TWIN SEEDS

WORK PACKAGE 2

Emerging trends of Global Value Chains and Multinational Enterprises in the pandemic time

Acknowledgements

This report is the second 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.

The report has been edited by Barbara Jankowska (PUEB), Katarzyna Mroczek-Dąbrowska (PUEB), Ewa Mińska-Struzik (PUEB) and Aleksandra Kania (PUEB), based on the contributions from the below-listed Work Package 2 participants:

Chapters	Authors	Participating organisation
1, 3, 5, 6	Barbara Jankowska	Poznań University of Economics and Business (PUEB)
1, 3, 5, 6	Katarzyna Mroczek-Dąbrowska	Poznań University of Economics and Business (PUEB)
1, 3, 5, 6	Ewa Mińska-Struzik	Poznań University of Economics and Business (PUEB)
1, 3, 5, 6	Aleksandra Kania	Poznań University of Economics and Business (PUEB)
3	Marian Gorynia	Poznań University of Economics and Business (PUEB)
3	Małgorzata Bartosik-Purgat	Poznań University of Economics and Business (PUEB)
3	Maciej Szymczak	Poznań University of Economics and Business (PUEB)
3	Anna Matysek-Jędrych	Poznań University of Economics and Business (PUEB)
3	Paweł Śliwiński	Poznań University of Economics and Business (PUEB)
2	Louise Curran	TBS Education, Toulouse (TBS)
2	Antonia Orsulic	Austrian Institute of Technology (AIT)
2	Bernhard Dachs	Austrian Institute of Technology (AIT)
2	Doris Schartinger	Austrian Institute of Technology (AIT)
2	Anna Wolfmayr	Austrian Institute of Technology (AIT)
2	Laura Resmini	Università di Milano Bicocca (UNIMIB)
2	Mara Grasseni	Università di Milano Bicocca (UNIMIB)
2	Simona Comi	Università di Milano Bicocca (UNIMIB)
4	Torben Pedersen	Copenhagen Business School (CBS)
4	Peter D. Ørberg Jensen	Copenhagen Business School (CBS)
3	Mahdi Ghodsi	Vienna Institute for International Economic Studies (wiiw)
3	Michael Landesmann	Vienna Institute for International Economic Studies (wiiw)
3	Olga Pindyuk	Vienna Institute for International Economic Studies (wiiw)
2, 3	Ferry Koster	Erasmus University Rotterdam (EUR)
2, 3	Nele Cannaerts	Erasmus University Rotterdam (EUR)

The report benefitted from the comments and guidance of Roberta Capello (Politecnico di Milano), Giovanni Perucca (Politecnico di Milano) and attendees of the TWIN SEEDS Work Package 2 workshop held online in September 2023.

Table of contents

List of Tables

List of Figures

Glossary

Base technologies – technologies encompassing internet of things, cloud services, big data and analytics

Friendshoring (allyshoring) - the strategy of transferring business operations or sourcing from countries regarded as political and economic allies.

Global production network (GPN) - 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

Global value chain (GVC) - production structures resulting from geographically dispersed stages of production, following locational advantages tied to a particular destination.

Industry 4.0 (Fourth Industrial Revolution; 4IR) - stage in the digital transformation of the manufacturing sector, characterised by the rise of data and connectivity, analytics, human-machine interaction, and improvements in robotics.

Multinational enterprise (MNE) is a company producing goods or delivering services in more than one country.

Nearshoring - the strategy of transferring business operations to a nearby country, especially in preference to a more distant one.

Reshoring - the strategy of transferring business operations that were previously offshored to foreign location back to the country from which they were originally relocated.

Resilience - capability to bounce back from a shock, leading to a rebound or a return of the system to the pre-shock path; the ability of the system to absorb the shock or a process of positive adaptation.

Services Trade and Modes of Supply Mode 1 - Cross border trade: services supplied from the territory of one Member into the territory of any other Member.

Services Trade and Modes of Supply Mode 2 – Consumption abroad: services supplied in the territory of one Member to the service consumer of any other Member.

Services Trade and Modes of Supply Mode 3 - Commercial presence: services supplied by a service supplier of one Member, through commercial presence, in the territory of any other Member.

Services Trade and Modes of Supply Mode 4 - Presence of natural persons: services supplied by a service supplier of one Member, through the presence of natural persons of a Member in the territory of any other Member.

Vaccine club - a phrase used to describe a group of countries that have the capacity to produce vaccines, namely China, Germany, India, Russia, the U.K., and the U.S.

Executive summary

The WP1 report on "Trends and drivers of global value chains in the pre-pandemic wave of globalisation" has outlined new empirical findings on EU's performance and specialisation in GVCs, the effects of changing trade and investment policies on the development of GVCs and MNEs, as well as the implications of technological innovations on the structure of production and knowledge creation in GVCs. Yet, the COVID-19 pandemic has exposed the fragility of the global production networks as the disruption we faced in 2020 had unparalleled magnitude and scale. Severe supply security issues have emerged stemming from lockdowns, the shortage of supplies of intermediate and final products, which in turn only heightened the GVC vulnerabilities.

