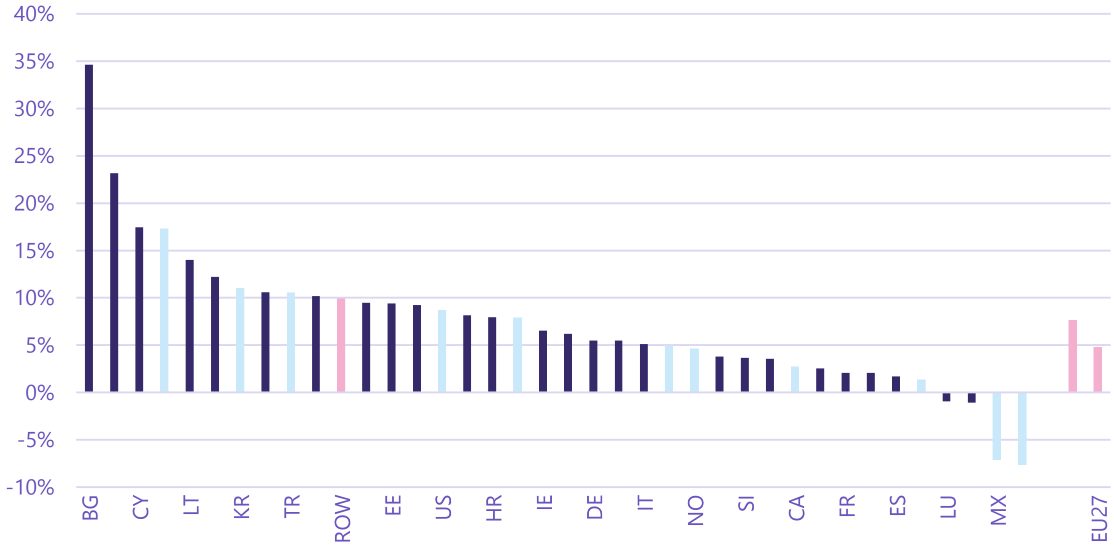
[13] The FIGARO database covers the years 2010 to 2019 and includes data for EU Member States, the United Kingdom, the US, China, and for the main trade partners of the EU.
[14] Data on business R&D expenditures at the sectoral level comes from Eurostat and the OECD. For India, we used national data from the National Science and Technology Management System from the Indian Department of Science and Technology.
[15] In addition, data on turnover at sectoral level comes from Eurostat.

disentangling the heterogenous impacts of different digital technologies. The TiVA dataset is the standard database used in scientific work to study GVCs. Using this data, we compute indicators of forward and backward linkages within GVCs, as proxies of the degree of embeddedness in GVCs. By combining meso- and micro-level data, we test a novel methodological approach for the study of GVCs in relation to firms' decisions. Such methodology shows great potential in terms of enriching the micro-evidence on GVCs. Due to the multi-level nature of the data, with firms nested within industries and countries, these analyses employ multilevel models (Generalised Linear Mixed Models).

Findings and discussion

The last decade saw mounting business R&D expenditures in almost all countries where data is available. However, growth was much more rapid in the US and China than in the EU27. Figure 13 confirms that, while over the period 2010-2019, BERD grew by an annual growth rate of 8.7% in the US and 17.3% in China, the corresponding value for the EU27 was only 4.6%. This was due to a slow growth in large member states including France and Germany. In contrast to Western Europe, we see fast catching up in some Central and Eastern European Member States (most notably, Bulgaria, Poland, Lithuania, Romania, Slovakia, and Hungary) with higher growth rates than in the US or China. While these growth rates are certainly welcome, the investment levels behind them are heterogeneous. European countries overall invest less than China in BERD. To give some examples, while China's BERD intensity (BERD as a share of GDP) is slightly above 1.5%, Bulgaria's is around 0.7% and Poland's is around 1%. In the EU27, only Belgium, Austria, Germany, Sweden, Denmark, and Finland invested at higher rates than China in 2019.[16]

Figure 13: Compound annual growth rate of BERD, 2010-2019

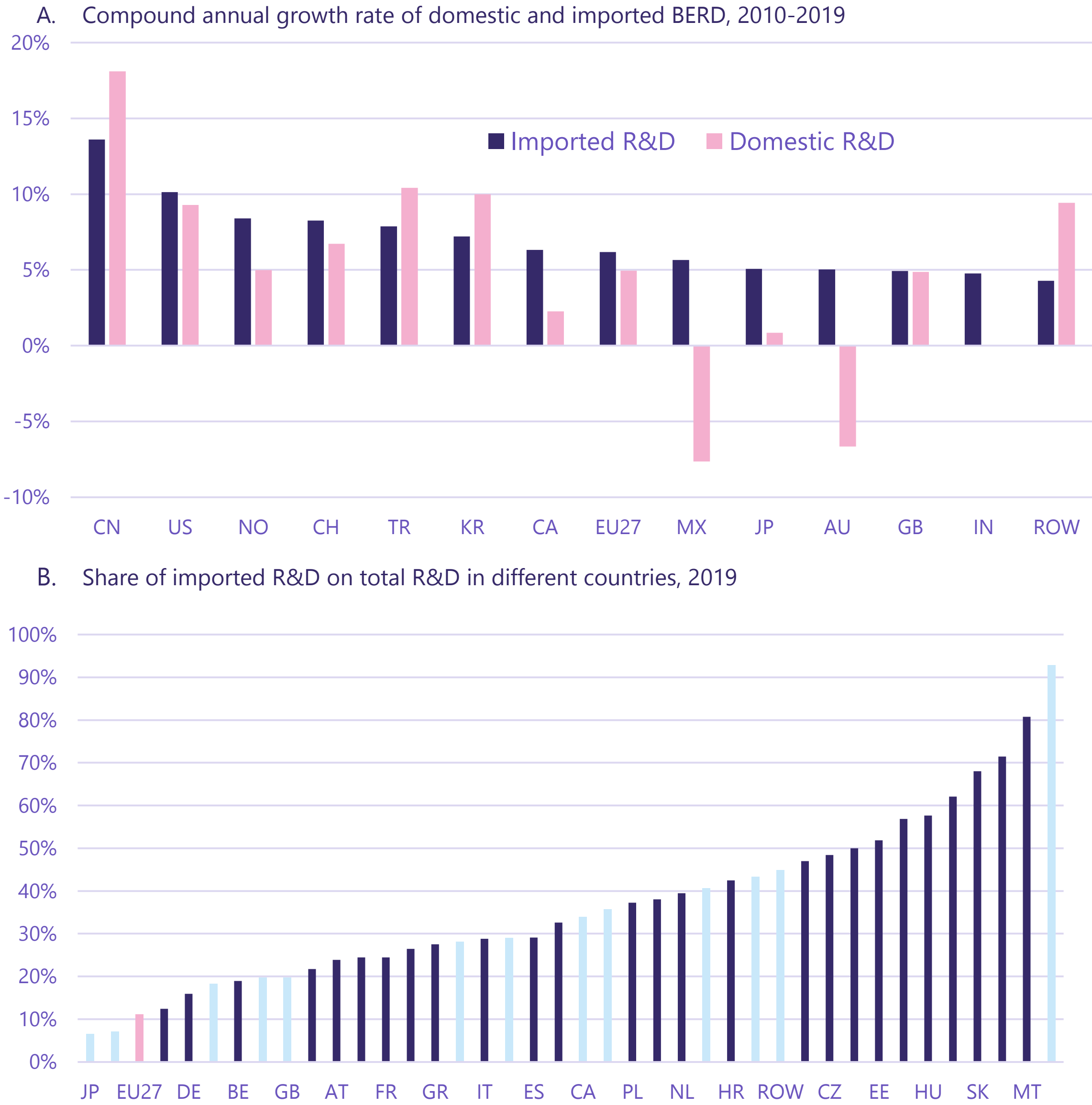


Note: Greece is missing due to lack of data for 2010. Countries in dark blue are EU member states; extra-EU countries are in light blue; aggregates are in pink.
Source: OECD, Eurostat, national statistical offices; own calculations.

[16] *These figures are based on own calculations based on OECD, Eurostat, and national statistical offices.*

R&D and innovation are increasingly traded within GVCs. From 2010 to 2019, there was an increase in imported BERD across all regions of the globe (see Panel A of Figure 14). With the notable exception of the Republic of Korea, in all advanced economies, including the EU27, imported R&D grew faster than domestic R&D. By contrast, in China, domestic BERD grew at almost 20%, while imported BERD at less than 15%. This shows that world economies are highly interlinked when it comes to new knowledge production and China is becoming an increasingly important player, ramping up its R&D efforts. We find enormous heterogeneity across the world in terms of dependence on foreign R&D (Panel B of Figure 14). Dependence is the lowest in Japan, the US, Germany, and the Republic of Korea, where the share of imported over domestic R&D is below 20%. For the EU-27 the dependence indicator is slightly higher compared to the US and Japan. China is also found among the countries with a low dependence. Our research also indicates that domestic R&D capabilities (measured by domestic R&D as a share of gross output) are negatively related to the share of imported R&D. Thus, domestic capacities are a substitute for imported R&D. This suggests that the idea of reducing dependencies by improving domestic capacities, reflected in some recent EU industrial policy documents (European Commission, 2021, 2022), might be supported by empirical evidence. More research is however needed to provide more solid empirical support.

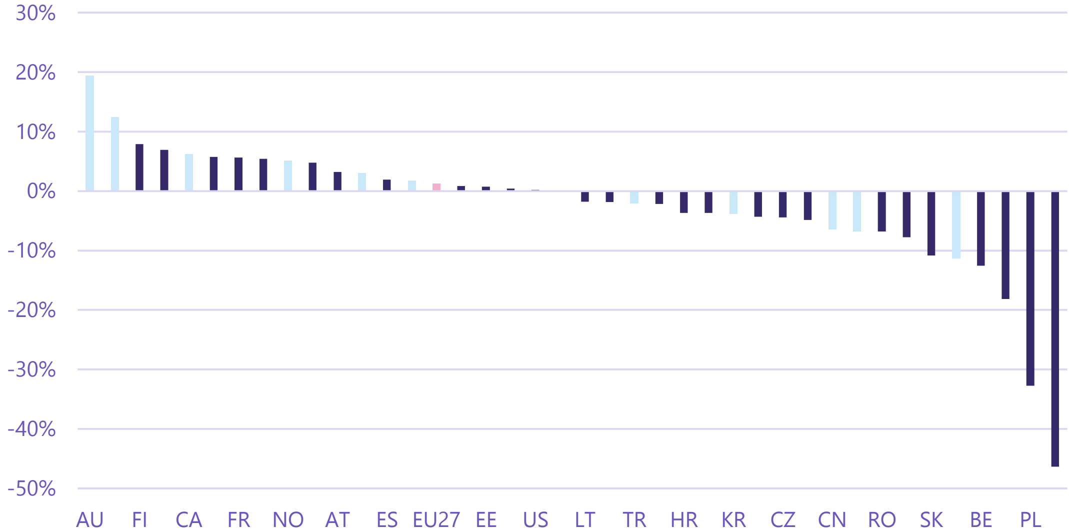
Figure 14: R&D and innovation in GVCs: The role of domestic and imported R&D



Note: In Panel B: Luxemburg is missing due to lack of data. Countries in dark blue are EU member states; extra-EU countries are in light blue; aggregates are in pink.
Source: OECD, Eurostat, national statistical offices; own calculations.

The EU27's dependence on foreign R&D has remained largely constant from 2010 to 2019. The same trends can be observed in Germany and the US (Figure 15). In around half of the countries under analysis, imported R&D made up a higher share of total R&D in 2019 compared to 2010. This indicates that dependence on foreign R&D has increased in these countries. Some examples are Australia and Canada and, in the EU, Finland, the Netherlands, and France. By contrast, newly emerging superpowers, notably China and India, reduced their dependence on imported R&D by almost the same amount as the developed countries. Some member states in Central and Eastern Europe, most notably Bulgaria and Poland, enjoyed the largest drops in dependence, also thanks to their rapidly growing domestic R&D, as shown in Figure 13.

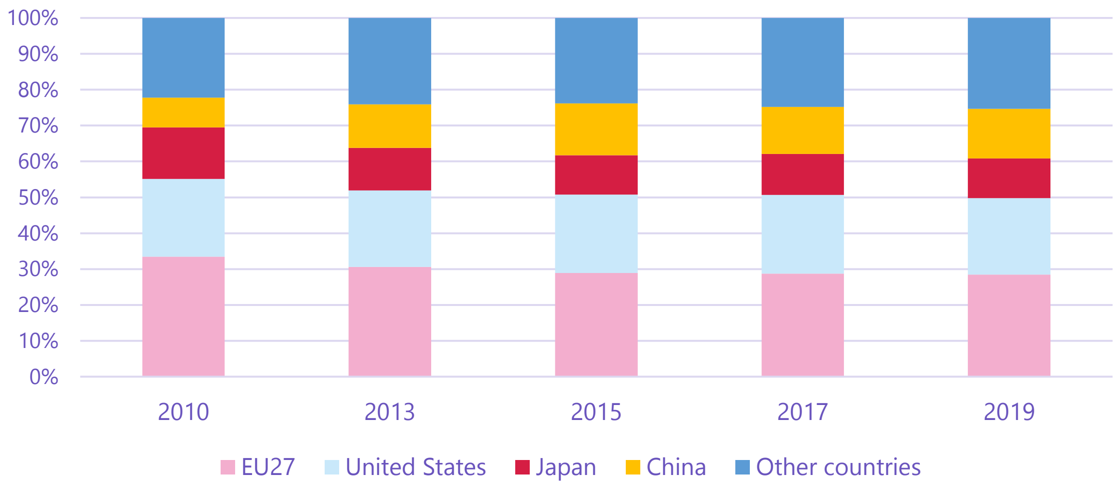
Figure 15: Change in the share of imported over total R&D, percentage points, 2010-2019



Source: OECD, Eurostat, national statistical offices; own calculations.

Overall, the US and the EU contribute the most to global knowledge production. We relate the contributions of individual countries to R&D in GVCs, to the total amount of R&D embodied in these GVCs. The remaining R&D expenditure of countries goes into the production of domestic final goods (Figure 16). What we see from these computations is that: i) the US and EU contribute about 30% each to global knowledge production; ii) the share of China is considerably smaller, albeit increasing (from 8% in 2010 to 14% in 2019); and iii) the combined share of the US and the EU dropped by four percentage points (from 59% in 2010 to 55% in 2019), while the biggest gains were made in China. Indeed, while thirty years ago, most of the global R&D expenditures of firms were concentrated in the US, Europe and to a smaller extent Japan, the rise of emerging economies in Asia has brought de-concentration and new players. Altogether, we see decreasing concentration in R&D supplied into GVCs, which also means that the technological capabilities worldwide are more evenly distributed than 10 years ago.

Figure 16: Share of different countries in total R&D embodied in GVCs, 2010-2019



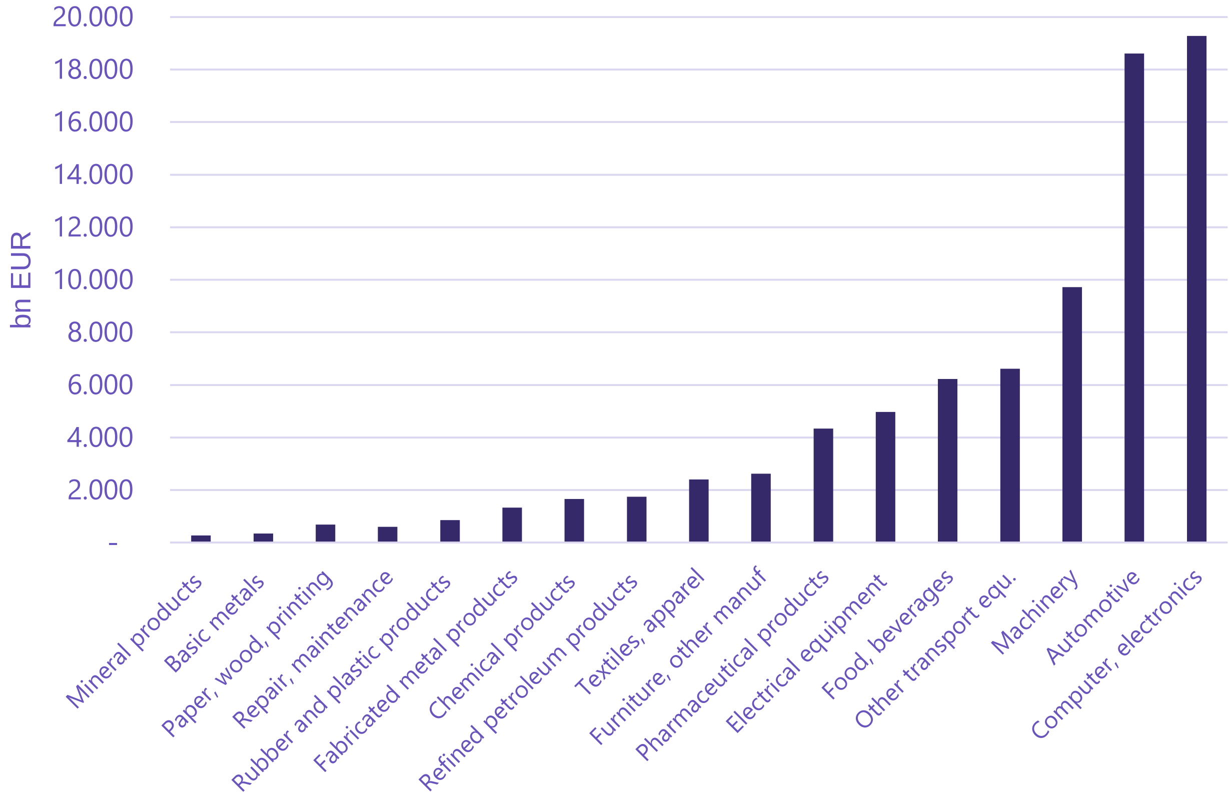
Source: OECD, Eurostat, national statistical offices; own calculations

The issue of R&D dependence can also be analysed from a sectoral perspective, as the dependence of imports is likely to vary greatly by industry, depending on the degree of local capabilities of the EU, the global division of labour in different industries, and the strategies that MNEs put in place in different industries. Figure 17 depicts imported R&D for different manufacturing sectors at the NACE 2-digit level in the EU. The largest dependencies for the EU on imported R&D are found in computers, electronic and optical products, automotive, and machinery. Computers and electronics is also the sector where public concerns about dependence are loudest. These sectors are very R&D intensive, and at the same time highly dependent on foreign knowledge. These results are consistent with other recent empirical evidence showing that the EU lags significantly behind the US and China in these more complex technology fields (e.g., computer technologies, digital communication, audio-visual technologies, optics, telecommunications, and semiconductors) (di Girolamo et al., 2023). Complementarities between R&D in the EU and outside the EU seem to be strong in these sectors, making decoupling a very challenging strategy in these industries. Large dependencies can also be observed for some service industries, including health, trade, transport, or telecommunications. R&D intensity in services is considerably lower in the EU than in the US.

On the other end of the spectrum lie basic industries like mineral products, metals wood, paper and print, and the chemical industry, a technology-intensive sector which has also been identified as strengths of the EU by other studies (e.g. Bykova and Stöllinger, 2023; Cordes et al., 2016; di Girolamo et al., 2023; Pintar and Scherngell, 2021).

Zooming in on the dependencies of the EU on China - a highly debated issue in present days, we find strong technological dependencies in the EU factory economies of Central and Eastern Europe, in particular in Hungary and Czechia. This is unsurprising when we consider the functional specialisations of these countries discussed in Chapter 2.

Figure 17: Imported R&D in the EU27 manufacturing by NACE2 sector, 2019



Source: OECD, Eurostat, national statistical offices; own calculations.

Turning to the role of digital technologies at the firm-level, our research shows that some digital technologies (namely logistics technologies and robots) positively contribute to firms' productivity. More specifically, an increase in one unit of the score of logistics technologies, which indicates a higher adoption rate of these technologies within firms (for details on how we compute these variables see Appendix G), increases turnover per employee by 13%. Similarly, a one-unit increase in the score of robots increases the same indicator by 7.4%. Additive Manufacturing does not show a significant impact on productivity (for technical details, see Appendix H).[17] Moreover, and as expected, an increase in productivity has a positive impact on exports. In particular, an increase of 1% in productivity (as measured by value added per employee) increases export intensity by 1.25% (see Appendix H). Thus, by making firms more productive, digital technologies spur firms' exports. This is particularly true for logistics technologies: as might be expected, logistics technologies are found to have the largest impact on productivity and in turn, on exports. The effect for robots is a little smaller but is still significant and positive. Additive manufacturing, on the contrary, has no significant impact (see Appendix H).

[17] This may be explained by the fact that additive manufacturing is most often used for its flexibility, to produce customized parts in small batches, and has only little impact on production costs, economies of scale, and thus productivity.

Some digital technologies also contribute to higher servitisation, i.e. they help firms create more value by coupling digitally enabled services with physical products. An increase in one unit of the score of logistic technologies, for example, raises the share of service in turnover (see Appendix H). Additive manufacturing and logistic technologies also have a significant impact on the probability to introduce a new service (see Appendix H). These results suggest that a digitalisation strategy may have different impacts depending on the adopted technology. For example, a firm that invests in robots pursues a different strategy to a firm which employs logistic technologies. The former will become more productive in its manufacturing activities, while the latter is likely to be better able to increase its turnover by adding a service component to its physical production.

By allowing firms to offer new services together with their products, digital technologies promote firms' exports. More specifically, our findings indicate that an increase in the probability to introduce new services by one unit increases the probability to export by 0.19 percentage points. The export intensity, meanwhile, rises by 7.8% with a one-unit increase in the probability to introduce new services (see Appendix H). Both additive manufacturing and logistics technologies are found to have a positive impact on service innovation and in turn on export likelihood and intensity. Altogether, these results indicate that digital technologies have a strong role to play in stimulating exports by facilitating the introduction of new service innovations.

Furthermore, digital technologies are positively associated with embeddedness in GVCs. Looking at the role of robots and data analytics, we find a positive and significant relationship between participation in GVCs and the adoption of both these technologies. Furthermore, we analyse the role of both backward and forward participation in GVCs as alternative proxies of GVCs' integration and find particularly strong results for forward participation (see Appendix I for details). Though it remains speculative why this is so, one interpretation could be that pressure from buyers abroad incentivises the adoption of these technologies. Another interpretation could be that these technologies assist organizations in being able to produce for foreign markets. That GVC embeddedness matters is interesting also because it shows that the openness of the sector affects the adoption of digital technologies within firms. These findings also suggest that innovation performance within GVCs is less a matter of incorporating knowledge from suppliers via imports and more of upgrading through exporting and being able to serve the needs of buyers abroad.

Finally, depending on the governance mode adopted, firms can reap even more benefits in terms of innovation by being integrated into GVCs. We study how firms organise the production, design and development of their goods and services in terms of four forms of governance: internalisation, internal collaboration (with establishments within the same company), external collaboration (with other companies), or outsourcing. Our findings show that the relationship between GVC embeddedness and innovation performance is mediated by the governance structure chosen, with the internalisation of the production and development of goods and services being the only positive and significant mediator (see Appendix I). In other words, when organisations internalise their production and development processes, while remaining open to GVCs, they are likely to benefit from this engagement and boost their innovation performance. Their integration into GVCs remains a positive influence on their innovation performance, but these benefits are smaller when they engage in internal or external collaborations or outsource production and development activities. This finding suggests that, although external relationships are particularly important when it comes to GVCs, this is not the complete story. Instead, it is suggested that GVCs governance is essential to understanding innovation effects, and it is vital that organizations develop internal mechanisms (resources and capabilities) to operate in GVCs. Our findings contribute to the literature on GVCs, innovation, and governance, by confirming the role that governance and in-house capabilities play in maximising the returns to participation in GVCs (e.g. Pietrobelli and Rabellotti, 2011; Steinberg et al., 2017).

5. Summary of key findings

The key findings of this report can be summarised as follows:

1. The share of the EU in GVC income has stabilized at about 18% since 2012, while oscillating at around 25% from 1990 to the Global Financial Crisis. Presently, the EU lags behind the U.S and China by a margin of around five percentage points. We find a continuously growing dependence of individual EU countries on foreign demand to generate GVC income in manufactures. All Eastern European countries have increased their share of GVC income over time, at the expense of Western European countries. Still, Eastern European shares remain much smaller than those of Western European countries.
2. Over the past three decades, the EU has been specialising more strongly in vehicles and transport equipment in global comparison. This deepened specialisation is driven in most part by the heightened participation of EU's new member states in these value chains. In terms of activities within the GVC, Western EU countries specialise in pre- and post-production functions, whereas Southern and Eastern EU countries specialise in production, suggesting a regional division of labour within the EU.
3. ICT assets and private R&D expenditures can contribute to the abilities of countries to specialise in R&D activities. In particular, the adoption of various statistical computing software, databases and database management systems can help spur R&D specialisations. At the same time, the positive impact of business R&D expenditures highlights the role of innovation policies for smarter integration in GVCs. These results hold particularly strongly for the less advanced economies of the EU, suggesting ICTs and innovation policies offer a valuable means of breaking away from path dependencies determining functional specialisations.
4. The trade policy regime in which the EU operates has changed quite significantly, especially following the Global Financial Crisis of 2008/09. Furthermore, the failure of the Doha Round and the rise of China also indicates more fundamental long-run structural changes in the global trade and investment regimes. The EU – in line with other main global actors – has moved much more strongly in the direction of bilateral and unilateral agreements, widened its portfolio of trade policy measures and increased its strategic leveraging of trade and investment in a rapidly changing geo-political and geo-economic environment.
5. Our detailed study of the impact of tariff and non-tariff measures (NTMs) showed that NTMs pose a higher challenge to MNEs' subsidiaries' activity and performance than tariffs. High-tech manufacturing subsidiaries are particularly vulnerable to these NTMs, as they suffer higher regulatory losses. However, multinational affiliates that have higher productivity, full foreign ownership, those that are embedded within a larger international network of subsidiaries, and those that are located in trading partners with deep preferential trade agreements can turn these trade challenges to their advantage.

6. Bilateral Investment Treaties (BITs) are a powerful instrument for promoting the expansion of MNEs' activities in less developed and emerging countries, with weak regulatory settings. MNEs are attracted by substantive provisions in treaties that provide greater investment protection, though no clause, *per se*, can condition the effectiveness of the entire treaty. All else being equal, BITs, however, do not seem to be effective at promoting the internationalisation of complex production processes, i.e. those characterising high-tech manufacturing products, and knowledge-intensive services, all else equal.
7. R&D and innovation are increasingly traded within GVCs. From 2010 to 2019, there was an increase in imported BERD across all regions of the globe. In all advanced economies, including the EU27 (and in contrast to China), imported R&D grew faster than domestic R&D. Consequently, albeit remaining by and large constant from 2010 to 2019, the dependence on foreign R&D for the EU27 is slightly higher than in the US and Japan. The largest foreign R&D dependencies of the EU27 are in computer, electronic and optical products, and automotive. Some member states in Central and Eastern Europe experienced the largest drops in dependence. Despite these dependencies, the US and the EU still contribute the most to global knowledge production. Meanwhile, at the global level we see decreasing concentration of the R&D supplied into GVCs, mostly attributable to the rise of China.
8. Digital technologies, and especially logistics technologies and robots, positively contribute to firms' productivity and export performances. More specifically, an increase in one unit of the score of logistics technologies increases turnover per employee by 13%, while a one-unit increase in the score of robots rises the same indicator by 7.4%. By making firms more productive, digital technologies spur firms' exports. This is particularly true for logistics technologies. The effect for robots is a little smaller but is still significant and positive. Some digital technologies also contribute to higher servitisation, and through that, to exports.
9. Digital technologies are also positively associated with embeddedness in GVCs. We find a positive and significant relationship between participation in GVCs and the adoption of robots and data analytics. The relationship between GVC embeddedness and innovation performance is mediated by the governance structure chosen, with internalisation of production and development being the only governance mode contributing positively to new innovations. This finding suggests that GVC governance is an essential factor mediating these relationships and it is vital that organisations develop internal mechanisms (resources and capabilities) to reap the benefit of GVC integration.

6. Conclusions and policy implications

The GVC approach poses a new angle to examine the competitive strength of economies in the global context. Any economic analysis that does not take into account the interdependencies created (and reinforced) by GVCs is bound to provide only a partial picture of global patterns of trade, production, and innovation. As we have shown in this report, recent trends in globalisation have created a fierce competition between firms and countries to capture jobs and income, influenced by evolving trade policies and new technologies.

Our study documents how both production and R&D activities became globalised since the turn of the century, with the latter particularly advancing in recent years. At the global level, the EU has so far successfully retained a strong hold both in terms of shares of income, high-quality jobs (in engineering and pre-and post-production activities), and R&D production. In terms of policy implications, these findings suggest that it is essential for the EU to maintain a firm grip on strategic activities within GVCs to stay at the forefront of technological development and effectively compete with other global superpowers. This is particularly important in some sectors, such as computers, electronics and optical products, and pharmaceuticals, where the EU displays the strongest dependency on foreign knowledge.

Within the EU, R&D activities are a prerogative of the old member states, but less advanced member states stand to gain by upgrading towards R&D-intensive activities within GVCs. While the new data gathered in this report show some dynamism in new member states in terms of higher income shares from GVCs through industrial convergence, high growth of domestic BERD, and shrinking dependence on foreign R&D, more efforts are needed if they are to catch-up with old member states in virtually all these dimensions. Crucially, this also calls for a clear industrial strategy in new member states to tackle the functional divergence that has emerged in the EU, thereby facilitating the diversification away from production and the uptake of R&D and innovation activities within GVCs.

Specialisations across different value chain functions appear to be driven by different forces. Hence, if a country is looking to functionally diversify into a specific task, it is important to understand the key factors influencing that particular specialisation. For countries to specialise more heavily in R&D activities, investments in new digital technologies and domestic knowledge creation can pave the way forward.

The geo-political and geo-economic environment in which the EU operates was changing long before the Covid crisis: with the failure of the Doha Round progress towards multilateral agreements had stalled and the main actors had moved towards bilateral and regionalist trade agreements and unilateral action. The world has moved towards what some authors have called ‘murky protectionism’. The range of trade policy tools has widened considerably, at times moving into the field of industrial policy covering both defensive and offensive aspects. It is likely that this tendency will continue and even deepen following the Covid crisis and increased geopolitical rivalry. The EU as a less effective unitary actor will have to tread a fine line between attempting to keep global international trade and production relations rules-based and relatively open, while also pursuing its own strategic goals in terms of strengthening its technological and industrial capabilities and defending its interests.

NTMs and BITs have powerful effects on international trade and investment relationships. The regulatory impact of NTMs is particularly strong in high-tech manufacturing industries. They have differentiated impacts on MNE affiliates that are higher up the productivity distribution, that are embedded within a larger network of subsidiaries and where the MNE has full ownership over its subsidiaries thereby making conforming to standards easier. Preferential Trade Agreements (PTAs) are very important to counteract the possible negative impact of NTMs on production and export activities of subsidiaries. For EU policies this is important, as including a wider set of economies within a common regulatory context will encourage trade and production linkages within the PTA region.

The research on the impact of BITs suggests that an improved foreign investment environment together with a credible commitment to a high level of investor protection are important to stimulate the formation and consolidation of GPNs driven by EU multinational companies. Hence, the creation of a sound investment environment is a key factor to achieve the so-called Open Strategic Autonomy, which has become one of the priorities of the EU for the coming years. Indeed, investment liberalisation, mainly if combined with trade liberalization, makes GPNs not only more efficient (by reducing the costs of doing business abroad and improving EU firms' competitiveness in international markets), but also more resilient to policy risks and other non-economic shocks. Furthermore, through the implementation of more EU-BITs, the EU can contribute to shaping global rules for a more sustainable and fairer globalisation.

Our findings also indicate that an open investment policy may have heterogeneous effects across regions within the same country with different levels of development. In particular, we found that BITs do not seem to further stimulate the creation and development of GPNs originating from high-income regions. In contrast, our results indicate that the impact of BITs is U-shaped in the other three categories of regions, being positive and significant in low and medium-high income regions but insignificant in medium-low income regions. These non-linearities raise concerns about potential regional disparities. This calls for policy interventions designed to promote and support the internationalisation of local firms in regions which host no or few MNEs.

Our research further shows that while digital technologies generally help economies embed into GVCs, they differ tremendously in their impact potential for functional upgrading, productivity, and trade. Whether firms should invest in one or another digital technology (e.g. robots or additive manufacturing), crucially depends on with the objective of their digitalisation strategy (e.g. efficiency in production, higher servitisation, etc.). As the EU industrial policy places more and more emphasis on digitalisation, a deeper understanding of the impact of different digital technologies is key to developing informed policies and incentive schemes.

Whether countries and firms can benefit from a (smart) insertion into GVCs critically depends on their technological capabilities and innovation efforts: the more they can rely on internal knowledge and complement it with externally produced innovation, the stronger the benefits from GVC integration. To this end, it is paramount that innovation efforts are ramped up and that the right governance mechanisms are in place, ensuring that R&D and innovation are not managed externally to the extent that they create high-risk dependencies.

As this discussion shows, our research contributes to several of the most heated policy debates currently shaping EU policymaking, including on dependencies and technological sovereignty, upgrading in GVCs, and convergence within the EU. In addition, we apply modern econometric techniques that are based on quantitative indicators of policy measures. We also enrich the academic literature on the interplay between GVCs, policies and digital technologies, by providing new data on issues such as the distribution of incomes and jobs within GVCs, specialisations in terms of activities and beyond traditional sectoral analyses, ad-valorem equivalents of NTMs and R&D embodied in GVCs. These data are analysed via state-of-the-art techniques, and with novel methodologies designed in the framework of this project.

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8. Technical appendices

Appendix A: Measuring business functions in global value chains

We follow the approach outlined in Timmer et al. (2013) which is an extension of a standard input-output decomposition technique introduced by Leontief (1949) towards a multi-country setting. Leontief provided a mathematical model which allows one to trace the factor inputs needed in all the stages of production a particular final good. By tracing the value added at all stages of production, it provides an ex-post accounting of the value of final products. This allows one to measure the importance of foreign demand relative to domestic demand for home-country value added growth, in a consistent framework.[18]

We start by assuming that there are N countries, S industries in each country.[19] Output in each industry of each country is produced using domestic production factors (capital and labor) and intermediate inputs, which may be sourced domestically or from foreign suppliers. Output may be used to satisfy final demand or be used as an intermediate input in production, at home or abroad. Final demand consists of household and government consumption and investment.[20] To track the shipments of intermediate and final goods within and across countries, it is necessary to define source and destination countries, as well as source and destination industries.

Let **y** be the output vector of dimension (SNx1), the elements of which represent output levels in each country-industry. We further define a global input-output matrix **A** of dimension (SNxSN) with elements $a_{ij}(s,t) = m_{ij}(s,t)/y_j(t)$, which are intermediate input coefficients. These give the cost shares of output from industry s in country i used by industry t in country j. They are defined as the value of intermediate inputs as a share of gross output by the using sector. The matrix **A** can be written as

$$\mathbf{A} \equiv \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1N} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{N1} & \mathbf{A}_{N2} & \cdots & \mathbf{A}_{NN} \end{bmatrix}, \tag{1}$$

where $\mathbf{A}_{ij}$ is an SxS matrix with typical element $a_{ij}(s,t)$. The sub-matrices on the main diagonal contain the cost shares of domestically produced intermediate inputs, while the off-diagonal sub-matrices contain the cost shares of foreign intermediate inputs. The matrix **A** thus summarizes the input requirements of all intermediate goods across industries and countries. We can use it to rewrite the stacked SN market clearing conditions as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_N \end{bmatrix} \equiv \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1N} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{N1} & \mathbf{A}_{N2} & \cdots & \mathbf{A}_{NN} \end{bmatrix} \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_N \end{bmatrix} + \begin{bmatrix} \sum_j \mathbf{f}_{1j} \\ \sum_j \mathbf{f}_{2j} \\ \vdots \\ \sum_j \mathbf{f}_{Nj} \end{bmatrix} \tag{2}$$

In this expression, $\mathbf{y}_i$ represents the S-vector with production levels in country i, and $\mathbf{f}_{ij}$ indicates the S-vector of final demands in country j for the products of country i. In compact form, this system can be expressed as:

$$\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f} \tag{3}$$

[18] See Miller and Blair (2009) for an elementary introduction into input-output analysis.

[19] We use the term country-industry to denote an industry in a country, such as the Chinese chemicals industry and the German transport equipment industry.

[20] In the input-output tables these final demand categories are separately modelled, but they are taken together for the empirical analysis.

Rearranging (3), we arrive at the fundamental input-output identity:

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \qquad (4)$$

I is an (SNxSN) identity matrix with ones on the diagonal and zeros elsewhere. (**I** - **A**)$^{-1}$ is famously known as the Leontief inverse. It represents the gross output values in all stages of production that are generated in the production process of one unit of final output. To see this, let **z** be a column vector with the first element representing the global consumption of products from the first country-industry, while all the remaining elements are zero. The production of final output **z** requires intermediate inputs given by **Az**. In turn, the production of these intermediates requires the use of other intermediates given by **A(Az)**, and so on. As a result, the increase in gross output in all industries is given by the sum of all direct and indirect effects $\sum_{k=0}^{\infty}\mathbf{A}^k\mathbf{z}$. This geometric series can be rewritten as $(\mathbf{I}-\mathbf{A})^{-1}\mathbf{z}$. This represents the gross output levels in each of the SN industries that are induced by global final demand for the products of the first country-industry.