This report builds on the WP1 analysis of the impacts of technological, geo-economic and geo-political changes on GVCs and production networks, now focusing on the pandemic period. The research explored how the pandemic induced changes in GVCs and production networks and assessed how sustainable the strategies adopted by MNEs were for their future operations. Key factors that we considered were: the role of reshoring practices in enhancing the resilience of GVCs, as well companies' digital shift to the Industry 4.0. technological paradigm.

The key messages of the report can be summarised as:

- In the first half of 2020, the COVID-19 crisis led to an increase in trade barriers in many countries, affecting 90 in total. These actions were in direct contradiction to the WTO's rules and ignored the World Bank's advice on how to use trade policy to cope with the pandemic. The outcomes of these actions were limited, partly since they effected contradicting impact: just as some markets were making imports cheaper, key producers were making goods more difficult to source. Healthcare products were often the main target, but the foodstuff trade was also limited by several countries. Likewise, when COVID-19 vaccines became available at the end of 2020, they created more tension as some governments imposed direct and indirect limits on their trade. On the other hand, restrictions on imports were used rarely and if applied, affected primarily 'other' goods. They were mainly implemented in developing countries.
- Since trade barriers were used to leverage trade policy to increase the domestic supply of key goods, we also observe that global production was restructured, but only in certain situations. The foreign subsidiaries' share of EU MNEs did not change much on average, which implies that EU MNEs remained cautious and did not undergo major shifts. To this effect the origin country of MNEs played a significant role. Specifically, MNEs from the hardest-hit regions of Central and Eastern European countries increased the number of foreign subsidiaries they control outside the EU on the total number of subsidiaries, while decreasing the share of subsidiaries in the European countries other than their own. On the other hand, MNEs based in the

worst-hit regions of Western European countries did the opposite, reducing their foreign subsidiaries' share, regardless of location within or outside the EU, as shown by the negative and significant COVID coefficients.

- When analysing healthcare and especially vaccine manufacturing, which were considered key GVCs in maintaining resilience, Europe has lagged in its response to the pandemic compared to the U.S. The U.S. acted swiftly and flexibly, launching a $10 billion program to support and expedite the development and production of four vaccine candidates. The U.S. also fostered the collaboration of the government, the private sector, and academic institutions to streamline the approval process. Europe has learned from some of these best practices and enhanced its preparedness and response capacity by creating the Health Emergency Preparedness and Response Authority (HERA) in 2021. HERA aims to improve readiness for potential health threats and manage and coordinate in a crisis, like the pandemic, in the future.
- A certain challenge is the funding structure in vaccine manufacturing, which is mostly directed to research on the mRNA vaccine. The mRNA vaccine has proven to be effective against COVID-19, but its ability to protect against other possible pandemic viruses is uncertain. Therefore, it is important to invest in a variety of vaccine technologies and not limit the research to one single approach. One of the difficulties in vaccine research is the unequal allocation of resources. Most of the money from big pharma is spent on the vaccine types with the largest potential for cancer treatment, leaving other vaccine types with less backing. This means that the research on other vaccine types is mainly carried out by universities and with some public funding, resulting in a more scattered and inconsistent landscape.
- Europe has achieved significant progress in developing, equipping and operating vaccine production plants across the continent, now possessing a much higher ability and capacity to produce vaccines than before the pandemic. The investments involve both European and US pharma companies scaling up their engagement, e.g. by partnership cooperation between Lonza, Catalent and Moderna, Pfizer-BioNTech with Sanofi or Novartis and Merck, all aimed at increasing vaccine manufacturing capacity. However, sourcing the vaccine ingredients remains a challenge. Although most of the over 200 vaccine ingredients required to make the vaccine are sourced within Europe, firms faced significant delays in deliveries of some of the ingredients during the pandemic. The most acute bottleneck, though, was with the components imported from China. These components are scarce and difficult to find elsewhere, and their delivery time rose from days to months during the crisis. Companies attempted to find other sources, but none of them satisfied the quality standards.
- The decision to apply reshoring, nearshoring or friendshoring as part of the production restructuring was caused by a multitude of drivers. Some companies took advantage of the technological innovations stemming from Industry 4.0 advancements, while others were pushed by the external shock and the disruption of supply and demand caused by the pandemic. In particular, companies affected by the pandemic claimed to have experienced higher costs and lower demand in their

foreign markets. Therefore, relocating was aimed at consolidating their production and avoiding the unnecessary fixed costs in foreign locations. On the other hand, companies that were not severely impacted by the pandemic based their reshoring decisions on the diminishing importance of relatively cheap labour and higher administrative and logistic costs overseas. Moreover, for these companies, quality and enhanced expertise were also essential factors in their strategy to reshore.