To measure the value added of activities in the production chain of a particular product, we need to model the production process more explicitly. Let the quantity of output in an industry be a standard function of the quantities of labor, capital and intermediate inputs used. By the usual accounting definition, the value of output of the industry is then equal to the value of all inputs used, and is expressed in dollars in our data. Let $y_i(s)$ be the value of output in industry s of country i, then we can define $l_i^u(s)$ as the value added by workers in activity u (as measured by their labor income plus capital income proportionally allocated) in industry s in country i per dollar output in the industry, and create the column vector $\mathbf{l}^u$ with dimension SNx1 for activity u. Importantly, the elements in this vector are country- and industry-specific[21]. This vector indicates the value added in one particular activity. We define a new matrix $\mathbf{L}^u$ that indicates the value in activity u in each country-sector that is added in all stages of production of a final product. We derive this for a particular product by pre-multiplying the gross outputs needed for production of this product as derived in (4):

$$\boldsymbol{L}^u = \widehat{\boldsymbol{l}^u}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \qquad (5)$$

where a hat indicates a diagonal matrix with the elements of a vector on the diagonal. If the final demand vector **f** is chosen to represent say worldwide final demand for the products sold by the German transport equipment industry, $\mathbf{L}^u$ represents the value added in activity u in each country-industry in the world that contributes to production. Elements in this matrix can be added across industries in a country to arrive at the activity contribution of countries in a particular value chain. By repeating the same decomposition for final demand for all manufacturing products in the world (the SN elements) and for each activity, and then summing across industries within a country provides the distribution of activity value added of a country in manufactures production.

[21] For the US, we use the same data sources as in Autor (2015), namely the 2000 Current Population Census and the annual American Community Surveys, containing industry-level information on around 800 occupations. To match the industries distinguished in the Inter-Country Input-Output Tables, all industry codes are converted into the ISIC rev. 4 classification, using conversion tables from the Bureau of the Census. The National Crosswalk Service Center provides a crosswalk of the SOC occupation codes to ISCO 2008. For Japan, we use detailed five-yearly occupational employment data by industry from the Japan Population Censuses, and derive relative wage data from the wage structure surveys by occupation for the same years. The industries distinguished in the Population Censuses are matched to the ICIOTs, and the occupations in the wage structure surveys are mapped to the occupations distinguished in the Population Census. For the Republic of Korea, we use the annual Korea Labor and Income Panel Study (KLIPS). For China, we obtain occupational employment by industry from the 2000 and 2010 population census. Wages by occupation are from the 2010 IZA wage indicator survey, which appears to be the only source that provides information on wages by occupation in China.

Appendix B: Measuring functional specialisations based on greenfield FDI

We rely on the methodology proposed by Stöllinger (2021), which constructs the 'Relative Functional Specialisation' (RFS) measure based on the number of jobs created by greenfield FDI projects. Following Stöllinger (2021), we obtain data for the RFS calculation from the fDiMarkets database maintained by Financial Times Ltd. This database provides detailed information on cross-border greenfield investment projects, including the destination and origin countries, industry, number of jobs generated by each project, and most importantly, the purpose of the established subsidiary (Table A1).

Table A 1: Purpose of the greenfield investment and function of the value chain

Business function in the fDi markets database	Value chain function
Research & Development	R&D
Design, Development & Testing	
Education & Training	
Manufacturing	Production
Recycling	
Extraction*	

Notes: Extraction activities are only for the chemical sector.

Grouping the projects based on these purposes to arrive at functions, one can intuitively calculate the RFS measure in a methodologically equivalent manner to the Balassa's (1965) Revealed Comparative Advantage index. The main difference here is that the unit of measure is the number of jobs generated by FDI projects, and the categorisation is based on five business functions—namely headquarters, R&D, production, sales, and technical services (see Stöllinger, 2021; Kordalska et al., 2022). We take advantage of the fact that business functions and industrial sectors are fully independent, and hence break down the RFS by the 10 major manufacturing industries, consistent with Stöllinger (2021) (Table A2).

Table A 2: NACE rev. 2 industries included in the analysis

Description Manufacture of:	NACE Rev. 2
food and beverages	10-12
textiles; wearing apparel; leather	13-15
Chemicals	20
Pharmaceuticals	21
non-metallic mineral products, metals and metal products	23-25
computer, electronic and optical products	26
electrical equipment	27
machinery and equipment	28
motor vehicles	29
other transport equipment	30

Formally, the RFS in function f of a country c in industry j can be denoted as:

$$RFS_{c,j}^{f} = \frac{J_{c,j}^{f}/\sum_k J_{c,j}^{f}}{\sum_c J_{c,j}^{f} / \sum_c \sum_f J_{c,j}^{f}},$$

where $J_{c,j}^{f}$ is the number of jobs generated by greenfield FDI projects serving function f in country c and industry j. $\sum_f J_{c,j}^{f}$ is the total number of jobs created by greenfield FDI projects in country c across all functions. The denominator represents the same operation as in the numerator, but for all countries c—in our case, EU-28.

Considering RFS at this level of granularity (i.e., a country-industry panel) would however result in significant volatility and missing observations—after all, one cannot reasonably expect that all EU countries will be able to attract sufficient (or any) FDI projects in each industry in each business function each year. To address this issue, we resort to the calculation of a 'stock-style' RFS measure, whereby the cumulative number of jobs is taken as the basis for the RFS calculations (as done in Kordalska et al., 2022). Furthermore, to make the RFS values symmetric around 0, we normalise the RFS values in an analogous way as done by Laursen (2015).

Appendix C: Econometric analysis of ICT and industrial policy determinants in R&D specialisations

We model specialisations in R&D ($RFS_{jct}^{R\&D}$) in industry *j*, country *c*, and period *t* as a function of past specialisations, ICT capacities, R&D expenditures, and industrial policy efforts. Specifically, we test the following model:

$$RFS_{jct}^{R\&D} = \alpha + \beta_1 \ RFS_{jct-1}^{R\&D} + \beta_2 \ CompHardware_{jct} + \beta_3 \ CompSoftware_{jct} + \beta_4 \ BERD_{jct} + \beta_5 \ StateAid_{ct} + \beta_6 \ GDPpc_{ct}$$

The first explanatory variable ($RFS_{jct-1}^{R\&D}$) is the lagged dependent variable and captures the impact of past specialisations. Controlling for past specialisations is deemed to be particularly relevant in our study, as path-dependence is a salient feature of functional specialisations. *CompHardware* and *CompSoftware* proxy the level of investment in ICT assets and more specifically, in stocks of computer hardware and software. In addition, business R&D expenditures (*BERD*) and *State Aid* (directly or indirectly) reflect business efforts in R&D and industrial policy efforts. Following the extant literature (Kordalska and Olczyk, 2022; Stöllinger, 2021), we control for the levels of socio-economic development as proxied by real GDP per capita in log form (*GDPpc*).

The full model, where all variables are included, is presented in the last column of Table A3 (Model 4). Models 1-3 introduce variables in sequence (first ICT-related variables, then BERD, then State aid, and finally GDP per capita). The variables treated as endogenous are the lagged dependent variable, computer software, BERD, and State aid intensity.[22] To limit the number of instruments, only lags 2 and 3 are used.[23] The number of instruments, the number of country-industry pairs, the p-value of the Hansen-Sargan test as well as the AR(2) test are reported at the end of the table. In all models, the number of instruments is lower than the number of groups, which is in line with the rule of thumb on the number of instruments suggested by Roodman (2009). In Models 1 and 2, the p-values of the Hansen-Sargan test are slightly below 0.1. This is considered acceptable, especially in view of the higher value (0.104) in Model 4. The p-values of the AR(2) tests are above 0.1 (in line with the suggestions by Roodman, 2006, 2009).

[22] To identify endogenous variables, we test the endogeneity of every variable by means of Hausman tests.

[23] This is one of the strategies priposed in the literature to limit the number of instruments and avoid weakening the Hansen test (Roodman, 2009). The choice of these particular lags is in line with extant literature (e.g. Cantore et al., 2017).

Table A 3: Baseline model results

	(1)		(2)		(3)		(4)	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Lag RFS_RD	0.911***	0.015	0.889***	0.019	0.886***	0.019	0.881***	0.021
CompHardware	0.005	0.010	0.003	0.009	0.002	0.007	-0.003	0.007
CompSoftware	0.004***	0.001	0.001	0.002	0.001	0.002	0.000	0.002
BERD			0.001***	0.000	0.001***	0.000	0.001***	0.000
StateAid					-0.026***	0.007	-0.018***	0.007
GDPpc							0.042***	0.012
Constant	-0.013	0.022	-0.016	0.027	0.000	0.028	-0.414***	0.124
Hansen/Sargan test	0.087		0.087		0.061		0.104	
AR(2)	0.452		0.441		0.452		0.456	
N. of obs	3825		3825		3825		3825	
N. of groups	240		240		240		240	
N. of instruments	102		146		190		191	

Notes: * 0.10 ** 0.05 *** 0.01. Two-step GMM with robust standard errors and Windmejier (2005) small sample correction. Time dummies are included but not reported.

In a second stage, we enrich our baseline model to test if and how certain determinants matter more at low levels of development. In particular, we are interested in investigating whether software, BERD, and state aid possess the potential to "create new paths" by enabling countries to specialise in R&D, thus diverging from their conventional specialisations. To this end, we create three interaction terms between our key variables of interest and GDP per capita (*CompSoftware*GDP, BERD*GDP, and Aid*GDP*) and estimate three augmented versions of our baseline model where these interaction terms are plugged into our baseline model one by one. The results of these estimations are reported in Table A4.

Table A 4: Interactions with levels of economic development

	(1) Interaction Computer software & GDP		(2) Interaction BERD & GDP		(3) Interaction State Aid & GDP	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Lag RFS_RD	0.893***	0.022	0.902***	0.019	0.871***	0.022
CompHardware	0.273**	0.124	0.001	0.001	0.000	0.002
CompSoftware	0.002	0.008	0.003	0.005	-0.002	0.009
BERD	0.001***	0.000	0.012**	0.006	0.001***	0.000
StateAid	-0.015**	0.006	-0.013**	0.006	-0.007	0.198
GDPpc * CompSoftware	-0.026**	0.012				
GDPpc * BERD			-0.001*	0.001		
GDPpc * StateAid					-0.002	0.021
GDPpc	0.043***	0.013	0.045***	0.011	0.040*	0.021
Constant	-0.429***	0.133	-0.439***	0.112	-0.397*	0.209
Hansen/Sargan test	0.129		0.112		0.375	
AR(2)	0.430		0.445		0.472	
N. of obs	3825		3825		3825	
N. of groups	240		240		240	
N. of instruments	149		149		149	

Notes: * 0.10 ** 0.05 *** 0.01. Two-step GMM with robust standard errors and Windmejier (2005) small sample correction. Time dummies are included but not reported.

Appendix D: The impact of tariffs and non-tariff measures (NTMs) on MNE subsidiaries' performance

D.1 The estimation of bilateral sectoral time-varying ad valorem equivalents (AVEs) of NTMs

The research on the impact of NTMs on international production networks (IPNs) involved the estimation of annual bilateral AVEs of regulatory NTMs at the six-digit level of the Harmonized System (HS) over the period 1996-2021 follow the methodology proposed by Kee et al. (2008, 2009). However, they estimated the unilateral AVEs of NTMs using a cross-section of bilateral trade data at the six-digit level. Using the bilateral trade data over the period, this paper estimated the time-varying AVEs of TBTs and SPS measures that vary over time and across importer-exporter-products.

Method:

To achieve that goal, we *first* need the bilateral import demand elasticities that vary across importer-exporter-products for the whole period. Import demand elasticates are usually less sensitive to changes in time as they are anchored to consumers' behaviour, which are more consistent over years than the trade impacts of NTMs which may vary over years. Import demand elasticities indicate how much (in percentage terms) the import volume changes when the import price changes by 1%. The bilateral import demand elasticities are taken from Adarov and Ghodsi (2022), which are estimated for the period 1996-2018. *Second*, we need to quantify the impact of regulatory NTMs on the volume of trade in goods at the six-digit level. Because TBTs and SPS measures are heterogeneous regulatory measures that are imposed on various products with different characteristics and specifications, we will need to estimate the average impact of TBTs and SPS measures imposed by all countries in the world on the trade of each six-digit product each year. Therefore, the second stage will estimate the impact of TBTs and SPS measures on the volumes of bilateral trade of six-digit products in each year. The data for the estimation of the impact of NTMs on trade volumes are improved and updated to more recent years for the period 1996-2021. *Third,* we calculate the annual bilateral AVEs of TBTs and SPS measures using the time-invariant bilateral import demand elasticities and the time-variant estimated coefficients of TBT and SPS measures from estimated gravity equations (see next section for details). Thus, the AVEs of NTMs would represent a tariff-equivalent indicator that could be positive like a tariff when it restricts trade, or negative like a subsidy when it promotes trade. In fact, this indicator could tell us how much a supply price of the bilateral goods sold in a particular (host) market would change when the NTM is removed from the bilateral trade flow of that good. The methodology to quantify the impact of NTMs on import volumes are elaborated below.

Using a gravity framework developed by Kee et al. (2009), we estimate the impact of regulatory NTM of type $n \in \{TBT, SPS\}$, on the volume of product h imported to country i from country j in year t as follows:

$$q_{ijht} = exp^{[\beta_{oht}+\beta_{oht1}\ln(1+T_{ijht}) + \sum_n \beta_{n,oht2}NTM_{n,ijht}+\beta_{oht3}X_{it}+\beta_{oht4}X_{jt}+\beta_{oht5}G_{ij}+\beta_{oht6}W_{ijt}]} + \mu_{oijt}, \quad (1)$$
$$\forall h \in HS, \forall t \in \{1, \dots, T\}, \forall i, j \in \{1, \dots i, \dots j, \dots, I\}, n \in \{TBT, SPS\}$$

where q_{ijht} is the volume of product h imported from country i to country j in year t; $\ln(1 + T_{ijht})$ is the log of tariffs in percentages, and they are added to one because they can equal zero for some bilateral trade flows; $NTM_{n,ijht}$ is the stock number of NTMs of type n which refer to either TBTs or SPS measures imposed by the importing country j in force in year t on the import of product h from the exporting country i; X_{it} and X_{jt} include country-level variables for the exporter and the importer, respectively, which has the nominal GDP in US dollars as an indicator of the size of the economy and real GDP per capita as a proxy for the level of development; G_{ij} includes time-invariant gravity variables that comprise geographic distance between the two trading partners, colonial history, common language, contiguity and having been the same country historically; W_{ijt} is a binary variable equal to one when both trading partners are members of the World

Trade Organisation (WTO) in that year; μ_{oijt} is the error term. Following the literature on the gravity frameworks (Santos Silva and Tenreyro, 2006; Head and Mayer, 2014), PPML model is used to estimate this equation which allows us to keep the zero trade volumes and controlling for the heteroscedasticity of the error term. When a regulatory NTM restricts trade, one can expect zero trade volumes. Therefore, excluding such an important observation will lead to biased estimation of NTMs.

Furthermore, NTMs could be usually endogenous in the estimation of imports due to three main reasons. Omitted variable bias, measurement error, and reverse causality are the three sources of endogeneity of NTMs (Ghodsi, 2020). Therefore, an instrumental variable (IV) approach will be applied following the literature (Kee et al., 2009; Bratt, 2017; Niu et al., 2018). Log of exports volumes of product h from country j to country i in year t $(\ln q_{jiht})$[24] and the growth of imported volumes in the previous year $(\Delta \ln q_{ijht-1})$ are the two exogenous variables that would control for the reverse causality bias. To control the bias rooted in the measurement errors, the price-weighted average of NTMs that are imposed across the globe excluding the ones imposed by the importing country is used as the third exogenous instrument. Kee et al. (2009) used the GDP-weighted average of NTMs imposed by several countries that are geographically the most close to the importing country. However, this assumption is relaxed here as distant countries might also impose similar regulatory measures. Furthermore, as quality of traded goods are sometimes affected by regulatory NTMs, price weights are used to construct this measure. Therefore, this instrument $\overline{NTM}^{p}_{jwht}$ for each NTM of type n that is imposed by country j against the import of product h from country i is constructed as follows:

$$\overline{NTM}^{p}_{jwht} = \sum_{i}\sum_{k}\frac{p_{kiht}}{\sum_{k} p_{kiht}} NTM_{n,kiht}\,, \quad k \neq j \ \wedge \ i \neq j \ \wedge \ i \neq k, \qquad (2)$$
$$\forall h \in HS, \forall t \in \{1, \dots, T\}, \forall i, j, k \in \{1, \dots i, \dots j, \dots k, \dots, I\}, n \in \{TBT, SPS\}$$

where p_{kiht} is the unit value of product h in year t imported from country i to country k, which is different from country j that is the importing country in equation (1). Thus, the first-stage equation to estimate the NTM of type n using PPML is as follows:

$$NTM_{n,ijht} = exp^{[\beta_{1ht}+\beta_{1ht1}\ln(1+T_{ijht}) + \beta_{n',1ht2}NTM_{n',ijht}+\beta_{1ht3}X_{it}+\beta_{1ht4}X_{jt}+\beta_{1ht5}G_{ij}+\beta_{1ht6}W_{ijt}+\beta_{1ht7}\ln q_{jiht}+\beta_{1ht8}\Delta \ln q_{ijht-1}+\beta_{1ht9}} + \mu_{1ijt}, \qquad \forall h \in HS, \forall t \in \{1, \dots, T\}, \forall i, j \in \{1, \dots i, \dots j, \dots, I\};\ n, n' \in \{TBT, SPS\}, n \neq n' \qquad (3)$$

When we estimate each NTM type n in equation (3), the NTM of other types n' is also included as the control variable. After obtaining the fitted values $\widehat{NTM}_{n,ijht}$ from equation (3), they will be inserted in the gravity equation as follows:[25]

$$q_{ijht} = exp^{[\beta_{2ht}+\beta_{2ht1}\ln(1+T_{ijht}) + \sum_{n} \beta_{n,2ht2}\widehat{NTM}_{n,ijht}+\beta_{2ht3}X_{it}+\beta_{2ht4}X_{jt}+\beta_{2ht5}G_{ij}+\beta_{2ht6}W_{ijt}]}\mu_{2ijt}, \qquad (4)$$
$$\forall h \in HS, \forall t \in \{1, \dots, T\}, \forall i, j \in \{1, \dots i, \dots j, \dots, I\}, n \in \{TBT, SPS\}$$

where equation (4) and equation (5) are run for each product and each year separately on the global bilateral trade of goods during the period 1996-2021. Since the EU single market has mutual recognition and harmonization of regulatory measures and standards, *intra-EU trade is not included in the sample of estimations*. However, single EU members can still impose NTMs that are independent from the NTMs

[24] As there are zero trade values in export and import quantities, hyperbolic sine transformation of these traded values is used instead of the natural logarithm, which yields asymptotic marginal effects as in natural logarithm (Bellemare and Wichman, 2020).

[25] According to the Sargan test statistics, $E(\widehat{NTM}_{n,ijht}\, \mu_{2ijt}) = 0$. The augmented Durbin-Wu-Hausman test proposed by Davidson and MacKinnon (1993) is used to test the inconsistency of estimating equation 3 without the IV PPML approach. Furthermore, the exogeneity of instruments is additionally tested using the Anderson-Rubin test (Anderson and Rubin, 1949). These test results are available upon request.

imposed by the EU or other members, which apply only third-party countries. Therefore, it is possible that the number of NTMs vary across EU member states. After obtaining the coefficients $\beta_{n,2ht2}$ from equation (4) that are statistically significant at 10% level, and using the time-invariant bilateral import demand elasticities ε_{ijh}, one could calculate the annual bilateral AVE of NTM of type n as follows:

$$AVE_{n,ijht} = \frac{1}{\varepsilon_{ijh}} \frac{\partial \ln(q_{ijht})}{\partial NTM_{n,ijht}} = \frac{e^{\beta_{n,2ht2}} - 1}{\varepsilon_{ijh}} \times 100, n \in \{TBT, SPS\}, i \neq j, \quad (5)$$
$$\forall h \in HS, \forall t \in \{1, \dots, T\}, \forall i, j \in \{1, \dots i, \dots j, \dots, I\}, n \in \{TBT, SPS\}$$

We truncate the resulting AVEs at the extreme values of the distribution (values below -100 at the low end and above 10,000 at the top end of the distribution). This has only a marginal impact on the data as these amount to less than 1% of all estimated AVEs.[26] Furthermore, as equation (4) was estimated using zero-trade flows, these AVEs could be used for both positive and zero-trade flows. As the global bilateral data of traded goods at the six-digit level of the harmonized system including zero-trade flows for the whole period of analysis is enormously large (i.e. with about 6.285 billion observations), the simple averages of these AVEs are used to calculate the AVEs for more aggregated sectors like NACE two-digit industries, which are used in the econometric analysis.