- Digitilisation supported industries' export resilience to the COVID-related shock. Across all industries it was mainly manufacturing industries that contributed explanatory power to the overall effect of digitalisation on the resilience of export activity, both over the longer-term and during the COVID-19 crisis. This strong effect of manufactured goods trade was mainly due to the heterogeneity within the set of services industries which contained industries highly affected by lockdowns and disturbances to international transport (such as travel/tourism and transport services themselves) and other industries which could switch well towards the provision of services on-line. This heterogeneity was well documented by results and, when this is taken into account, the digitalisation-intensive group of service industries showed particularly high resilience in their exports during the COVID-19 crisis.
- Many of the MNEs' projects related to the adoption of I4.0 technologies were initiated before the outbreak of COVID-19, and the choice of technological solutions was not aligned with the pandemic but with the market demand and requirements. Companies are using digitalisation as means for increasing the effectiveness and efficiency of resource usage by focusing especially on AI-based technologies, automatisation, big-data analysis and cloud computing. However, digital transformation has become an inherent element of companies, where the mere adoption of innovative technological solutions does not guarantee the creation of tangible competitive advantage but primarily allows companies to remain a player in the market.
- I4.0 technologies that companies implemented during the pandemic were not restricted to manufacturing processes but were also adopted in other operational units like procurement, sales or back office processes. These technologies were labelled as "competence-enhancing", i.e. the companies leveraged their existing knowledge to improve their operations without making the previous ones irrelevant and without applying drastic layoffs within their employment structures.
- In contrast to the existing literature, which mostly assumed a decrease in R&D due to a crisis, in the case of COVID-19, we revealed a diverse range of outcomes, from large increases to substantial reductions. Firms with an ex-ante low R&D intensity on average performed better than R&D intensive firms. Moreover, firms with higher shares of public funding on R&D expenditures performed significantly better during the crisis than firms with lower or no public funding.
- The COVID-19 pandemic also affected the employee management and relationships among MNEs. Companies' approaches to the issue differed depending on the GVC

mode (market, modular, relational, captive, hierarchical) adopted. Organisations in market-mode GVCs tend to invest less in human capital than those in other modes, while organisations in modular-mode GVCs were more likely to provide upskilling opportunities, consult with staff, and share decision-making processes in a transparent and participatory way. However, these differences do not imply a significant impact of GVC governance modes on employment strategies during the COVID-19 pandemic. Instead, the level of collaboration in the GVC is more relevant for determining the outcomes of employee strategies. The higher the collaboration, the greater the investment in human capital, the more frequent consultation with representatives, and the more extensive participation in decision-making by employees.

1. Introduction

One of the most profound crises of recent times, the COVID-19 pandemic, has impacted the world in unprecedented ways, causing societal disruption, affecting the business landscape and hampering global trade (Kilpatrick and Barter, 2020; Chowdhury et al., 2021; Verbeke & Yuan, 2021). It is estimated that following the outbreak of the virus globally, nearly 60% of the firms faced severe delays in shipping their components and raw materials from China, while strict lockdowns and travel restrictions caused altogether 75% of the firms experience some disruptions in their supply chains during the first year of the pandemic (Fortune, 2020). These disruptions triggered challenges related to sudden drops in economic activity and financial and credit market instability.

The coronavirus pandemic required companies to act swiftly and, unlike previous shocks, in unprecedentedly uncertain conditions (Gkeredakis, Assaf-Lifshitz and Barrett, 2021; Nasih et al., 2022). But not only companies were bent on building their resilience capacity. Governments were very active in trade during the pandemic. Faced with shortages of key products in the first weeks and months, they quickly responded with a raft of trade policy measures, including both trade bans and export restrictions on the one hand and trade facilitation and tariff reductions on the other (Curran et al., 2021; Evenett et al., 2022). Over time, concerns about the security of supply of key pandemic products led to increased policy rhetoric on the risks of relying on GVCs and the need for 'autonomy', 'self-reliance' and 'resilience'. Despite extensive debate on whether reconfiguring GVCs would increase resilience (Gereffi et al., 2022; Jean & Vicard, 2020; Miroudot, 2020), many governments began to develop new policy interventions aimed at supporting the development of national or regional value chains. Although these interventions are not 'trade policy' as such, the subsidization of local production capacity with the express intention of reducing trade, especially when support is dependent on the nationality of the manufacturer, is also a form of 'trade protectionism'.

Supply chain disruptions caused by the COVID-19 pandemic, coupled with governmental attempts to draft new policy interventions, created significant challenges for international firms in terms of governance, supply chain reconfiguration, and regionalization (Verbeke, 2020). In addition, the narrowing gap in labour costs (Tate, 2014) and concerns about product quality have diminished the competitive edge of the offshored countries (Ancarani, Di Mauro, Mascali, 2019). As a result, firms were compelled to re-evaluate their supply chain strategies, with an increasing number of companies opting for a reshoring strategy to bring their sources of intermediate goods closer to their home markets.

As the TWIN SEEDS project aims to provide robust empirical evidence on how GVCs have been affected by globalisation and most recent developments, as well as examine the trends in international trade, MNE behaviour, and production organisation in relation to the changing policy environment and new technologies ('twin seeds'), this report - the second in the series of seven reports (see Figure 1)- is expanding the analysis presented in WP1 report. It analyses the effects of the COVID-19 pandemic on GVCs, in particular investigating the reconfiguration of GVCs and MNEs and supply security issues as well as providing insight

into specific industries which on one hand significantly impact the output and security of the European economy and on the other hand have been themselves subjected to major changes.

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

Source: Authors' elaboration.

The report is organised into six chapters: the introduction that sets the background for further exploration, three analytical chapters, a discussion of the results and finally, policy implications stemming from the research. In Chapter 2, we investigate how the pandemic has affected the structure of GVCs and MNEs. Here, we focus on how trade policy interventions have evolved since COVID-19 and what impact it has had on EU value chains. In light of these regulations, we also investigate the changes in the geographical and sectoral composition of global production networks (GPNs). We then examine backshoring and nearshoring as strategies companies employed as a response to lockdowns, supply bottlenecks and other challenges posed by the pandemic. In Chapter 3, we study the impact of the COVID-19 pandemic on the degree of digital transformation. Although digital transformation in both manufacturing and service industries had been initiated before the outbreak of the coronavirus, here we investigate whether European companies have undergone any major shift in how digital solutions, including Industry 4.0 advancements, have been approached. Since the COVID-19 pandemic shed varying impact on industries, in Chapter 4 we focus primarily on the healthcare sector, exploring how the pandemic and policy responses to it affected the competence to develop and manufacture large-scale vaccines globally. This sector deserves special consideration as the pandemic has exposed supply security issues in the GVCs of significant European bearing. In the remainder of the report, Chapters 5 and 6 summarise the key findings and provide policy implications stemming from the findings.

2. Reconfiguration of Global Value Chains

Contextual background and research objectives

The global economy is currently highly interconnected through GVCs (Strange, 2020). At the same time, these connections are affected by global developments. WP 1 report on "Trends and drivers of global value chains and the role of MNEs in the recent wave of globalisation" has revealed that prior to the pandemic EU countries found themselves more and more dependent on foreign demand to generate GVC income in manufacturing. Although over time the Eastern European countries increased their income share at Western European countries' expense, overall the latter ones still enjoyed much higher shares in total. Likewise, Europe has undergone an increased specialisation in the roles countries played in the value chains, with Western EU countries focused on pre- and post-production activities within the GVC, and Southern and Eastern EU countries focused on production itself.

The COVID-19 pandemic can therefore be seen as a major disruption that potentially could impact the trends and outputs generated through the previous decades. Although the COVID-19 pandemic was indeed a temporary shock, it undeniably had disruptive effects on global markets, not only because the illness severely affected millions of people but also because of the policy instruments implemented by every state to inhibit the diffusion of the pandemic. Since these measures were not coordinated at the supra-national level, they caused scattered interruptions of the production chain, thus making global production networks less efficient and more difficult to coordinate and monitor at a distance. The transitory nature of the shock may have suggested a wait-and-see approach, while the severity of the shock may have induced MNEs to react by either finding new locations, potentially less affected by the pandemic, where to move some stages of the production process or reducing their international exposure and reshoring some stages of the production process in the country of origin or the neighbouring countries to reduce transportation and coordination costs.

Not only the policy measures aimed at curtailing the pandemic outspread but also government interventions which seek to restructure GVCs face very different contexts depending on their geography, governance and pre-pandemic structure; reactions to the pandemic varied at firm, GVC and country level and inappropriate public policy can do more harm than good. Although there is extensive research on GVCs and their evolution, we still know relatively little about the role of the state in GVCs and how such production structures might react to government interventions which consciously seek to reshape them. The indirect role of the state and the manner in which regulation and facilitation help to structure the geography of production has been relatively little explored, both in GVC analyses more generally (Curran et al., 2019) and in relation to the pandemic in particular.

Chapter 2 of this report will therefore tackle research questions that relate to regulatory sphere and how, if at all, these regulatory interventions affected the GVC organisation. At

the same time the GVC (re)organisation will be studied at the firm-level to understand the reasons and explore directions underlying GVC changes. The main research questions include:

- What were the objectives of the policy support provided by states seeking to restructure GVCs, and which key government trade policy interventions were implemented during the pandemic?
- Did the pandemic shock force EU MNEs to re-organize their production networks and if yes, was the reorganization homogenous across economic sectors?
- To what extent and in what way did COVID-19 affect key governance strategies, including offshoring/reshoring strategies, employment strategies and firm-level organisational changes?