D.2 Estimating the effects of tariffs and non-tariff measures (NTMs) on MNE subsidiaries' performance

We are interested to analyse how the performance of non-service subsidiaries of MNEs respond to trade costs associated with different types of trade policy measures that are affecting the trade patterns between the home country ('home' or 'origin') of the MNE and the host country ('host' or 'destination') of its subsidiaries. We would like to understand how the trade costs related to regulatory NTMs could affect the performance of MNEs and how preferential trade agreements (PTAs) could play a role in that.

Following the literature on gravity models (Head and Mayer, 2014; Yotov et al., 2016) one needs to control for multilateral resistance while studying the bilateral trade or investment relationships. This is usually taken care of by including country-sector-time fixed effects for both trading partners in addition to bilateral sector fixed effects. While tariffs could vary over time by each bilateral sector, regulatory NTMs such as TBTs and SPS measures are usually unilaterally imposed against all exporting countries. Therefore, by including exporter-sector-time fixed effects, these unilateral trade policy measures would be excluded from the econometric analysis. Thus, one needs to find a way to include these unilateral measures in the gravity settings. Furthermore, what matters for MNEs that are heavily involved in the global value chains (GVCs) are the trade costs associated to these regulatory measures rather than their mere existence of proliferation. Thus, one needs to include a measurement on their trade costs that could vary bilaterally over years in each sector. One main way to do this is to estimate the time-varying bilateral ad-valorem equivalents (AVEs) of NTMs, which could differ not only across sectors and importers but also across exporters and over years. While the methodology for the estimation of AVEs of NTMs are elaborated in the sub-section below, the econometric methodology to analyse the performance of subsidiaries of foreign MNEs are explained here. The equation for the estimation of the performance of foreign subsidiaries is as follows:

[26] This is a common practice in the literature. In our case, the threshold level is less restrictive in comparison with the literature. For instance, Bratt (2017) removes about 2% of the estimated AVEs: 1% from the top and 1% from the bottom of the distribution. In our case, the bottom threshold level of -100 is used, as a trade-promoting NTM can reduce the price of an imported good potentially by maximally only 100%. The upper threshold of 10,000 is used to have a comparable number of observations truncated from each side of the distribution.

$$Y_{fgdosrt} = EXP\,[\gamma + \gamma_n \sum_n PTA_{n,dot-1} \times (\gamma_{n,1}\,\mathrm{arc}\,AVE_{n,dost-1} + \gamma_{n,2}\,\mathrm{arc}\,AVE_{n,odst-1}) + \gamma_3\,\mathrm{arc}\,T_{odst-1} + \gamma_4\,\mathrm{arc}\,T_{dost-1} + +\gamma_7 X_{ft-1} + \gamma_8 l_{ft-1} + \gamma_9 GDP^{sim}_{dot-1} + \gamma_{10} HC^{dif}_{dot-1} + \gamma_{11} KL^{dif}_{dot-1} + \gamma_f + \gamma_g + \gamma_{ost} + \gamma_{dst} + \gamma_{dos} + \gamma_{rt}] + \nu_{fgdosrt}\,, \quad \forall t \in \{1, \ldots, T\}, \forall o, r \in \{1, \ldots o, \ldots r, \ldots, I\}, n \in \{TBT, SPS\} \tag{6}$$

where $Y_{fgodsrt}$ is the performance indicator of the subsidiary f in NACE two-digit sector s in destination country d that is owned by the global ultimate owner (GUO) g in sector r that is in the origin country o at time t; the performance indicator could take one of the following variables in each specification: operating revenue (alternatively, turnover[27]) O_{ft}, and labor productivity $prod_{ft}$ (number of employees relative to turnover) of the subsidiaries of foreign MNEs; $PTA_{n,dot}$ indicates the depth of the preferential trade agreement between the two countries d and o with special provisions on NTM type n that is either the TBT or SPS measure. The data on this PTA variable is borrowed from Hofmann et al. (2017), which could take higher values up to 4 (that is the case of EU member states) when more than one agreement is signed between the two countries[28]. $\mathrm{arc}\,AVE_{n,dost}$ is the arcsine transformation of the simple average of AVEs of NTMs of type n in NACE two-digit sector s imposed by country d against the imports of goods at the six digit-level of Harmonized System (HS) from the country o. And, vice versa, $\mathrm{arc}\,AVE_{n,odst}$ is the arcsine transformation of the simple average of AVEs of NTMs of type n in NACE two-digit sector s imposed by country o against the imports of goods at the six digit-level of HS from the country d. Since AVEs could take on zero and negative values, arcsine log transformation is used following the literature (Bellemare and Wichman, 2020; Mullahy and Norton, 2022)[29]. These AVEs are interacted with PTA variables to infer conclusions on the heterogeneity of impacts of NTMs on the performance of subsidiaries with and without PTAs. $\mathrm{arc}\,T_{odst}$ is the arcsine transformation of the simple average tariffs imposed by country o against six-digit products imported in sector s from country d in year t. And, AGAIN, vice versa, $\mathrm{arc}\,T_{dost}$ is the arcsine transformation of the simple average tariffs imposed by country d against six-digit products imported in sector s from country o in year t. As tariffs could be zero for many products and countries, the arcsine transformation is used. X_{ft} is either labor productivity of the subsidiary f in year t when the dependent variable is either turnover or sales, or it is the capital (total assets) to labor ratio of the subsidiary KL_{ft} when the dependent variable is labor productivity of the subsidiary. l_{ft} is the number of employees of firm f in year t that measures the size of the subsidiary. Then, following the literature on Knowledge-And-Physical-Capital model (KAPC) model of Bergstrand and Egger (2007, 2013) extending the knowledge-capital (KC) model of Markusen (2002, 2013) bilateral country variables are included as control variables.

[27] We shall refer to the two alternative variables as proxies for 'output' or 'sales' at times in the following.

[28] When there is no PTA between two countries, the value of this variable should be equal to zero. That is the minimum value of this variable. Therefore, the interaction between the PTA and the NTM variable would suggest that if we want to consider the impact of NTMs for countries without PTAs, we should look at the single coefficient of the NTM, rather than the interaction term. However, the interaction term would hint at the effect of NTMs after the two countries deepen their PTAs.

[29] Tariffs on many products traded between many countries are set to zero under many preferential trade agreements. In addition, some tariffs on some products in some countries are strictly larger than 100 percent. For instance, in 2008, Australia imposed a tariff equal to 5000 percent on imports of 'Tobacco, not stemmed/stripped' from several countries. Or in 2019 South Africa imposed a tariff equal to 5000 percent on the imports of Waters, including mineral waters and aerated waters, containing added sugar or other sweetening matter or flavored from several countries. Therefore, tariffs or AVEs or any other variable that is a continuous variable including zeros need to be transformed using the hyperbolic sine transformation as the literature recommends, which gives a better estimate as the logarithmic form of the variable plus one.

GDP_{dot}^{sim} is similarity in size of the two countries is calculated as follows:

$$GDP_{dot}^{sim} = log\left[\left(\frac{GDP_d}{GDP_d + GDP_o}\right) \times \left(\frac{GDP_o}{GDP_d + GDP_o}\right)\right] \quad (7)$$

When country d and o are identical in size, similarity is maximized ($GDP_d = GDP_o \leftrightarrow GDP_d = \frac{1}{2} \times (GDP_d + GDP_o) \leftrightarrow GDP_{dot}^{sim} = \frac{1}{4}$); HC_{dot}^{dif} is the logarithm of absolute value in the difference in human capital of both countries; and KL_{dot}^{dif} is the logarithm of absolute value in the difference in capital to labour ratio of both countries in year t; The data on these country-level variables are collected from the 2021 edition of Penn World Table 10.0[30] provided by Feenstra et al. (2015). Using these country-country level variables one can identify the dominance of horizontal versus vertical FDI in the data. For instance, a positive and significant coefficient of size similarity in GDP indicates the dominance of market seeking and horizontal FDI (as countries of similar size might have stronger commonalities in terms of 'taste formation', as a reminder of the Linder hypothesis; Linder, 1961). A positive and significant coefficient of difference in the physical capital to labour ratio shows the dominance of vertical FDI due efficiency seeking (comparative advantage based on factor endowment differences) motives. Similarly, a positive and significant coefficient of difference in human capital shows the dominance of vertical FDI between knowledge-intensive headquarters and subsidiaries (of course, there could also be 'horizontal' skill differentiation effects when MNCs try to complement their own host-situated human capital with human capital situated in other countries; this leaves scope to interpret the results obtained).

Furthermore, γ_f and γ_g respectively control for subsidiary and owner fixed effects; γ_{ost}, γ_{dst}, and γ_{dos} are origin-sector-time, destination-sector-time, and bilateral sector fixed effects that are controlling for multilateral resistance terms in trade policy measures following the gravity literature (Head and Mayer, 2014; Yotov et al., 2016); and γ_{rt} is the owner's sector-time fixed effects that control for technological change in the sectors of the foreign owners. Furthermore, one could think of the endogeneity bias caused by the PTA or the trade policy variables. However, as Baier and Bergstrand (2007) analysed the endogeneity of PTAs in gravity models, and as Yotov et al. (2016) also note, one major solution to control for the endogeneity of PTAs or trade policy measures in the panel data is to use either first-differencing bilateral flows or bilateral fixed effects. Therefore, using the bilateral fixed effects in equation (1) will control for the endogeneity bias of the trade policy measures. Furthermore, the choice of the one-lag dependent variables would additionally eliminate the reverse causality. As the dependent variables include both positive and zero values, the Poisson pseudo-maximum-likelihood (PPML; Santos Silva and Tenreyro, 2006; Head and Mayer, 2014) will be used that is also robust against heteroscedasticity in the error term.

The benchmark specification in equation (1) will be run on the whole sample of subsidiary-owner relationships for non-services subsidiaries that are owned directly or indirectly by the foreign owner. Major ownership (i.e. more than 50.01%) is considered here. As a robustness check, the specifications are run on the sample of subsidiary-owner relations with 100% ownership (directly or indirectly). Further, robustness checks are run excluding the subsidiaries in Offshore Financial Centres (OFCs). However, since the estimations include the number of employees of subsidiaries, all offshore accounts or special purpose vehicles without employees are not included in the benchmark specification either. Additional estimations are undertaken on the sample of high-tech manufacturing which includes NACE two-digit sectors 21, 26, 30.3 which are respectively 'Manufacture of basic pharmaceutical products and pharmaceutical preparations', 'Manufacture of computer, electronic and optical products' and 'Manufacture of air and spacecraft and related machinery' A further additional analysis is undertaken to check the differentiated impacts of trade costs on firms located

[30] https://www.rug.nl/ggdc/productivity/pwt/?lang=en

across a productivity level distribution: here, the main NTM variables will be interacted with the labour productivity of subsidiaries to utilise the heterogeneity of firms (Melitz, 2003) and the implications for the impact of trade costs across the productivity distributions. Moreover, one can argue that the size of the MNE network may represent the scope and scale of capabilities to counter regulatory costs. An MNE that has subsidiaries in many countries may be better equipped with regulatory compliance as the amount of knowledge and intangible assets of firms make it easier to know about diverse regulations and standards. Therefore, in a further analysis, a new variable NW_g is generated as the number of subsidiaries in the network of a GUO and it is interacted with the NTM variables.

D.3 Results from the econometric estimations of the effects of tariff and non-tariff measures on MNE subsidiaries' performance characteristics

Our first set of results refers to the entire sample of multinationals operating in all non-service sectors. In this part we also investigate the role of productivity and network size in how multinationals react to trade barriers. The second set of results refers to high-tech multinationals, which are an important source of growth in the midst of the digital transition and the fourth industrial revolution.

Each set of results represents the estimation on two samples: 1) the entire sample of (high-tech) firms and 2) the sample of firms that are 100% foreign owned (instead of firms with at least 50.01% foreign ownership stake). As explained, we investigate two issues: how (a) multinational firms' production performance (as represented by turnover and sales) and (b) efficiency (as represented by labour productivity) vary with respect to various trade policy measures such as tariffs and NTMs. We lag the explanatory variables assuming that trade policy measures take time to affect MNEs' affiliates abroad. For robustness check, we exclude multinationals operating in offshore financial centres (OFC) which attract mainly conduit FDI. These investors, led by short-term financial motives, can hinder the real picture of cross-border investment.

The results reveal that multinationals' output and productivity performances are sensitive to changes in tariffs and non-tariff barriers, the latter having statistically and economically more significant effects. The high-tech sector is more sensitive to changing trade policy measures than the rest of the non-service sector, which has important economic implications. Multinational affiliates that are fully foreign-owned, more productive and those that operate in a wider international network of subsidiaries are more resilient to changing trade barriers. Furthermore, participation in a PTA significantly adjusts the impact of NTMs in a positive direction.

The effects of trade policy measures on non-service multinationals firms

Table A5 presents the first set of results referring to the two defined samples. Panel I of Table A5 presents the results for major ownership of subsidiaries (50.01+), while panel II of this table presents the results for the subsidiaries that are fully owned by the foreign GUO. The results reveal that different trade policies affect multinational firms' turnover/sales performance differently and these impacts are in turn differentiated given the productivity levels of the subsidiary, which supports the literature on heterogeneous effects from different policy tools (Ghodsi and Stehrer, 2022). Traditional policy barriers in the form of tariffs - levied by home or host economies - do not seem to affect multinational firms' performance abroad. On the other hand, the FDI performance (sales) is positively (and marginally) affected by tariffs imposed by the host economy, suggesting that production abroad by multinationals gets encouraged when facing higher tariffs in the host economy. This behaviour supports the 'tariff-jumping' motive behind setting up subsidiaries. We also see that the greater effect on FDI firms stems from non-tariff barriers, in line with the growing economic importance of these measures (Adarov and Ghodsi, 2023; Ghodsi and Stehrer, 2022; Ferrantino, 2016; Laget et al., 2021).

Table A 5: PPML results: entire sample of non-service MNEs

	I			II		
	Base regression			(sample of 100% foreign-owned firms)		
Dependent variable:	o_{ft}	s_{ft}	$prod_{ft}$	o_{ft}	s_{ft}	$prod_{ft}$
$PTA_{TBT,dot-1}$	0.13	1.13***	0.26	-0.051	-0.055*	-0.25
	-0.15	-0.09	-0.17	-0.13	-0.031	-0.2
$\text{arc}\,AVE_{TBT,dost-1}$ (d against o)	0.021	-0.064	0.04	0.15	0.12	-0.91**
	-0.083	-0.084	-0.25	-0.12	-0.12	-0.36
$\text{arc}\,AVE_{TBT,odst-1}$(o against d)	-0.18**	-0.26***	0.05	-0.41**	-0.34*	-0.99*
	-0.087	-0.096	-0.24	-0.17	-0.2	-0.51
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,dost-1}$	0.016	0.11	-0.74**	0.038	-0.0063	1.00**
	-0.13	-0.16	-0.33	-0.16	-0.18	-0.39
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,odst-1}$	0.32***	0.45***	0.29	0.76***	0.61***	1.08**
	-0.11	-0.11	-0.24	-0.21	-0.23	-0.49
$PTA_{SPS,dot-1}$	-0.19	-1.21***	-0.19	0.011		0.19
	-0.15	-0.088	-0.15	-0.13		-0.17
$\text{arc}\,AVE_{SPS,dost-1}$ (d against o)	-0.14	-0.14	0.18	-0.39*	-0.33	0.057
	-0.14	-0.14	-0.38	-0.24	-0.21	-0.62
$\text{arc}\,AVE_{SPS,odst-1}$(o against d)	-0.35***	-0.44***	-0.78*	0.33	0.32	0.35
	-0.13	-0.15	-0.43	-0.21	-0.23	-0.57
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,dost-1}$	0.44*	0.17	0.066	0.52	0.6	0.04
	-0.22	-0.28	-0.51	-0.35	-0.37	-0.63
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,odst-1}$	0.74***	0.63***	0.85	0.45	0.19	-2.17**
	-0.23	-0.23	-0.54	-0.36	-0.35	-0.88
$\text{arc}\,T_{odst-1}$ (o against d)	0.12	0.14	0.19	0.66***	0.58**	2.36***
	-0.081	-0.12	-0.14	-0.24	-0.27	-0.58
$\text{arc}\,T_{dost-1}$ (d against o)	0.20*	0.23	0.25	-0.24	-0.44	0.42
	-0.11	-0.21	-0.49	-0.26	-0.5	-0.6
$prod_{ft-1}$	0.35***	0.35***		0.42***	0.41***	
	-0.031	-0.03		-0.023	-0.024	

l_{ft-1}	0.39***	0.39***	0.19***	0.44***	0.44***	0.095
	-0.032	-0.029	-0.036	-0.023	-0.025	-0.063
GDP^{sim}_{dot-1}	0.13**	0.30***	0.19	0.21**	0.22**	-1.00**
	-0.062	-0.067	-0.31	-0.11	-0.11	-0.5
HC^{dif}_{dot-1}	0.0092	0.0044	0.028*	0.018	0.020*	0.079***
	-0.0063	-0.007	-0.016	-0.011	-0.011	-0.02
KL^{dif}_{dot-1}	0.00099	0.0012	-0.041***	0.0046	-0.0066	-0.069***
	-0.0042	-0.005	-0.01	-0.0067	-0.0085	-0.017
KL_{ft-1}			0.080***			-0.023
			-0.029			-0.061
Constant	14.7***	15.1***	16.6***	13.5***	13.8***	15.8***
	-0.61	-0.59	-0.96	-0.51	-0.52	-1.64
Observations	165262	112288	156614	64785	44165	60841
Pseudo R-squared	0.989	0.989	0.97	0.988	0.988	0.963
AIC	1.17E+12	7.55E+11	4.34E+10	3.52E+11	2.55E+11	1.74E+10

Robust standard errors in parentheses; *** p<0.01; ** p<0.05; * p<0.1

NTMs in the form of TBTs and SPS measures have an important effect on the production and efficiency of multinational affiliates abroad. Yet, a significant difference exists with respect to whether NTMs are imposed in the home or in the host economy from the investor's point-of-view. The size of the coefficients reveals that NTMs imposed by the home (origin) economy against the host (destination) economy have a more significant effect on multinational affiliates' performances. This seems to indicate that exporting activities of MNE's affiliates to the home countries are significantly affected by NTMs levied on the host economy. This can be interpreted as evidence that supports the presence of export-platform FDI (i.e. supplying goods or inputs to the MNE's home base), suggesting that a significant share of foreign subsidiaries' activities are based on exporting, which is why TBTs levied on the host economy negatively affect subsidiaries' performance, as lead to a cut in revenues from exporting (Ekholm et al., 2007).