Methods of analysis and data

To address the key issues raised in this Chapter, we applied various research questions which were divided into two separate perspectives: country- and region-level analysis to study policy interventions and GVCs reorganization, as well as firm-level analysis to investigate the COVID-19 impact on the internal governance changes of MNEs.

For the first research question, we mobilised the databases of the International Trade Centre (ITC) and the Global Trade Alert (GTA) to detail the extent of trade policy interventions during the pandemic and their nature. We then explored the specific case of restrictive interventions in medical goods, highlighting that personal protective equipment (PPE), especially masks, were key targeted products. In light of this, we explored trade policy interventions in this GVC in more detail, focusing on key suppliers. We then used the ITC TradeMap database to explore evolutions in trade in this sector in key world traders. Finally, we undertook a more detailed analysis at the EU level.

Next, to shed light on the possible impact that COVID-19 might have exerted on global production networks (GPNs) created by EU MNEs, we assembled and merged two different datasets: information on EU-MNEs and their foreign subsidiaries (Amadeus-Orbis), and the severity of the pandemic (OxCGRT).

Information on EU-MNEs and their foreign subsidiaries information has been drawn from Amadeus-Orbis, a dataset provided by Bureau van Dijk, which includes comprehensive information on financials and detailed corporate structure of about 21 million companies across Europe. In particular, we extracted data about European "Global Ultimate Owners" (GUOs), i.e. the independent companies at the top of the corporate structure headquartered in the EU and their foreign affiliates. We ran the analysis thrice in 2014, 2018, and 2021. As MNEs, we considered those firms that controlled at least one foreign subsidiary in one of the listed years. To assess how the pandemic shock may have altered GPNs, we constructed a balanced dataset that excludes any bias from MNEs' market entry or exit. We analysed 8,838 EU MNEs over a three-year period, resulting in 26,514 observations after removing any missing values from any source.

The reorganization of global production by multinational enterprises can be measured in several ways. Initially, we used as a dependent variable the share of foreign subsidiaries – i.e. controlled firms located outside the country of origin of the MNEs – held by each multinational company on the total number of subsidiaries owned. Subsequently, to understand whether the reorganization of the production networks has implied the reshoring of production stages within the EU, we also considered as a dependent variable the share of subsidiaries located in the EU on the total number of subsidiaries controlled by each EU MNE.

The impact of the COVID-19 pandemic has been measured first by the number of COVID-19 deaths at the NUTS2 level and then by the degree of stringency of the anti-COVID-19 measures implemented at the country level. The data on the number of deaths in each EU region were collected from Eurostat. In particular, we considered the excess of mortality, i.e. the variation (in percentage) in the average number of deaths (regardless of the cause) in the last two years with respect to the average number of deaths in the previous five years.

Data on the degree of stringency were collected from The Oxford COVID-19 Government Response Tracker (OxCGRT). The stringency index is a composite index measured at the country level, calculated using several indicators of closure and health system response. Since it varied daily, we computed a simple annual average. The value of the index in the years 2014 and 2018 is, by definition, always zero.

The internal governance changes were studied applying both quantitative and qualitative methods on the firm-level. We used a comparative multiple case study of five firms with the aim of uncovering patterns of causes and effects around the three topics of reshoring, COVID-19 and Industry 4.0 (I4.0) technologies among Austrian companies. We thereby followed a systematic selection process to identify firms, which included a search of media database for news on firms' reshoring activities starting from late 2019, expert interviews, and information from the "European Reshoring Monitor" (Nassimbeni et al. 2019). Overall, this resulted in a list of 24 potential firms that were all contacted in early 2023 and in five firms that participated in the study itself. The interview partners were strategic employees in managerial positions such as Chief Executive Officers (CEOs) or heads of prominent functions such as purchasing or procurement and took place in May/June 2023. Qualitative data collected through semi-structured firm interviews has been complemented by supplementary data from the media analysis and firm websites. In accordance with the multi-case theory building approach proposed by Eisenhardt and Graebner (2007), the analytical process was initiated by meticulously constructing comprehensive case histories for each enterprise under investigation.

Finally, a survey was conducted among 978 organisations in the Netherlands (a response rate of 54 per cent) from different sectors (both private and public) and varying in size. The questionnaire consisted of around 100 questions about international trade, GVC governance, digitalization, employment strategies, and performance. Of these organisations, 405 participate in GVCs. Additionally, to gain more insight into firm-level organisational changes due to COVID-19, we also conducted a qualitative case study using semi-structured interviews to collect data from different organizations, who are part of a GVCs. Appendix D

summarizes the methodology, the internal consistency of the scales, explains how the GVC modes are constructed and provides insight into the qualitative study.

Findings and discussion

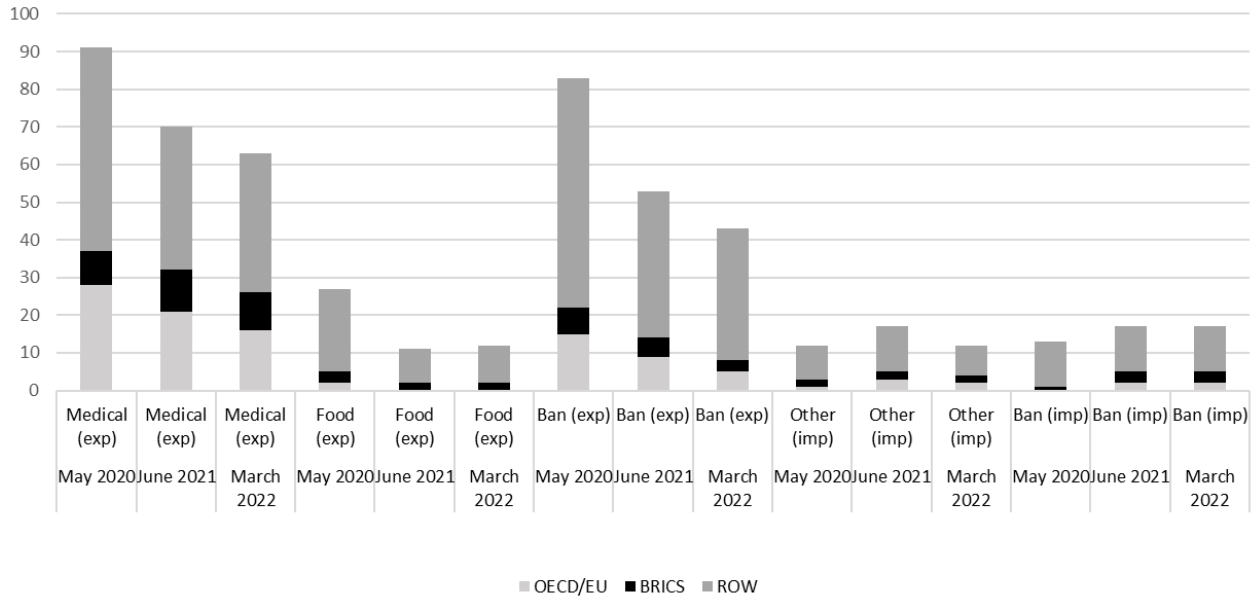
As the pandemic spread, it quickly became evident that the combination of the impact of widespread lockdowns on industrial productive capacity and soaring demand for certain products vital to containing the pandemic, were causing shortages globally. Faced with this problem, many governments reacted with the most straightforward and blunt of policy instruments – export bans and import liberalisations. Concretely, governments sought to use trade policy to both prevent (or restrict) exports and to facilitate critical imports, through tariff reductions, reducing red tape and waiving previously imposed anti-dumping duties and other restrictions (Evenett et al., 2022).

By restricting firms' capacity to export and making imports cheaper, policymakers hoped to increase local supply. By early May 2020, the COVID-19 pandemic triggered trade restrictions in 90 countries. These measures were at odds with the principles of the WTO (WTO, 2020) and went against the World Bank's recommendations on how to use trade policy to tackle COVID-19 (World Bank, 2020). The success of these policy measures was muted, not least because they had contradictory effects: just as some markets were making imports cheaper, key producers were making goods more difficult to source. Although medical goods were often the key concern, exports of foodstuffs were also restricted by several countries (WTO, 2020a). As vaccines started to emerge at the end of 2020, they became a further source of conflict, with several governments enacting direct and indirect restrictions on their trade (Evenett et al., 2021).

Restrictive measures, presented in Figure 2, were concentrated on controls on exports (exp in the figure) and focused on medical goods. As the figure shows, they were highest at the beginning of the pandemic in May 2020, when 91 measures were in place. They slowly fell over time, with 63 measures still in place in March 2022. It should be noted that the nature of these measures varied over the pandemic. While some restrictions persisted, many were removed (for example, on PPE), although they were often replaced with new regulations (on vaccines). The most restrictive export trade policy interventions in OECD/EU countries were in medical goods. Restrictions on food exports were mostly undertaken by developing countries. Overall, bans on trade were surprisingly common. Although they also fell steadily over time, there were still 43 export bans in place in March 2022, mostly targeting medical goods or food.