TBTs and SPS measures imposed by the home economy exert negative and significant effects on subsidiaries' performance (operating revenue and turnover), possibly resulting from lower exports to the home countries abroad and thus leads to loss of revenues/turnover from these activities. This negative effect on subsidiaries' performance also could imply lower vertical integration along the host-home economies' value chain, due to higher NTMs.

Interestingly, the size of the negative effect of SPS on the production performance of subsidiaries in the host economy is twice as high as that of TBTs.[31] This implies that higher-value exports (on which SPS are usually imposed) are even more affected due to higher bio or hygiene requirements on imports. As countries that produce already in line with the SPS measures should not be affected by these changes in regulatory NTMs, one can conclude that the countries where MNC subsidiaries operate, are in the majority non-compliers of imposed measures and have less capacity to cope with the standards (Ghodsi and Stehrer, 2022). The evidence points at the restricting impact on global value chains of increased imposition of SPS measures, in line with other empirical evidence (Beghin et al, 2015).

The effect of TBTs and SPS measures is, however, positive among those countries that have preferential trade agreements with TBTs or SPS provisions, respectively, both being relevant for FDI (Laget et al., 2021). Under these PTAs, home and host economies have more aligned non-tariff policies inducing production in the host economy. This effect seems to counteract the negative effects of NTMs imposed by the home country against the host country disincentivising supply chains. These results are in line with the growing literature on PTA's effects on FDI (Medvedev, 2012; Bacinni et al., 2017; Laget et al, 2021). Laget et al. (2021) show that increasing the scope of PTAs coverage increases FDI by 1.4%.

TBTs and SPS measures imposed by the host (destination) economy (against the home economy), do not significantly affect the performance of subsidiaries abroad (in the host economy). They will only negatively affect productivity if the home and host economies have preferential trade agreements with TBT provisions. This could be following the model description à la Melitz (2003) that larger trade costs keep the most productive firms in the market increasing the productivity threshold, while lower trade costs induced by PTAs could reduce the productivity threshold of exporters, leading to lower productivity of subsidiaries in the sample. The insignificant effect on firm performance (sales and turnover) but impacting negatively efficiency (labour productivity) points to the mechanism via which TBTs affect firm performance - via imports of inputs. Importing goods from home countries can raise the costs of the material inputs due to higher trade costs associated with NTMs facing them. The results show that sales (revenue and turnover) of MNEs' affiliates are not affected, yet higher importing costs of inputs (and reducing the sourcing of – quantity and variety of - inputs from abroad) reduce firm efficiency. Possibly, many of the MNCs' affiliates have well-established supply chains in a FDI host economy with the home economy). Therefore, they rely on the foreign supply chain, including that of the home economy, because foreign suppliers meet better their quality standards.

As for the control variables, they fully support previous research by Bergstrand and Egger (2013). Larger subsidiaries are more productive and have higher sales. The similarity in the home and host countries' GDPs (market size) matters for foreign direct investment decisions and thus for production/sales and productivity (scale effects) abroad; we referred here to the Linder effect (similarity of demand structures in similarly sized economies). Home and host country human capital differences, on the other hand, do not affect multinational productions abroad, but they do affect significantly and positively their productivity. This is in line with the theory of relative backwardness (Findlay, 1978) suggesting (although in the context of technologies) that the greater the technology gap between countries the greater the scope for knowledge diffusion and the faster catching-up rate. Hence, stronger impact on productivity due to a higher human capital gap could indicate faster catching-up process due to knowledge transfers between the home (headquarters) and host (affiliates) economy. The negative effects from capital-labour differentials on productivity, on the other hand, implies different production processes being used in the home and host economies (capital intensive vs labour intensive); consequently the traditional neoclassical (Solovian) growth

[31] One should also note that these are marginal effects as the variables of AVEs of NTMs are in logarithmic forms, which makes their magnitudes comparable.

model can be referred to in that the bigger the gap in in capital-labour endowments between home and host economy, the bigger also the gaps in labour productivity levels of subsidiaries in the host economy.

The effects on fully foreign-owned MNEs

An alternative analysis is undertaken on the sample of the fully foreign-owned (100%) multinationals, which account for less than 40% of the entire sample as the majority of MNEs' affiliates (60%) are established as joint ventures or through mergers and acquisitions with lower shares. The estimation results are presented in panel II of Table A5. This can affect the nature of the subsidiary's decision-making regarding trade policy measures. Mainly because MNEs' headquarters have a stronger say in the decision-making process of subsidiaries in the host economy if it is fully foreign-owned (Guar et al., 2019). These subsidiaries also tend to have superior knowledge protection to joint ventures (Javorcik and Saggi, 2010), as they choose their entry strategy to protect their intellectual property from leaking. As a result, they may produce higher value-added output and have an advantage in exporting too. Fully foreign-owned firms may also benefit financially from their headquarter in the home economy, which gains importance in the wake of adverse events (Vujanovic et al. 2021b). On the other hand, firms with some domestic ownership are likely to be better linked with the home supply chain and depend less on the supply chain of the home country.[32] These factors altogether can lead to different responses to trade policy measures. Our results confirm that.

The results show that the significance of the effects from TBTs is higher on this shrunk sample, but the effects from SPS measures is lower. In other words, TBTs imposed by the home economy against the host economy lower sales (revenue and turnover) even more when a subsidiary is missing domestic representation. Evidently, exporting activities are the dominant income source of MNEs' affiliates (which is why TBTs affect them greatly), strengthening our hypothesis regarding export-platform FDI or vertical integration. Partially foreign-owned subsidiaries are more likely to base their sales also on the domestic market and thus counteract better the negative impact from TBTs, as borne out by the smaller size of the negative coefficient. The effect turns positive for countries that have PTAs, and the size of the effect is again larger than in the base sample, further showing the importance of abolishing TBTs for export activities.

On the contrary, SPS measures affect neither the output nor productivity of fully foreign-owned subsidiaries possibly because these MNEs already comply to phytosanitary conditions in their main markets even prior to the imposition of further measures over the estimation period. It is also important to note that SPS measures are highly concentrated in particular industries. As explained, fully foreign-owned firms tend to have superior knowledge that they create through internal R&D (within a subsidiary) and not only sourced from their headquarters (Guar et al., 2021), allowing them to service products that are aligned with the quality (bio and hygiene) standards.

Tariffs imposed by the home economy on the host economy affect positively the sales (revenue, turnover) and productivity of fully foreign-owned subsidiaries. This differs from the sample when we included firms with heterogenous ownership structures, in which case the positive and significant effect fades. The results imply that as local firms reduce their exports, fully foreign-owned multinationals can then increase their exports because they gain market shares in their country of origin. Greater market shares gained this way counteract the losses incurred from increased tariffs that the home country imposes. The results together show that the interplay between MNEs and local firms in the host economy has an important effect on the export performance when tariffs increase, as the former are likely to have a competitive advantage.

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[32] Empirical evidence finds that foreign firms do not always source inputs locally, as local supplies do not meet the quality requirements necessary for the MNE's affiliate production (Damijan et al. 2013; Merlevede et al., 2014).

The role of MNE subsidiaries' productivity

It is widely known that multinationals are more productive than domestic firms due to various factors, such higher R&D investment, innovation capacity, access to finance, know-how, better technology (Dunning and Lundan, 2008). However, productivity heterogeneity also exists amongst the MNEs and then amongst subsidiaries of these MNEs, depending on differentiated technology know-how of the MNE (or GUO) itself which they can pass on to their subsidiaries; these might be more or less relevant depending on the host country or the industry in which they operate (Yang and Driffield, 2022; Kafouros et al, 2012). Traditionally MNEs centralised their R&D activities in their home country, but in the post-World War II period they started decentralising it in developed economies and more recently, in the 21st century, in emerging markets (Belderbos et al. 2013; Egan 2017). In addition, not all innovative activities of MNEs affiliates relate to R&D. Some innovations (specifically in product specifications) are conducted to conform to the requirements of the respective markets and thus do not necessarily take the form of R&D but involve less demanding innovative activities (Vujanovic et al., 2022). All these factors affect productivity of MNEs' affiliates and can to a large extent determine their resilience to trade shocks resulting from rising trade barriers.

We hypothesise that MNEs' affiliates with higher levels of productivity/efficiency are better positioned to deal with the impact of higher trade barriers. To test this hypothesis, we interact NTM variables with labour productivity levels of the subsidiary and find that more productive firms indeed can more easily absorb the trade shock following the imposition of stronger NTMs. The results are presented in Table A 6. Higher productivity subsidiaries show better output performances (operating revenues and turnover) when facing increasing trade costs associated with the TBTs imposed by the home against the host economy when the two countries do not have bilateral PTA with TBT provisions. Just like in the case of foreign owned firms, higher productivity subsidiaries gain more in revenue (and in this case this may come from exports to the home economy), despite increasing trade costs. This is because they can gain market shares at the cost of other (less productive) firms. When two countries have PTAs with TBT provisions, it is the lower productive firms that can gain from TBTs imposed by origin (home) against the destination (host). This makes sense as PTAs are designed to allow lower productive firms to remain in the market (Melitz, 2003). More productive multinational subsidiaries, however, maintain a marginally better position withstanding rising trade costs related to SPS measures, as they increase sales when facing SPS measures levied on the home economy. Again, for countries with PTAs with SPS provisions, the less productive firms gain in sales and revenues with larger trade costs of SPS measures. This again suggests that such PTAs enable low productive firms to survive in the market that is covered by costly SPS measures. These results confirm the importance of interplay between different types of companies (higher/lower productivity companies) when it comes to exposure to higher trade barriers.

Table A 6: PPM results: non-service multinationals and the effects of NTMs with productivity heterogeneity

Dependent variable:	O_{ft}	S_{ft}
$prod_{ft-1}$	0.35***	0.35***
	(0.030)	(0.028)
$PTA_{TBT,dot-1}$	1.31***	2.00***
	(0.44)	(0.33)
$\mathrm{arc}\,AVE_{TBT,dost-1}$ (d against o)	0.67	1.15
	(0.66)	(0.74)

$\text{arc}\,AVE_{TBT,odst-1}$(o against d)	-1.20**	-1.51***
	(0.53)	(0.57)
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,dost-1}$	-2.37**	-2.10
	(1.21)	(1.58)
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,odst-1}$	1.54**	2.08***
	(0.66)	(0.77)
$PTA_{SPS,dot-1}$	-1.04**	-1.74***
	(0.44)	(0.33)
$\text{arc}\,AVE_{SPS,dost-1}$ (d against o)	-1.44	-1.99*
	(0.88)	(1.02)
$\text{arc}\,AVE_{SPS,odst-1}$(o against d)	-0.23	-0.36
	(0.48)	(0.50)
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,dost-1}$	-2.12	-2.83
	(1.91)	(2.76)
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,odst-1}$	4.04**	13.0***
	(1.95)	(4.22)
$prod_{ft-1} \times PTA_{TBT,dot-1}$	-0.14***	-0.098**
	(0.040)	(0.039)
$prod_{ft-1} \times \text{arc}\,AVE_{TBT,dost-1}$ (d against o)	-0.068	-0.13
	(0.070)	(0.079)
$prod_{ft-1} \times \text{arc}\,AVE_{TBT,odst-1}$(o against d)	0.11*	0.14**
	(0.058)	(0.063)
$prod_{ft-1} \times PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,dost-1}$	0.25*	0.23
	(0.13)	(0.17)
$prod_{ft-1} \times PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,odst-1}$	-0.13*	-0.18**
	(0.072)	(0.085)
$prod_{ft-1} \times PTA_{SPS,dot-1}$	0.10***	0.062
	(0.040)	(0.039)
$prod_{ft-1} \times \text{arc}\,AVE_{SPS,dost-1}$ (d against o)	0.15	0.21*
	(0.10)	(0.12)

$prod_{ft-1} \times \text{arc}\, AVE_{SPS,odst-1}$(o against d)	-0.015	-0.013
	(0.053)	(0.055)
$prod_{ft-1} \times PTA_{SPS,dot-1} \times \text{arc}\, AVE_{SPS,dost-1}$	0.29	0.35
	(0.22)	(0.32)
$prod_{ft-1} \times PTA_{SPS,dot-1} \times \text{arc}\, AVE_{SPS,odst-1}$	-0.37*	-1.40***
	(0.22)	(0.48)
$\text{arc}\, T_{odst-1}$ (o against d)	0.12	0.14
	(0.081)	(0.12)
$\text{arc}\, T_{dost-1}$ (d against o)	0.25**	0.32
	(0.11)	(0.21)
l_{ft-1}	0.39***	0.39***
	(0.032)	(0.029)
GDP^{sim}_{dot-1}	0.14**	0.31***
	(0.061)	(0.065)
HC^{dif}_{dot-1}	0.0099	0.0041
	(0.0063)	(0.0070)
KL^{dif}_{dot-1}	0.00017	0.00044
	(0.0042)	(0.0050)
Constant	14.7***	14.7***
	(0.60)	(0.60)
Observations	165262	165262
Pseudo R-squared	0.989	0.989
AIC	1.16551e+12	1.16551e+12

Robust standard errors in parentheses; *** p<0.01; ** p<0.05; * p<0.1

The role of multinational network size

The size of the multinational network can be an important cause for productivity differences between multinationals and their respective subsidiaries. Kafouros et al. (2012) find that the productivity differentials of MNEs depend on how well they benefit from the so-called global ‘knowledge reservoirs’ of their subsidiaries abroad, especially in relation to technology and, vice versa, how subsidiaries benefit from the wider ‘knowledge pool’ but also from economies of scope and scale they can draw on when they are linked to a wider network. MNEs that spread their operations across many international markets will benefit more from intra-MNEs knowledge exchange than those that have concentrated activities in a few locations. Moreover, MNEs tend to decentralise their R&D activities abroad too, thereby exploiting benefits from location-appropriate comparative advantages, and from diversification and specialisation processes (Noailly and Ryfisch, 2015). Thus, MNEs' network size can be a significant factor to show resilience in the wake of restrictive trade policies. In addition, affiliates embedded within a larger MNEs network may have greater financial resources to deal with external trade shocks.

To understand what role the size of the MNE's network plays we augmented the base regression (Table A5), regression set I) by adding the variable on the MNEs network size (number of subsidiaries) which we interact with NTM variables. The results are presented in Table A7.

Table A 7: PPML results: the role of MNEs network size

	Non-service firms		
	Op. Revenue	Turnover	Productivity
$\mathrm{arc}\,AVE_{TBT,dost-1}$ (d against o)	-0.068	-0.045	0.14
	(0.089)	(0.098)	(0.26)
$\mathrm{arc}\,AVE_{TBT,odst-1}$(o against d)	-0.37***	-0.39***	0.47
	(0.12)	(0.14)	(0.31)
$\mathrm{arc}\,AVE_{SPS,dost-1}$ (d against o)	-0.022	0.028	0.39
	(0.15)	(0.15)	(0.36)
$\mathrm{arc}\,AVE_{SPS,odst-1}$(o against d)	-0.38**	-0.55***	-1.67***
	(0.15)	(0.17)	(0.52)
$NW_g \times \mathrm{arc}\,AVE_{TBT,dost-1}$	0.0026*	0.000077	-0.0083
	(0.0014)	(0.0019)	(0.0054)
$NW_g \times \mathrm{arc}\,AVE_{TBT,odst-1}$	0.0089***	0.0089***	-0.013
	(0.0027)	(0.0030)	(0.0082)
$NW_g \times \mathrm{arc}\,AVE_{SPS,dost-1}$	-0.0010	-0.0059*	-0.019**
	(0.0030)	(0.0031)	(0.0076)
$NW_g \times \mathrm{arc}\,AVE_{SPS,odst-1}$	0.0034	0.0049**	0.033***
	(0.0023)	(0.0023)	(0.0092)
$\mathrm{arc}\,T_{odst-1}$ (o against d)	0.13	0.15	0.17
	(0.082)	(0.12)	(0.14)
$\mathrm{arc}\,T_{dost-1}$ (d against o)	0.21*	0.28	0.31
	(0.11)	(0.21)	(0.50)
$prod_{ft-1}$	0.35***	0.35***	
	(0.031)	(0.030)	
l_{ft-1}	0.39***	0.39***	0.19***
	(0.031)	(0.029)	(0.036)
GDP^{sim}_{dot-1}	0.14**	0.29***	0.22
	(0.061)	(0.067)	(0.31)
HC^{dif}_{dot-1}	0.0099	0.0063	0.025

	(0.0063)	(0.0071)	(0.016)
KL_{dot-1}^{dif}	0.00073	0.0015	-0.040***
	(0.0043)	(0.0050)	(0.010)
$PTA_{TBT,dot-1}$	-0.044**	-0.052**	0.035
	(0.019)	(0.022)	(0.080)
KL_{ft-1}			0.085***
			(0.030)
Constant	14.7***	15.1***	16.6***
	(0.61)	(0.59)	(0.96)
Observations	165262	112288	156614
Pseudo R-squared	0.989	0.989	0.970
AIC	1.16571e+12	7.53858e+11	4.33392e+10

The results confirm our expectations. MNEs' subsidiaries belonging to larger networks can withstand better the negative trade shocks upon rising trade restrictive TBTs levied on both, home and host economies. Likewise, subsidiaries belonging to a wider international network of subsidiaries have higher sales when the MNEs' home economy levies trade restrictive SPS measures with larger AVEs[33], possibly exploiting the higher knowledge potential (in line with bio and hygiene standards). Their sales increase when facing these trade barriers possibly through the use of higher 'knowledge' and other resources from their network. This may also mean that while regulatory NTMs restrict trade between host and home countries, the subsidiary can rely on trade relations within the network of subsidiaries or in the production network of the GUO, where the trade restriction from regulatory measures might not be as high as the one between the host and home countries. This comparative advantage shows in our estimates over other MNEs (with smaller network sizes) whose output suffers as the result of reduced exports to home countries that levy higher NTMs (as shown by the negative and significant effect). As discussed earlier, domestic firms and lower productivity affiliates and, now, MNEs affiliates belonging to smaller networks may lose market shares due to rising TBTs, to the benefit of MNEs with larger networks.

The effects of trade policy measures on high-tech multinational firms

'Manufacture of basic pharmaceutical products and pharmaceutical preparations', 'Manufacture of computer, electronic and optical products' as well as 'Manufacture of air and spacecraft and related machinery' are the two high-tech manufacturing sectors defined by Eurostat which are used in this part of the analysis. Eurostat's definition can only to a limited extent meet the definition of digital FDI.[34] FDI's high-tech sector

[33] To be precise, it is not more SPS measures in numbers, but more trade-restrictive SPS measures, as measured by their AVEs, which is equivalent to tariffs.