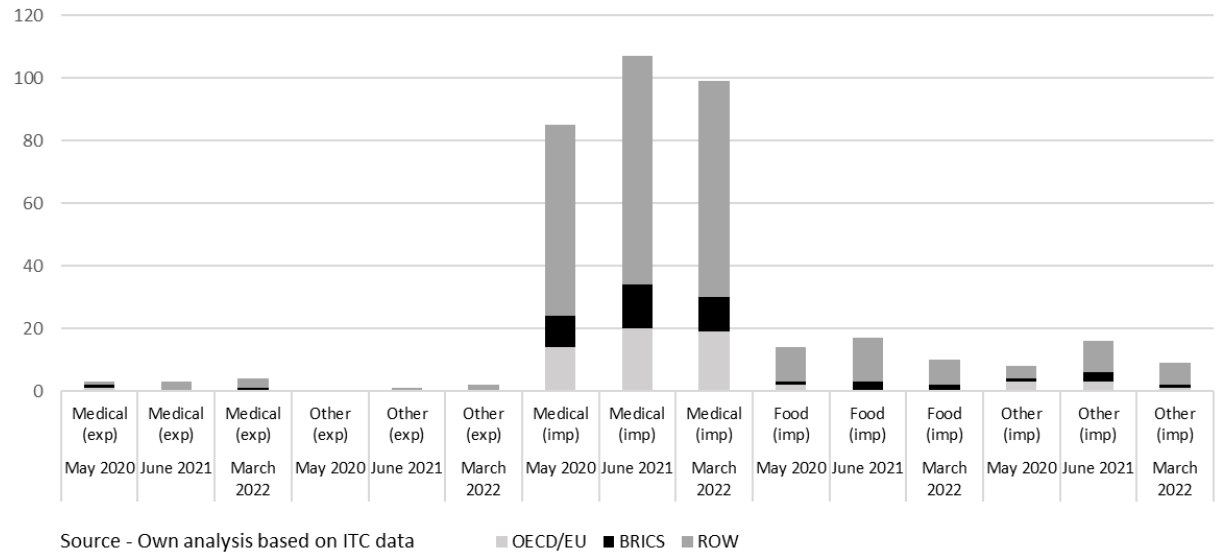
Restrictions on imports (imp in the figure) were rare and primarily affected ‘other’ goods. They were mainly taken in developing countries. As highlighted by Curran et al. (2021) although these measures were not widespread, they were amongst the most problematic in trade policy terms, as they often seemed unlikely to be WTO-compatible.

Figure 2: Restrictive COVID-related measure: 2020-22



Source: Authors' own elaboration based on ICT data.

Figure 3: Liberalising COVID-related measures: 2020-22



Source: Authors' own elaboration based on ICT data.

Liberalising measures (Figure 3) include simple facilitating measures like speeding up or waiving import controls, as well as more substantive tariff elimination on critical goods. Like restrictions, they were concentrated in medical goods, but focused on imports and were mostly taken in developing countries. Contrary to restrictions, they increased during the first year of the pandemic and remained high in 2022 (99 measures). The next most important set of interventions was in food imports. These were again concentrated in developing countries, although 'other' measures were almost as high in the two most recent periods.

These included liberalization measures on iron and steel in India and the reduction of customs duties to 5% in the British Virgin Islands.

Many governments reacted to COVID by seeking to leverage trade policy to increase domestic supply of key goods. It is rather ironic that restrictions on exports emerged at the same time (and often in the same countries) as liberalisation measures aimed at increasing imports. While most measures focused on medical goods, several governments intervened to address food supply and other concerns. Simultaneously, governments did not hesitate to ban trade, although this is contrary to the principles of WTO, especially Article 11, which outlaws prohibitions and restrictions on trade. From a GVC perspective, trade bans clearly undermine the usual functioning of the value chain, regardless of their governance structure. If bans cover all trade, lead firms have limited leeway. If only some sources are hit (as in the case of initial restrictions on imports from China), depending on the level of flexibility within the GVC, lead firms may be able to shift their sourcing structures in response. Although the analysis has presented the short-term, more immediate policy responses to the pandemic rather than these longer-term shifts, it should be noted that these are part of a much wider move towards more interventionist policy, both in the EU and globally, which will likely have important long-term impacts on the geography and nature of many GVCs. In light of these policy responses to COVID-19, we now turn to reporting the observed changes in the reorganization of GVCs.

The COVID-19 pandemic indeed had an impact on the reorganization of global production but under specific circumstances. The impact of COVID-19 on the share of foreign subsidiaries[1] was, on average, insignificant, suggesting that EU MNEs adopted a wait-and-see approach. However, when the country of origin of MNEs is taken into consideration interesting results emerge. In particular, multinational firms located in the most affected regions of Central and Eastern Europe increased their overall share of foreign subsidiaries but at the same time reduced the share of subsidiaries located in Europe (except for the country of origin of the MNE). In contrast, MNEs headquartered in the most COVID-affected regions of Western Europe made a different choice, reducing the share of foreign subsidiaries, regardless of the location.