[34] UNCTAD considers 'digital MNE firms' those that engage in ICT, e-commerce, and internet platforms and that have some digital content (e.g. digital media). Our definition differs in a way that we focus more on the sophistication of the technology firms use, as defined by Eurostat. These industries are the manufacture of basic pharmaceutical products and

covers to some extent digital FDI, which has gained momentum, but also other industries such as pharmaceuticals and medicine. According to the latest World Investment Report, digital MNEs' sales have increased five times faster than the so-called 'tradition MNEs', and the pandemic gave it a further boost. Trentini et al. (2022) show that digital MNEs were indeed expanding in the post-pandemic times further: from 2016 to 2021 total assets and sales of digital MNEs rose by 21%. In addition, these MNEs use fewer physical assets to reach a host destination, making this type of cross-border investment particularly appealing. These firms amount to about 12% of the non-service MNEs (Table A5, Regressions I), which is quite a large share confirming the importance of this industry in FDI.

The negative effects of trade policy measures are particularly detrimental to high-tech firms' productivity, as judged by a very high coefficient estimate. The results that are presented in Table A8 reveal that high-tech MNEs are more affected than the base sample by trade policy measures imposed against the host FDI economy, no matter whether these measures are in the form of tariffs or TBTs, and it is true for all our dependent variables (revenue, turnover, productivity).[35] These negative impacts are in fact concerning as companies in high-tech sectors have been gaining importance in overall FDI as well as in economic growth. On the other hand, if the home and host economies have a PTA with TBT provisions that could lead to harmonization or mutual recognition, high-tech multinationals can boost their output and productivity (the latter particularly strongly). Hence, high-tech MNEs seem in this case to be able to gain an even higher share of their revenues on exporting possibly at the cost of also a shift in market shares towards them and away from other industries in which the PTA effect of moderating the negative TBT effect is less strong. The strong positive productivity effect of PTA agreements in these high-tech industries is an important indication of the impact of trade agreements amongst important trading partners even in a world of rising trade-restrictive TBTs.

Trade restrictive SPS measures imposed by origin (home) against the destination (host) pose a lower threat to the production performances and productivity of MNEs in high-tech industries (the effects are lower in significance and size). Hygiene and bio standards are more likely to affect other non-service industries i.e. those that involve food, plant or animal life in their production processes. Fast growing FDI happens to be specifically in the ICT sector and the manufacture of electronics and space-craft that are less affected by SPS measures (on the other hand, pharmaceuticals, which are also part of the group of high-tech industries, is highly exposed to SPS measures). However, while SPS measures imposed by the host had no statistically significant impact on the output (turnover, revenue) variables in the whole sample, they show a strong negative impact on productivity of high-tech subsidiaries. In fact, when the trade costs associated with the SPS measures imposed by host against home increases by 1%, the productivity of the high-tech subsidiary in the host decreases by about 2.52%. This means that any host economy which would try to invite investors of pharmaceutical to its country should reduce the trade costs of SPS measures to offer a conducive environment.

The productivity of fully foreign-owned high-tech multinationals (which take up about 44% of firms in high-tech industries with diverse ownership structures) is even more sensitive to TBTs. Irrespective of whether imposed by the home or the host economy, trade-restrictive TBTs decrease the productivity of fully foreign-owned high-tech manufacturing subsidiaries, as these firms seem to be highly embedded into GVCs,

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pharmaceutical preparations, the manufacture of computer, electronic and optical products, and the manufacture of air and spacecraft and related machinery (source: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:High-tech_classification_of_manufacturing_industries).

[35] As robustness check we have estimated the whole sample as that presented in Table 1, while interacting the variables with a binary variable presenting the high-tech sectors. The results show that the effects are stronger and more significant for these high-tech sectors. These results are available upon request.

(through importing and exporting), which is why their performance decreases so much upon imposed TBTs. This negative effect is circumvented greatly once the home and host economies have PTAs aiming to recognize bilateral TBTs, in which case productivity is further enhanced and significantly more than in the overall sample of high-tech firms. Thus, these companies with a much stronger control of their subsidiaries benefit particularly from PTAs which can translate their relative strength into further productivity performances.

Hence, while the literature points out that high-tech trade is in principle more resilient to shocks and outperforms overall goods trade in general (Miller and Wunsch-Vincent, 2021), we show that there are strong impacts of TBTs (and tariffs) in high-tech industries which however get strongly moderated through PTAs and multinationals with full ownership control of subsidiaries benefit more strongly from these (specifically in productivity terms).

TWIN SEEDS

Table A 8: PPML results: sample high-tech manufacturing sector

	I			II		
	Base regression			(Sample of 100% foreign-owned firms)		
Dependent variable:	o_{ft}	s_{ft}	$prod_{ft}$	o_{ft}	s_{ft}	$prod_{ft}$
$PTA_{TBT,dot-1}$	0.25	-0.034	0.33	0.045	0.044	0.16
	(0.18)	(0.062)	(0.32)	(0.067)	(0.079)	(0.25)
$\text{arc}\,AVE_{TBT,dost-1}$ (d against o)	-0.094	-0.094	0.54	0.027	0.072	-1.39**
	(0.17)	(0.15)	(0.51)	(0.19)	(0.18)	(0.70)
$\text{arc}\,AVE_{TBT,odst-1}$(o against d)	-0.39***	-0.49***	-1.43**	-0.34	-0.34	- 3.20***
	(0.14)	(0.15)	(0.57)	(0.23)	(0.25)	(0.87)
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,dost-1}$	0.19	0.13	-1.80***	0.22	0.21	2.33***
	(0.21)	(0.24)	(0.67)	(0.25)	(0.29)	(0.72)
$PTA_{TBT,dot-1} \times \text{arc}\,AVE_{TBT,odst-1}$	0.66***	0.68***	4.34***	0.69**	0.51	6.04***
	(0.24)	(0.24)	(0.96)	(0.34)	(0.35)	(1.36)
$PTA_{SPS,dot-1}$	-0.30*		-0.12	0	0	0
	(0.17)		(0.23)	(.)	(.)	(.)
$\text{arc}\,AVE_{SPS,dost-1}$ (d against o)	-0.12	0.029	-2.52**	-1.24**	-0.76**	-2.03*
	(0.39)	(0.30)	(1.22)	(0.49)	(0.34)	(1.13)
$\text{arc}\,AVE_{SPS,odst-1}$(o against d)	-0.40*	-0.40*	-0.42	0.41	0.73**	3.02***
	(0.21)	(0.21)	(0.82)	(0.36)	(0.37)	(1.00)
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,dost-1}$	0.097	-0.42	3.95*	2.74***	2.15***	-0.41
	(0.79)	(1.01)	(2.06)	(0.86)	(0.78)	(2.85)
$PTA_{SPS,dot-1} \times \text{arc}\,AVE_{SPS,odst-1}$	0.52	0.10	-0.32	0.78	0.10	- 9.07***
	(0.45)	(0.41)	(1.35)	(0.68)	(0.57)	(2.42)

$\mathrm{arc}\,T_{odst-1}$ (o against d)	-3.44**	-2.46	-24.9**	-1.72	-0.56	1.89
	(1.43)	(1.54)	(11.0)	(1.92)	(2.06)	(6.01)
$\mathrm{arc}\,T_{dost-1}$ (d against o)	0.80	0.70	10.2**	0.22	-0.61	-5.00
	(0.88)	(0.96)	(4.73)	(1.10)	(1.16)	(5.44)
$prod_{ft-1}$	0.38***	0.35***		0.44***	0.43***	
	(0.040)	(0.041)		(0.044)	(0.043)	
l_{ft-1}	0.42***	0.39***	0.23**	0.47***	0.45***	-0.13
	(0.041)	(0.042)	(0.098)	(0.045)	(0.043)	(0.18)
GDP^{sim}_{dot-1}	0.42***	0.47***	0.35	0.39	0.30	-3.64***
	(0.16)	(0.15)	(0.86)	(0.28)	(0.27)	(1.09)
HC^{dif}_{dot-1}	0.016	0.017	0.16***	0.14***	0.10**	0.13*
	(0.022)	(0.020)	(0.055)	(0.047)	(0.040)	(0.064)
KL^{dif}_{dot-1}	0.0075	0.018	-0.19***	-0.0031	0.0064	-0.39***
	(0.014)	(0.017)	(0.049)	(0.024)	(0.029)	(0.081)
KL_{ft-1}			0.082			-0.27
			(0.083)			(0.18)
Constant	15.4***	15.9***	20.4***	14.2***	14.1***	21.0***
	(0.95)	(0.95)	(3.10)	(1.30)	(1.18)	(5.11)
Observations	19218	14537	18030	8417	6597	7789
Pseudo R-squared	0.985	0.985	0.975	0.981	0.982	0.956
AIC	4.18452e+11	3.20803e+11	1.48347e+10	1.58694e+11	1.32348e+11	7.70E+09

Robust standard errors in parentheses; *** p<0.01; ** p<0.05; * p<0.1

Appendix E: Bilateral Investment Treaties (BITs) and GVCs: the experience of regions

E.1 Compiling the database on the strength of protection of BITs

BITs are not standardized (Alschner, Skougarevskiy, 2016), but may vary according to the presence or absence of a variety of provisions, which may be extremely relevant for MNEs' foreign activities (Frenkel, Walter, 2018; Aisbett et al., 2018; Berger et al. 2013). We moved a step forward with respect to the existing literature and claimed that BITs differ from each other not only because of the presence/absence of a specific clause but also according to the content of these clauses. Operationally, we considered the following five provisions:[36]

A) *National treatment.* This clause requires each party to treat the investments of the other party's investors no less favorably than it treats its own investments or those of any other foreign investors.

B) *Most-favored-nation treatment*: This clause requires each party to provide investors of the other party with treatment no less favorable than that it provides to investors of any third party.

C) *Expropriation*: This clause requires each party to ensure that expropriation of investments is done only for a public purpose, in a non-discriminatory manner, in accordance with due process of law, and with prompt, adequate, and effective compensation.

D) *Transfer of funds*: This clause requires each party to allow investors of the other party to transfer funds related to their investments freely and without delay, subject to certain exceptions.

E) *Denial of benefits*: this clause is a provision commonly found in BITs that allow the host country to deny certain benefits to investors who do not meet certain criteria or engage in certain practices.

To cluster BITs according to the strength of protection each clause grants to investors of the contracting parties, we proceeded as follows. First, we downloaded all the BITs ever signed by one of the EU-28 countries from the EDIT website: they amounted to 1,394. Then, for each of the five provisions discussed above, we selected only those treaties that, according to EDIT, contained that specific provision. Lastly, we compared the textual content of the articles regulating the issue (Alschner, Skougarevskiy, 2016). To do so, we used embeddings to assign mathematical values to each article in a treaty. The idea behind *learning word embeddings* is grounded in the theory of distributional semantics, according to which similar words appear in similar contexts. Thus, by looking at the contexts in which a word frequently appears in a large body of text, it is possible to find similar words that occur in nearly the same context. In the case of specific-domain language processing, it is important to use embeddings trained on that domain in order to capture the nuances of technical terminology. For this purpose, we used *LEGAL-BERT*, a family of embedding models trained in the legal domain.[37] The result of applying an embedding algorithm to a piece of text is a vector of N dimensions, each of one representing a feature describing the text. Considering these vectors as a geometrical space in multiple dimensions makes it possible to define distances between different texts. Finally, we applied a *k*-mean clustering technique to the numerical distances between articles to group the treaties into 3 clusters, according to the degree of protection offered to foreign investors, i.e. weak protection (cluster 0), standard protection (cluster 1), and strong protection (cluster 2).[38]

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[36] At the beginning of the work, we also considered provisions concerning entry and sojourn. We uncover that this clause is included in a very limited number of BITs entered into force during the sample period. Indeed, personnel movements are usually part of national and MFN treatment.

[37] The model was pre-trained on 12 GB of publicly available resources regarding the EU legislation.

[38] This classification was done with the assistance of legal experts.

E.2 Estimating the effects of BITs on EU-centred GPNs

To investigate the effect of bilateral treaties on GPNs in a given sector, we adopt the same approach vastly used in the trade literature and used a Poisson Pseudo-Maximum Likelihood (PPML) estimator. As Santos Silva and Terreiro (2006) pointed out in their methodological paper, this technique is a special case of the Generalized Non-Linear Model (GNLM) in which the variance is assumed proportional to the mean and efficiently produces consistent estimates of the coefficients in the presence of heteroskedasticity, by properly dealing with the high frequency of zeros. Furthermore, to get consistent coefficients with a Poisson maximum likelihood regression, there is no need for a distribution assumption of the dependent variable since only its conditional mean should be correctly specified (Gourieroux et al., 1984). More specifically, we considered a PPML model, in which the unit of observation is the triad *region – sector – destination country* and estimated the following equation:

$$GPN_{rscd,t} = \exp\left(BIT_{cd,t-1}\beta + X_{d,t-1}\gamma + \delta_t\right)\varepsilon_{rscd} \qquad (1)$$

where $GPN_{rscd,t}$ is a measure of the Global Production Networks in which a region *r* in country of origin *c*, sector *s*, and the destination country *d* is involved at time *t*; $BIT_{cd,t-1}$ is a variable indicating that a BIT between countries *c* and *d* is entered into force; $X_{d,t-1}$ is a set of time-varying variables, defined at destination country level and one year lagged (i.e., observed at t-1); δ_t are year dummies, and ε_{rscd} is our set of fixed effects defined at region*sector of activity*destination country level.

As a dependent variable, we considered first the measure of GPN $network_{rscd,t}$. Then, we split it into its two main components, i.e. the number of GUOs located in region *r* and operating in sector *s,* with subsidiaries in destination country *d* at time *t* ($GUO_{rscd,t}$), and the number of subsidiaries that GUOs headquartered in region *r*, sector *s* have in destination country *d* at time *t* ($SUB_{rscd,t}$).

The variable $BIT_{cd,t-1}$ is a step variable that switches from zero to one the year after a BIT entered into force between country *c* and the destination country *d*. In doing so, we focused on the changes occurring over time rather than cross-sectionally and, by taking lagged values, avoided reverse causality.

The vector $X_{d,t-1}$ contains a set of control variables defined at the destination country level. In particular, we controlled for the country's development level, broadly defined, by including the (ln of the) GDP per capita ($lnGDPpc_{d,t-1}$). W ealso included the (ln of the) population to control for the size of the host country (Blonigen et al., 2003). Finally, to capture whether MNEs prefer to invest in capital or in labor-intensive countries, we included in the regression equation the (ln of the) capital-labor ratio (Bergstrand and Egger, 2007). Year dummy, δ_t, are included to control for common macroeconomic global shocks. It is also well known that both skilled labour endowments and the quality of the institutions are important for foreign plant set-ups (e.g. Bénassy-Queré et al., 2007; Checchi et al., 2007). However, introducing these variables would have led to a huge loss of usable observations so we decided not to include them among the control variables. However, the potential omitted variable bias should not be relevant, given that the level of GDP per capita is positively associated with the quality of the institutions and the level of education of the population, among many other factors (e.g. Dixon, Haslam, 2016).

Since the independent variable of interest, $BIT_{cd,t-1}$, does not vary across regions and sectors but only across origin-destination country pairs and time, we clustered standard errors accordingly (Wooldridge,1999).

In studying the heterogenous effect of $BIT_{cd,t-1}$ along different dimensions – like the degree of protection offered by the treaty, the sector of activity, the geographical spread of the destination countries, the characteristics of the region of origin, and so on – we adopted a full interaction specification; thus, we interacted the step variable $BIT_{cd,t-1}$ with the full set of time-invariant dummies. This strategy allows for increasing results readability.

E.3 Results regarding BIT effects of EU-centred GPNs

Baseline estimations

The results of our baseline equation are reported in Table A9. We estimated the impact of having a BIT on the total number of firms belonging to the GPN (*network, column 1)*, on the number of GUOs leading GPNs in a given destination country (*GUO*, *column 2*), and on the number of foreign subsidiaries (*subsidiaries, column 3*). We found evidence that having BITs in force increases the size of GPNs. However, the magnitude of the impact is slightly different on the three variables of interest. Indeed, estimates indicate that the entry in force of a BIT is related to a 20 per cent increase in the average number of firms in the network and, respectively, to a 15 per cent and 21 per cent increase in the average number of GUOs and in the number of foreign subsidiaries, respectively.[39] These figures suggest that the entry into force of a BIT would lead the average size of a GPN to increase from 6.38 to 7.77. The number of GUOs, i.e. firms creating a production network with their foreign activity in a given destination country, would increase from 1.84 to 1.9, while the number of foreign subsidiaries controlled by existing GUOs in an average destination country and year from 4.54 to 5.6. Overall, the results are in line with the prediction that BITs are among the most important instruments that countries can use to promote the internationalization of national companies.

[39] Given the discrete nature of the BIT explanatory variable, $(e^{\beta} - 1)$ can be considered as a semi-elasticity.

Table A 9: The effect of BITs on GPNs. Baseline estimates. Poisson pseudo-maximum likelihood estimates (PPMLE), 2007-2017

	(1)	(2)	(3)
VARIABLES	Network	GUO	SUB
BIT	0.199**	0.146*	0.212**
	(0.0811)	(0.0870)	(0.0922)
Ln GDP per capita	3.421***	2.556***	3.751***
	(0.611)	(0.489)	(0.704)
Ln Population	1.944***	0.839	2.431***
	(0.506)	(0.546)	(0.508)
Ln Capital-labour ratio	-1.405***	-1.167***	-1.521***
	(0.307)	(0.249)	(0.349)
Constant	-51.73***	-27.33***	-62.82***
	(10.13)	(9.993)	(10.79)
Observations	71,304	71,304	71,304
R-squared			

Notes: Each control variable included in the regression is one year lagged. BIT is a step variable that switches to one the year after a BIT entries into force. Standard errors clustered at country pairs in parentheses. Each regression includes sector by region- destination country fixed effects. *** p<0.01, ** p<0.05, * p<0.1

The estimated coefficients of the control variables are statistically significant and rather robust across the specifications reported in Table A9. The higher the average destination country's development level (GDP per capita) and the larger the market size (population), the higher the propensity of investing in that country to expand the network. The GDP per capita is also positively correlated with the number of GUOs in host countries. In contrast, an increase in the capital-labour ratio affects negatively GPNs, indicating that, *ceteris paribus*, EU MNEs invest abroad for efficiency reasons, rather than for strategic reasons.

Strength of protection of BITs

So far, we have considered the average impact that the entry into force of a BIT exerts on the formation of GPNs. In this section, we move a step forward by focusing on the degree of protection granted by BITs. The inclusion or not of some provisions and the way in which these provisions are written in the agreement may exert a differential impact on GPNs. In particular, we focussed on different provisions clustered in three groups from the least to the highest degree of protection granted to foreign investors.

Table A10 summarizes the results. In Column (1) the expropriation provision is considered. The absence of this clause does not seem to harm foreign investors, given that the BIT variable maintains its positive sign and significant effect on GPNs. In contrast, different modulations of the norm generate different impacts. The results provide a clear indication that an expropriation clause offering a standard degree of protection is positively associated with GPNs. Indeed, a clause granted a standard degree of protection establishes conditions under which expropriation may occur and regulates how compensation should be computed, clearly stating that it shall amount to the market (real) value of the investment immediately before expropriation. Furthermore, it gives foreign investors the right to promptly review their cases by judicial or other independent authorities of the party that expropriates. Establishing the period within which compensation must take place does not have additional effects on BITs.

Table A 10: The effect of BITs on GNP by the degree of protection. PPML estimates. 2007-2017

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Network	Network	Network	Network	Network
No-Expropriation	0.183***				
	(0.0705)				
Expropriation- weak protection	0.0143				
	(0.187)				
Expropriatio- standard protection	0.374***				
	(0.127)				
Expropriation- Strong protection	-0.0591				
	(0.265)				
No-MFN		0.177*			
		(0.0911)			
MFN weak protection		-0.163***			
		(0.0498)			
MFN standard protection		0.919***			
		(0.318)			
MFN strong protection		-			
No- National treatment			0.0872		
			(0.102)		
National treatment weak protection			0.508***		
			(0.0897)		
National treatment standard protection			0.306*		
			(0.166)		
National treatment strong protection			2.066***		
			(0.436)		
NO- Transfer of payment				0.177**	
				(0.0711)	

Transfer of payment weak protection				0.0987	
				(0.212)	
Transfer of payment standard protection				0.413**	
				(0.175)	
Transfer of payment strong protection				0.579**	
				(0.254)	
NO- Denial of benefits					0.174*
					(0.0905)
Denial of benefits					1.203***
					(0.434)
Constant	-52.14***	-52.03***	-51.91***	-51.95***	-52.05***
	(10.15)	(10.12)	(10.13)	(10.14)	(10.11)
Observations	71,304	71,304	71,304	71,304	71,304

Notes: Standard errors clustered at country pairs in parentheses. Each regression includes sector by region- destination country fixed effects and the GDP per capita of the country of destination (in log, and one year lagged), the population of the country of destination (in log, and one year lagged) and the capital/labor ratio of the country of destination (in log, and one year lagged). *** p<0.01, ** p<0.05, * p<0.1

Column (2) considers the Most Favoured Nation (MFN) clause. As before, BITs promote GPNs even in the absence of the MFN clause, although the level of significance becomes weak. However, the effects of the presence in the BITs of this clause are mixed: provisions granting standard protection suffice to incentivise GPNs, while provisions offering a weak degree of protection have a negative impact on GPNs, suggesting that in the lack of a strong commitment to non-discriminatory treatment, the risk of the investment increases deterring the set-up of new production facilities.

In column (3), the findings related to the national treatment clause are reported. The absence of the provision is unable to stimulate GPNs, while its presence does it, with an impact whose magnitude increases as the clause become more protective for foreign investors. Therefore, the presence in the BITs of a strong commitment to non-discrimination treatment between foreign and national investors/investments support GPNs.

In column (4) we considered the potential impact of the transfer of payment provision. The coefficients are always positive and significant, with, not surprisingly, the exception of the clauses ensuring foreign investors with a weak degree of protection, like those stating that the free transfer of payments in connection with an investment may be delayed or prevented under specific circumstances.

Lastly, Column (5) of Table A10 shows the results related to the Denial of benefits clause. The findings indicate that this provision plays a crucial role in enhancing GPNs in an average region, sector of activity, and destination country. However, we were unable to consider potential textual differences because this clause appears in a quite limited number of BITs.

Overall, the results indicate that the degree of protection granted by BITs depends on how a specific issue is normed rather than the presence/absence of the provision regulating the issue. In particular, our findings indicate a positive association between less discretionary BITs and GPNs. From a policy perspective, our results support the argument that protecting foreign investors against discriminatory measures is a key aspect of BITs and plays an important role in the formation of GPNs.

Heterogeneity

Using the PPML estimator with baseline specification control variables, we interacted the BIT variable with different sources of heterogeneity. Table A11 shows the results of the effect of BITs on s GPNs in relation to different destination geographies. It shows that the positive effect previously found is driven exclusively by three geographic areas: sub-Saharan Africa (SSA), Latin America and the Caribbean (LAC), and South Asia (SA). Entering into a BIT with a country belonging to one of these areas increases the average number of firms in the network by 42, 26, and 51 percent, respectively. In all three cases, the most sustained effect is on foreign subsidiaries, although the impact on GUOs remains positive and significant as well. In addition, the results also show a possible negative effect of BITs, limited to GUOs, for East Asian (EA) and Other European (OE) countries (with coefficients of -0.279 and -0.387, respectively). This negative effect might indicate a potential conflict between treaty norms and local informal institutions and a deterioration in institutional quality due to increased arbitrariness.

Table A 11: The effect of BITs on GPN by destination areas. PPML estimates. 2007-2017

	(1)	(2)	(3)
VARIABLES	Network	GUO	SUB
BIT*Central Asia	0.474	0.340	0.513
	(0.371)	(0.314)	(0.397)
BIT*East Asia	-0.215	-0.279*	-0.188
	(0.142)	(0.165)	(0.139)
BIT*Latin America	0.261***	0.235**	0.267***
	(0.0781)	(0.108)	(0.0920)
BIT*Middle East and North Africa	0.289	0.168	0.328
	(0.183)	(0.155)	(0.212)
BIT*Other EU	-0.357	-0.387**	-0.361
	(0.237)	(0.170)	(0.283)
BIT*South Asia	0.514***	0.320*	0.682***
	(0.128)	(0.184)	(0.108)
BIT*Sub Saharan Africa	0.425**	0.310*	0.475**
	(0.181)	(0.183)	(0.203)
Constant	-51.74***	-27.38***	-62.81***
	(10.19)	(10.05)	(10.84)
Observations	71,303	71,303	71,303

Notes: Standard errors clustered at country pairs in parentheses. Each regression includes sector by region- destination country fixed effects and the GDP per capita of the country of destination (in log, and one year lagged), the population of the country of destination (in log, and one year lagged) and the capital/labor ratio of the country of destination (in log, and one year lagged). *** p<0.01, ** p<0.05, * p<0.1

Table A12 shows the results in relation to the per capita income quartiles of the destination countries. Overall, a BIT stimulates GPNs in the poorest countries (first quartile) and, though to a lesser extent in destination countries belonging to the third quartile of the GDP per capita distribution (the coefficient goes from 0.473 to 0.181). In both cases, the effect is driven exclusively by foreign affiliates. This result seems to suggest that BITs when extending the action of strong institutions to less developed countries increase the average number of foreign affiliates of existing MNEs.

Table A 12: The effect of BITs by quartile of GDP per capita of destination countries in 2006. PPML estimates. 2007-2017

	(1)	(2)	(3)
VARIABLES	Network	GUO	SUB
BIT*1st quart	0.473**	0.303	0.563**
	(0.209)	(0.210)	(0.228)
BIT*2nd quart	0.101	-0.00201	0.139
	(0.151)	(0.113)	(0.181)
BIT*3rd quart	0.181*	0.152	0.187*
	(0.0970)	(0.119)	(0.106)
BIT*4th quart	0.284	0.215	0.294
	(0.239)	(0.204)	(0.273)
Constant	-51.68***	-27.30***	-62.76***
	(10.18)	(10.05)	(10.83)
Observations	71,304	71,304	71,304

Notes: Standard errors clustered at country pairs in parentheses Each regression includes sector by region- destination country fixed effects and the GDP per capita of the country of destination (in log, and one year lagged), the population of the country of destination (in log, and one year lagged) and the capital/labor ratio of the country of destination (in log, and one year lagged). *** p<0.01, ** p<0.05, * p<0.1

Turning on sectoral heterogeneity, Table A13 shows that BITs seem to be an effective policy instrument to promote foreign investments in the services sectors, mainly in no knowledge-intensive services sectors (low KIS). Quite surprisingly, BITs do not affect the formation and extension of GPNs in primary and manufacturing sectors. Two not mutually exclusive reasons may explain these unexpected results. First, as discussed before, this may depend on the intangible nature of services, which, in order to be internationally tradeable, need the presence of suppliers and clients in the same place. Moreover, the production chain is shorter and less fragmentable with respect to manufacturing goods. Thus, bilateral agreements with their strong legal commitments represent an effective instrument to stimulate EU MNEs operating in services to expand internationally the markets they may serve because they reduce the risks to operate abroad. In contrast, MNEs producing manufacturing goods, having a longer and more geographically dispersed production chain, may need more complex policy instruments to expand further their networks. Indeed, they need the free movement of people, goods and services, financial capital, and technology not only between the country of origin and the destination of specific tasks or functions but also between the different stages forming the production chain. The lack of a significant impact on knowledge-intensive services may depend on the fact that BITs do not include specific provisions to protect intellectual property rights.

Table A 13: The effect BITs by GUO sector of activity. PPML estimates. 2007-2017

	(1)	(2)	(3)
VARIABLES	Network	GUO	SUB
BIT*KIS	0.147	0.179	0.120
	(0.133)	(0.131)	(0.147)
BIT*no KIS	0.679***	0.359***	0.840***
	(0.116)	(0.122)	(0.126)
BIT*High tech	-0.0855	-0.155	-0.0714
	(0.0982)	(0.119)	(0.104)
BIT*Low tech	0.208	-0.0380	0.315
	(0.230)	(0.209)	(0.252)
BIT*Primary sector	0.344	0.110	0.441
	(0.253)	(0.218)	(0.269)
BIT*construction and public utilities	0.102	0.447***	0.0785
	(0.113)	(0.165)	(0.153)
Constant	-51.77***	-27.35***	-62.85***
	(10.14)	(9.992)	(10.79)
Observations	71,304	71,304	71,304

Notes: Standard errors clustered at country pairs in parentheses. Each regression includes sector by region- destination country fixed effects and the GDP per capita of the country of destination (in log, and one year lagged), the population of the country of destination (in log, and one year lagged) and the capital/labor ratio of the country of destination (in log, and one year lagged). *** p<0.01, ** p<0.05, * p<0.1

Last, but not least, we explored whether the impact of BITs may vary according to the characteristics of the regions of origin. To this respect, we considered the levels of development of EU regions, proxied by the quartiles of the GDP per capita distribution. We found interesting results able to shed new light on the link between investment liberalization and GPNs.

According to our findings (Table A14), BITs are positively associated with an expansion of GPNs only in the first three quartiles of the distribution of regions by GDP per capita. However, the magnitude of the impact is U-shaped, being larger in low- and middle-high income regions. Overall, these results confirm that BITs act as a signal of an investor-friendly environment, stimulating more EU firms to become international. In contrast, BITs are not effective in promoting GPNs originating from the richest regions perhaps because

MNEs headquartered in those regions have already cumulated enough expertise on how to operate successfully in foreign markets. This issue deserves further investigation.

Table A 14: The effect of BITs by region of origin ranked by GDPpc in 2006.
PPML estimates. 2007-2017

	(1)	(2)	(3)
VARIABLES	Network	Guosum	Subsum
treat_q1	0.568***	0.572***	0.540***
	(0.147)	(0.156)	(0.167)
treat_q2	0.141*	0.220**	0.113
	(0.0753)	(0.0987)	(0.0725)
treat_q3	0.596***	0.404**	0.685***
	(0.183)	(0.170)	(0.202)
treat_q4	-0.138	-0.192	-0.128
	(0.168)	(0.118)	(0.204)
Constant	-51.98***	-27.45***	-63.13***
	(10.15)	(10.01)	(10.81)
Observations	71,304	71,304	71,304

Notes: Standard errors clustered at country pairs in parentheses. Each regression includes sector by region- destination country fixed effects and the GDP per capita of the country of destination (in log, and one year lagged), the population of the country of destination (in log, and one year lagged) and the capital/labor ratio of the country of destination (in log, and one year lagged). *** p<0.01, ** p<0.05, * p<0.1

Appendix F: How we measure R&D dependency in GVCs

The methodology behind the analysis of embodied R&D and R&D dependency in GVCs is based on the following set of metrics. We create a proxy of the R&D content of each stage of a value chain by weighting the intermediate goods supplied to downstream stages by the R&D efforts of this stage. Thus, we can consider the R&D content of a certain good as the sum of the R&D efforts in upstream sectors and own R&D efforts of the producing sector. The decomposition of a value chain in its domestic and foreign upstream components weighted by their R&D content allows to measure the direct and indirect R&D content in global value chains.

There are two ways to look at the embodied R&D content in GVCs: i) from the perspective of the country that utilizes R&D for its own production; and ii) from the perspective of the country which contributes R&D to production activities in other countries.

We start with the perspective of the receiving country. In a first step, we calculate an R&D input coefficient vector r by dividing R&D expenditures by gross output. The total R&D content of a final goods production consists of domestic and GVC (imported) R&D content and is calculated as:

$$\mathbf{RDc}_{\mathrm{f}}^{\mathrm{global}} = \left(\mathbf{r}' \cdot \mathbf{L} \cdot \hat{\mathbf{f}}\right)'$$

where $\mathbf{L}$ is the global Leontief inverse and $\mathbf{f}$ the final demand vector. ^ denotes the diagonalised final demand vector.

We can now separate the total R&D content into purely domestic R&D and imported R&D embodied in GVCs. The purely domestic R&D content includes R&D by the sector itself as well of R&D in domestic upstream sectors and is calculated as

$$\mathbf{RDc}_{\mathrm{f}}^{\mathrm{dom}} = \left(\mathbf{r}' \cdot \bar{\mathbf{L}} \cdot \hat{\mathbf{f}}\right)'$$

where $\bar{\mathbf{L}}$ denotes the (block-diagonal) Leontief inverse. The results are aggregated over industries to the country level.

Absolute values for the R&D content, however, are difficult to compare across countries. This is why we calculate intensities for the global and domestic R&D content in final goods production for each country as:

$$\mathrm{shRDc}_{\mathrm{f}}^{\mathrm{c,global}} = \frac{\mathrm{RDc}_{\mathrm{f}}^{\mathrm{c,global}}}{\mathrm{f}^{c}} \quad \text{and} \quad \mathrm{shRDc}_{\mathrm{f}}^{\mathrm{c,dom}} = \frac{\mathrm{RDc}_{\mathrm{f}}^{\mathrm{c,dom}}}{\mathrm{f}^{c}}$$

where f^{c} denotes country c’s final goods production (either consumed domestically or exported). In a nutshell, this indicator shows the degree to which goods production in a particular country is dependent on foreign technology. The difference between the global and the domestic intensity can be interpreted as ‘imported’ (i.e. not purely domestic) R&D content. Imported R&D thus also includes domestic R&D which has been supplied into GVC activities and was re-imported.

A second perspective is that of the source country that contributes R&D to the production processes of all other countries. It tells how much R&D of a particular country is embodied in the final demand or export output of all other countries, or, in other words, how much a particular country contributes to production in other countries in terms of R&D. All countries are at the same time source and destination countries.

Domestic and GVC R&D source figures are calculated as:

$$\mathbf{RDs}_{\mathrm{f}}^{\mathrm{global}} = (\hat{\mathbf{r}} \cdot \mathbf{G} \cdot \mathbf{f}) \quad \text{and} \qquad \mathbf{RDs}_{\mathrm{f}}^{\mathrm{dom}} = (\hat{\mathbf{r}} \cdot \overline{\mathbf{G}} \cdot \mathbf{f})$$

where $\mathbf{G}$ and $\overline{\mathbf{G}}$ denote the global and purely domestic Ghosh inverses and f is the global final demand vector. These are aggregated over industries to the country level.

We calculate the share of a country's R&D in global final goods production as:

$$\mathrm{shRDs}_{\mathrm{f}}^{\mathrm{c,global}} = \frac{\mathrm{RDs}_{\mathrm{f}}^{\mathrm{c,global}}}{\sum_c \mathrm{f}^c} \qquad \text{and} \qquad \mathrm{shRDs}_{\mathrm{f}}^{\mathrm{c,dom}} = \frac{\mathrm{RDs}_{\mathrm{f}}^{\mathrm{c,dom}}}{\sum_c \mathrm{f}^c}$$

This measure can, for example, be compared with country c's share in global R&D expenditures. The difference between $\mathrm{shRDs}_{\mathrm{f}}^{\mathrm{c,global}}$ and $\mathrm{shRDs}_{\mathrm{f}}^{\mathrm{c,dom}}$ indicates how much a country contributes to R&D in global final demand via GVC integration (irrespective of whether consumption takes place in the country or in other countries).

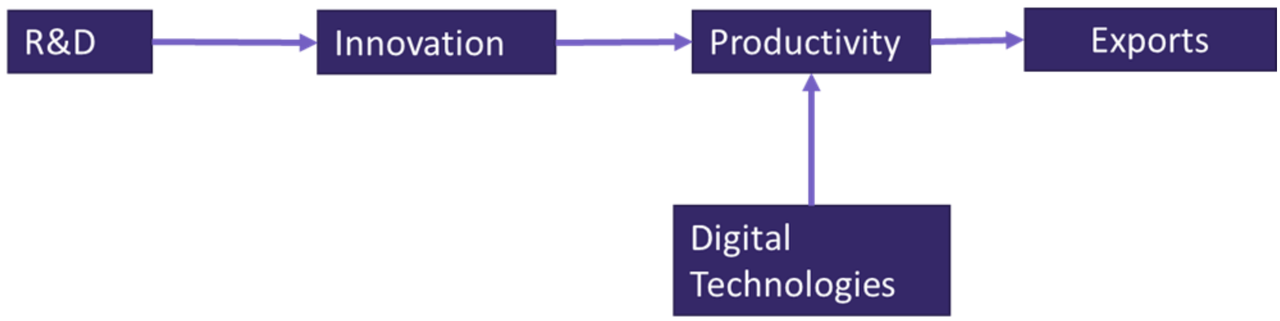
Appendix G: The data and method used for the analysis of the impact of different digital technologies on trade

To determine the channels through which digital technologies affect exports, we employ structural equation modelling. Two channels are tested: the productivity channel and the services channel. The next sections describe the models in more detail and give information on the variables included in the different stages of the models.

The Productivity Channel

For the productivity channel we make use of the model developed by Crépon, Duguet, and Mairesse (1998), or CDM model. The model consists of three stages. First, the decision to invest in R&D is taken care of by using a Heckman selection model. Second, taking the R&D investment decision into account, the knowledge production function with innovation as dependent variable is estimated. In the final stage the effect of innovation on productivity is evaluated. As shown in Figure A 1, we extend the original model by two factors. First, we include a fourth stage considering export probability and intensity. Second, we do not only evaluate the impact of innovation on productivity but also include digitalisation as an additional determinant of productivity.

Figure A 1: Structural Model of the productivity channel



Stage 1: "R&D" - Modelling the decision to invest in R&D and the size of the investment

First, we estimate the probability of a firm investing in R&D. Then the size of R&D spending is accounted for taking the first stage into consideration. Formally, the model is defined as follows:

$$rd \sim \beta_1 lemp + \beta_2 \log(mark_{share} + 1) + \beta_3 mean\_turnin + \beta_4 sector \qquad (1)$$

$$\log(rdexp + 1) \sim + \beta_1 \log(mark\_share + 1) + \beta_2 mean\_turnin + sector \qquad (2)$$

Lemp accounts for the firm's size measured by the logarithm of the number of employees. Market share is defined as the share of the firm's turnover in total turnover of the main industry of the firm (*mark_share*). We use the mean turnover in an industry made with new products to proxy demand pull effects (*mean_turnin*). Technology opportunities are proxied by the sector variable which is a categorical variable with four levels from low to high technology. We include firm size as an exclusion restriction in the first stage to increase the robustness and consistency of our estimation.

While in the first equation, the dependent variable is a dummy variable equal to one if the firm is involved in R&D (*rd*), in the second we explain *rdexp*, which is defined as the share of R&D expenditure in the total firm's turnover. The selection model is estimated using maximum likelihood estimation.

Stage 2: "Innovation" - Estimating the Knowledge Production Function

Taking the R&D investment decision into account, the knowledge production function is defined as:

$$innov \sim \beta_1 lemp + \beta_2 tert + \beta_3 up\_sec + \beta_4 rdexp^* \qquad (3)$$

where the dependent variable is a dummy variable equal to one if a new or significantly improved product was introduced in the market, and zero otherwise. The binary nature of the dependent variable requires the use of a probit specification. In addition to the explanatory variables from the first stage, two variables accounting for skills - the share of employees with a university or college degree (*tert*), and the share of technicians and skilled workers (*up_sec*) - are accounted for. Furthermore, $rdexp^*$ is the predicted R&D intensity and *lemp* the firm size.

Stage 3: "Productivity" – The estimation of the Production Function

The production function is estimated by a Cobb-Douglas production function:

$$\log(prod) \sim \beta_1 lemp + \beta_2 up\_sec + \beta_3 up\_sec^2 + \beta_4 innov^* + \beta_5 lp\_investm + \beta_6 fadm\_15 + \beta_7 flog\_15 + \beta_8 fcps\_15 + \beta_9 sector \qquad (4)$$

Labour productivity is measured in two alternative ways: the logarithm of value added per employee is used (*lp_va*), and the logarithm of turnover per employee (*lp_turn*). Productivity is a function of firm size (*lemp*), human capital (*up_sec*), predicted innovation ($innov^*$), investment per employee (*lp_investm*), and digitalisation as proxied by additive manufacturing (*fadm_15*), logistics (*flog_15*) and robotics (*frob_15*) (see Box 1 for details on how digital technologies are measured). To account for non-linearities between human capital and productivity, we include the quadratic term of *up_sec*.

Box 1. Measuring digital technologies with EMS data

A unique feature of the EMS dataset is the richness of information on digital technologies. EMS gives detailed information on the **adoption of 20 different digital technologies**, coded as binary variables with one if the firm has installed a certain technology, and zero otherwise. For better identification of our model, however, we need the information of the year when the technology was introduced, such that we can construct technology factors lagged by two years. This information is only available for 11 out of these 20 technologies. Hence, we are only able to use a reduced number of technologies. To reduce the correlation between the individual technologies, we identify technology groups with **principal component analysis**. Based on this analysis, we can identify three groups of technologies which are listed in Table A 15 below, together with the factor loadings of the individual technologies showing the weight of the variables in the technology groups. The three technologies are: logistics technologies, additive manufacturing, and robots.

Table A 15: Technologies and technology groups identified by principal component analysis

Technologies	Logistics Technologies	Additive Manufacturing	Robotics
Mobile/wireless devices for programming and controlling facilities and machinery	0.56		
Digital solutions to provide drawings work schedules or work instructions directly on the shop floor	0.67		-0.24
Software for production planning and scheduling (e.g. ERP system	0.57		0.17
Digital Exchange of product/process data with suppliers/customers (Electronic Data Interchange EDI)	0.58		0.18

Near real-time production control system (e.g. Systems of centralized operating and machine data acquisition, MES	0.58		0.27
Systems for automation and management of internal logistics (e.g. Warehouse management systems, RFID)	0.56		0.24
Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management	0.43		0.24
Industrial robots for manufacturing processes (e.g. welding, painting, cutting)	0.11		0.77
Industrial robots for handling processes (e.g. depositing, assembling, sorting, packing processes, AGV)	0.18		0.80
3D printing technologies for prototyping (prototypes, demonstration models, 0 series)		0.86	0.14
3D printing technologies for the manufacturing of products, components and forms, tools, etc.)		0.87	

Source: Own calculation based on EMS data.

Stage 4: "Export" – Estimating the export probability and export intensity

The final stage estimates the export probability and intensity taking into consideration the indirect effect of the digital technologies through its effect on productivity by including the predicted level of productivity ($prod^*$). Both productivity measures from the previous stage are predicted and used in separate regression models. In our estimations, the export performance of firms is estimated as follows:

$$export \sim \beta_1 lemp + \beta_2 tert + \beta_3 up\_sec + \beta_4 prod^* + \beta_5 mass + \beta_6 supp + \beta_7 sector \qquad (5)$$

where *export* can either be *EXPstat*, a dummy variable taking the value of one if the firm exports, or as *log(EXPint+1)*, i.e. the export intensity, which is defined as turnover per employee generated by exports in Million Euro. In addition to the productivity and the three technologies, the regressors consist of the firm size (*lemp*), the share of university graduates (*tert*), the share of skilled workers (*up_sec*) and the classification of the firms in low to high technology sectors (*sector*). *Mass* represents a dummy variable equal to one if the firm's main product is produced in large batches and *supp* is a dummy variable that has a value of one if the products are supplied to company suppliers, whereas it is equal to zero if the product is supplied to consumers or contract manufacturers.

While the model specification with EXPstat is evaluated using probit estimation, the model estimating the export intensity relies on OLS estimations.

The services channel

The second channel through which digital technologies can impact trade in GVCs is by allowing higher servitisation, i.e. by allowing companies to offer services together with their physical products. This channel is estimated in two stages. The first stage focus on the effect of digital technologies on servitisation, and the second stage tests how the predicted servitisation indicators affect export probability and intensity.

Stage 1: The determinants of servitisation

For the analysis of the service channel, we first estimate and predict services and then evaluate the effect of the services on the exports. Formally, the first stage is estimated in the following way:

$$serv \sim \beta_1 lemp + \beta_2 lemp^2 + \beta_3 mass + \beta_4 supp + \beta_5 complex + \beta_6 innov + \beta_7 sector + \beta_8 fadm\_15 + \beta_9 frob\_15 + \beta_{10} flog\_15 \quad (6)$$

where the dependent variable *serv* is measured by two alternative indicators: the share of turnover in services (*sturn*), or *sinnov*, a dummy variable being equal to one if the firm has introduced a new product-related service since 2015. In addition to the explanatory variables defined in the previous equations, we include the squared term of *lemp* to account for non-linearity in the size of the firm; *complex*, which accounts for the complexity of the product, and *innov* being equal to one if the firm has introduced an innovative product since 2015. Finally, sector dummies are included. Similar to the production stage in the CDM framework, we include the three lagged digital technology factors *fadm_15*, *frob_15* and *flog_15*.

Stage 2: Estimating export probability and intensity

In the second and final stage of the analysis, the export probability and intensity are estimated while considering the indirect impact of digital technologies through their influence on the two servitisation indicators. This is achieved by incorporating the predicted values of the servitisation indicators depicted in equation (7) via $serv^*$. Formally, we estimate the following model:

$$export \sim \beta_1 lemp + \beta_2 tert + \beta_3 up\_sec + \beta_4 serv^* + \beta_5 mass + \beta_6 supp + \beta_7 sector \quad (7)$$

Export is again either a dummy variable, *EXPstat*, equal to one for an exporting firm, or the export intensity, *EXPint*. As control variables, we use the same indicators included in equation (5).

Appendix H: Selected results from the analysis of the impact of different digital technologies on trade

The results of the estimation of the production function of the productivity channel, showing the impact of digital technologies on firms' productivity, are reported in Table A 16. Column (1) shows the estimation results for the log of the value added per employee, whereas in column (2) the log of the turnover per employee is used as the dependent variable.

Table A 17 reports the regression results of the model that explains how digital technologies affect exports through the productivity channel. While columns (1) and (2) examine the determinants of the probability to export, columns (3) and (4) explain export intensities. Columns (1) and (3) include the predicted value added per employee as a measure of productivity, while columns (2) and (4) use the predicted turnover per employee as an alternative indicator of productivity.

Table A18 shows the results of the estimations of the determinants of servitisation. This represents the first stage of the model on the services channel, which explores if digital technologies impact trade by enabling new (digitally-enabled) services. Column (1) uses the share of services on total turnover (*sturn*) as the dependent variable, and column (2) uses as the dependent variable the indicator *sinnov*, i.e. a dummy variable equal to one whenever the firm has introduced a new service since 2015.

The second stage of the model, analysing the impact of servitisation on exports, is presented in Table A 19. Columns (1) and (2) focus on the factors that influence the likelihood of exporting, whereas columns (3) and (4) assess how the same explanatory variables affect export intensities. Columns (1) and (3) use the predicted share of services in turnover as a proxy for servitisation, while columns (2) and (4) use the predicted probability of introducing a new innovative service as an alternative proxy.

Table A 16. The production function: estimating the impact of digital technologies on productivity

	Dependent variable	
	log(lp_va + 1)	log(lp_turn)
	(1)	(2)
lemp	-0.004	-0.028
	(0.004)	(0.039)
up_sec	0.030	0.247
	(0.054)	(0.424)
up_sec^2	-0.139**	-1.847***
	(0.066)	(0.621)
Innov*	0.082**	0.570*
	(0.038)	(0.320)
lp_investm	1.055***	10.032***
	(0.349)	(1.616)
lp_investm.NA	0.013*	0.187***
	(0.008)	(0.045)
sector-mhitech	0.002	0.114
	(0.010)	(0.082)
sector-mlowtech	-0.007	-0.043
	(0.011)	(0.089)
sector-lowtech	0.007	0.151
	(0.011)	(0.098)
fadm_15	-0.001	-0.022
	(0.002)	(0.015)
flog_15	0.010***	0.130***
	(0.003)	(0.022)
frob_15	0.008**	0.074***
	(0.003)	(0.021)
Observations	1,026	1,328
R^2	0.104	0.164
Adjusted R^2	0.094	0.156
Residual Std. Error	0.080 (df = 1013)	0.659 (df = 1315)
F Statistic	9.849*** (df = 12; 1013)	21.463*** (df = 12; 1315)

*p<0.1**p<0.05***p<0.01, Bootstrapped standard errors in parentheses (rep=499)

Table A 17: The impact of productivity on exports

	Dependent variable			
	EXPstat		log(EXPint + 1)	
	probit		*OLS*	
	(1)	(2)	(3)	(4)
lemp	0.364***	0.371***	0.013***	0.014***
	(0.073)	(0.076)	(0.004)	(0.003)
tert	1.070*	1.153**	0.078**	0.099**
	(0.618)	(0.567)	(0.039)	(0.039)
up_sec	0.750*	0.765*	0.067***	0.105***
	(0.404)	(0.436)	(0.022)	(0.025)
mass	0.183	0.190	0.024**	0.025**
	(0.145)	(0.152)	(0.010)	(0.011)
supp	0.596***	0.597***	0.021***	0.020***
	(0.099)	(0.101)	(0.007)	(0.007)
Prod_va*(log)	2.232		1.245***	
	(2.412)		(0.177)	
Prod_turn*(log)		0.144		0.113***
		(0.215)		(0.016)
sector-mhitech	0.156	0.137	-0.006	-0.018
	(0.229)	(0.228)	(0.015)	(0.014)
sector-mlowtech	-0.076	-0.092	-0.031**	-0.037***
	(0.226)	(0.216)	(0.014)	(0.013)
sector-lowtech	-0.292	-0.310	-0.027*	-0.039**
	(0.229)	(0.216)	(0.015)	(0.016)
Constant	-1.073***	-0.592	-0.126***	0.208***
	(0.403)	(0.588)	(0.025)	(0.040)
Observations	1,271	1,271	1,271	1,271
R^2			0.194	0.193
Adjusted R^2			0.189	0.188
Log Likelihood	-430.313	-430.510		
Akaike Inf. Crit.	880.626	881.020		
Residual Std. Error (df = 1261)			0.109	0.109
F Statistic (df = 9; 1261)			33.802***	33.591***

*p<0.1**p<0.05***p<0.01, Bootstrapped standard errors in parentheses (rep=499). Raw coefficients are reported

Table A 18: The determinants of servitisation

	Dependent variable:	
	sturn	*sinnov*
	Fractional logit	*probit*
	(1)	(2)
lemp	-0.585^{**}	-0.492^{**}
	(0.263)	(0.233)
I(lemp2)	0.057^{**}	0.066^{***}
	(0.027)	(0.024)
mass	-0.579^{***}	-0.178
	(0.191)	(0.118)
supp	0.363^{***}	0.022
	(0.128)	(0.095)
complex	0.285^{**}	0.078
	(0.111)	(0.092)
innov	-0.013	0.586^{***}
	(0.108)	(0.090)
fadm_15	0.009	0.141^{***}
	(0.043)	(0.033)
frob_15	-0.253^{***}	-0.030
	(0.058)	(0.041)
flog_15	0.094^{*}	0.085^{**}
	(0.051)	(0.041)
Constant	-1.750^{**}	-0.254
	(0.734)	(0.580)
Sector Dummies	Yes	Yes
Country Dummies	Yes	Yes
Observations	1,217	1,467
Log Likelihood		-608.866
Akaike Inf. Crit.		1,249.732

$^{*}p<0.1$ $^{**}p<0.05$ $^{***}p<0.01$, Standard errors in parentheses.
Raw coefficients are reported.

Table A 19: Servitisation and exports

	Dependent variable			
	EXPstat		log(EXPint + 1)	
	probit		*OLS*	
	(1)	(2)	(3)	(4)
lemp	0.387***	0.362***	0.022***	0.019***
	(0.069)	(0.069)	(0.004)	(0.004)
tert	1.074*	0.872*	0.156***	0.137***
	(0.552)	(0.516)	(0.038)	(0.038)
up_sec	0.743*	0.596	0.002	-0.010
	(0.390)	(0.414)	(0.021)	(0.022)
supp	0.537***	0.516***	0.032***	0.027***
	(0.109)	(0.095)	(0.008)	(0.007)
mass	0.140	0.220	0.024**	0.036***
	(0.158)	(0.138)	(0.011)	(0.011)
Sturn*	-1.084		-0.215	
	(2.193)		(0.143)	
Sinnov*		0.983*		0.078**
		(0.574)		(0.035)
sector-mhitech	0.242	0.173	-0.010	-0.019
	(0.219)	(0.210)	(0.015)	(0.015)
sector-mlowtech	-0.106	-0.079	-0.055***	-0.051***
	(0.202)	(0.201)	(0.016)	(0.014)
sector-lowtech	-0.375*	-0.323	-0.042**	-0.034**
	(0.214)	(0.204)	(0.017)	(0.016)
Constant	-0.808*	-0.908***	0.001	-0.012
	(0.413)	(0.329)	(0.028)	(0.021)
Observations	1,433	1,433	1,296	1,296
R^2			0.158	0.160
Adjusted R^2			0.152	0.154
Log Likelihood	-506.355	-504.878		
Akaike Inf. Crit.	1,032.710	1,029.755		
Residual Std. Error (df = 1286)			0.111	0.111
F Statistic (df = 9; 1286)			26.876***	27.290***

*p<0.1**p<0.05***p<0.01, Bootstrapped standard errors in parentheses (rep=499), Raw coefficients are reported.

Appendix I: A summary of the results on the interplay between digital technologies and GVCs' governance

Table A 20 summarises the main findings of the analysis on the interplay between digital technologies and GVC embeddedness. The table reports the coefficients on two proxies of GVCs' embeddedness – backward and forward participation, with the dependent variables being the adoption of three digital technologies – robots, data analytics to improve production processes, and data analytics to monitor employee performance. These results are generated in different estimations.

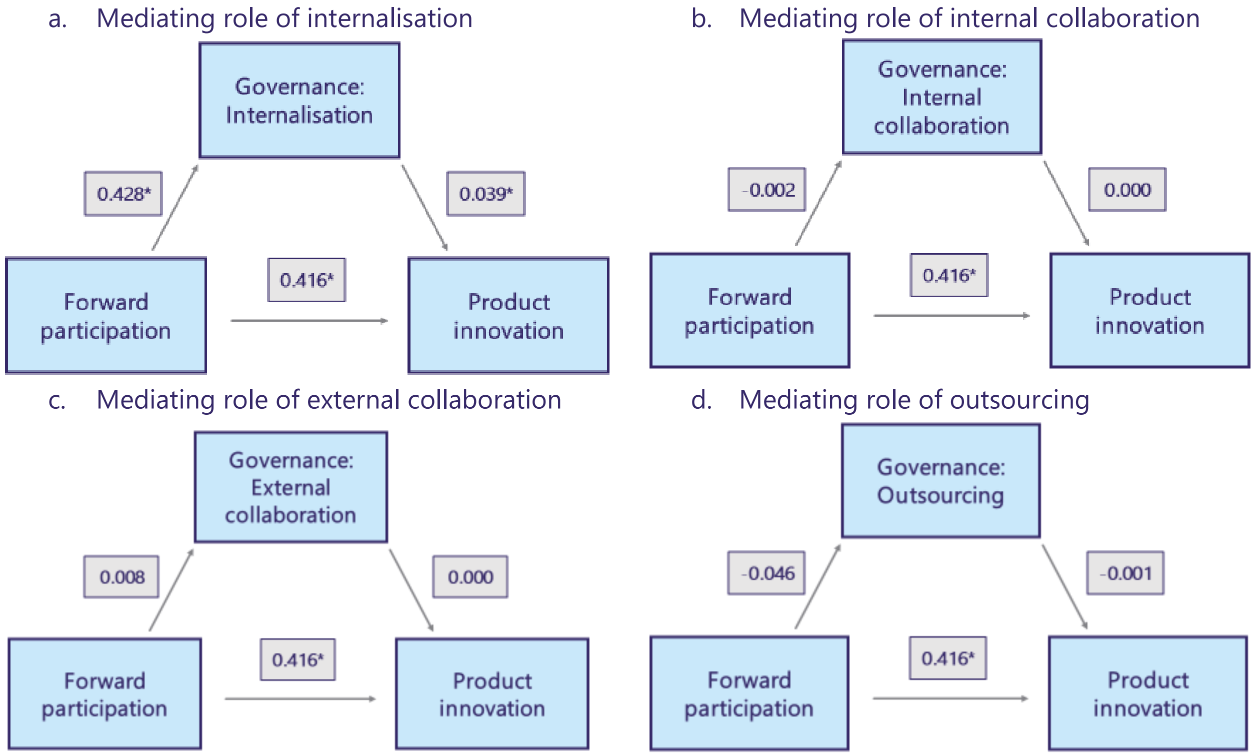
Table A 20: Key results from the analysis on the interplay between digital technologies and GVC embeddedness

		Digital technologies		
		Robots	Data analytics to improve production processes	Data analytics to monitor employee performance
Measures of GVC embeddedness	Backward participation	0.67*** (0.12)	0.10* (0.05)	0.12** (0.05)
	Forward participation	0.76*** (0.06)	0.18*** (0.03)	0.18*** (0.03)

*p<0.1**p<0.05***p<0.01, Standard errors in parentheses.

Figure A 2 reports the coefficients of the mediating role of governance. In particular, we study the role of GVC embeddedness on different types of innovations (product, process, and marketing), and how this relationship is mediated by four governance modes: internalisation, internal collaboration, external collaboration, and outsourcing. We study these relationships in two main categories of firms' activities: i) the production of goods, assembly of parts, or delivery of services; and ii) the design or development of new products or services. For these two types of activities, firms are asked how these activities are organised (i.e. the governance of these activities, as classified above). In the figure below, we report the results of production activities, with product innovation being the dependent variable and forward participation (independent variable) being the proxy for GVC embeddedness. Coefficients and significance are reported in the grey boxes.

Figure A 2: The mediating role of governance: Internalisation promoting innovation in GVCs



*p<0.05