Several reasons may explain the heterogenous impact of pandemics on global production reorganization, which cover: (i) an increase in transportation costs, which may induce MNEs to increase the number of production facilities in the destination markets or (ii) an increase in the costs of doing business abroad, which instead may induce MNEs to reduce their international exposure. Other factors specific to Western and Eastern Europe may also be at work, including the quality of the local institutions and the overall degree of confidence in the socio-economic characteristics of regions of origin, stronger in Western rather than in Eastern EU countries. The increased confidence in the resilience of the national economic system may be the underlying reason for the reshoring process characterizing MNEs headquartered in Western EU regions.

[1] As mentioned in theMethods section here we define 'share of foreign subsidiaries' as controlled firms located outside the country of origin of the MNEs.

The data confirm the hypothesis that COVID-19 had an impact on the location decisions of multinationals, leading them to restructure their global production networks and relocate their subsidiaries. Furthermore, our results suggest that the severity of the shock matters, as MNEs based in the hardest-hit regions show different location patterns from those based in the least-hit regions. The study also revealed that the effects of COVID-19 vary widely across firms. In particular, within each geographical area, the impact of COVID-19 is mediated by:

- *the degree of internationalization of MNEs*; measured by the distribution of the share of foreign affiliates over the total number of firms controlled by each MNE. In Eastern European countries, MNEs headquartered in the most COVID-affected regions with a low or around the median share of foreign subsidiaries, have increased their foreign investments more than MNEs in the least COVID-affected regions. In contrast, the most internationalized MNEs tend to modify their location choices by reducing the weight of foreign subsidiaries compared to domestic ones. Thus, the shock represented a breaking point for both types of firms, making GPNs more homogeneous in size. In Western EU countries, the impact of COVID-19 was always negative, regardless of the degree of internationalization of the MNEs, though smaller in magnitude for companies with the largest number of foreign affiliates.

- *the sector in which MNEs operate*; in particular, we found that MNEs located in the Eastern EU regions most affected by COVID-19 have increased the complexity of their GPNs in the low value-added sectors more than the MNEs in the least affected regions. In the most COVID-affected Western European regions, MNEs in manufacturing sectors and in knowledge intensive sectors have been let to reshore their production stages. However, in the other economic sectors, the impact of COVID was insignificant.

- *the size of the headquarters*, measured in relation to number of employees. We categorize companies into three groups based on the number of employees: small (less than 50), medium (50 to 250), and large (more than 250). We found that COVID-19 led to a reorganization of small GPNs only, i.e. those with headquarters with less than 50 employees, regardless of headquarters' location. However, the pandemics had different effects on the reorganization of Eastern and Western European MNEs. In the former, we observed an increase in the share of foreign affiliates, while in the latter, we observed a decrease. This supports the idea that Western EU MNEs re-shored their activities while Eastern EU MNEs off-shored them.

- *the stringency of the anti-COVID measures*. National governments' policies to contain the virus also influenced the impact of COVID-19 on MNEs. Specifically, we discovered that MNEs in regions with a high number of COVID cases and strict anti-COVID measures decreased their internationalization level more than MNEs in regions with a low number of COVID cases within the same country. The shares of foreign affiliates have grown more for MNEs based in regions that suffered more from COVID-19 in countries with a low stringency index, compared to MNEs based in regions that

suffered less within the same country. This means that national governments' policies to shut down activities and reduce social contact have made it more likely for MNEs to relocate their activities back to their home countries. It is important to note that the most severe policies have been applied in Western EU countries

COVID-19 has affected the complexity of GPNs differently across regions. In the West, where GPNs were more intricate, COVID-19 has made them simpler. In the East, where GPNs were less elaborate, COVID-19 has increased their expansion. Yet, this general finding conceals a lot of variation, which becomes evident when we account for the size and the sector of the MNEs involved. Table 1 and 2 show these more detailed results.

Table 1: Impact of the COVID-19 on GPN; Dep. Variable: Share of Foreign Subsidiaries

	Total	Sector type						Size		
		HM	LM	KIS	LKIS	AGR	E&C	<=50 empl.	50-250 empl.	> 250 empl.
Eastern Europe: most COVID-affected regions	⇧	----	⇧	----	⇧	⇧	----	⇧	----	----
Western Europe: most COVID-affected regions	⇩	⇩	⇩	⇩	----	----	----	⇩	----	----

Note: ---- coefficient not statistically significant
HM - High-Tech Manufacturing
LM - Low-Tech Manufacturing
KIS - Knowledge-intensive Services
LKIS - No Knowledge-intensive Services
AGR - Agriculture
E&C - Energy and Construction
Source: Authors' own elaboration.

The country- and regional-level data indicated significant changes in the GVCs' reorganization during the pandemic period. Therefore, a crucial question remained on how these shifts rolled out within firm-level governance models. The two key aspects this report focuses on include the impact of the pandemic on the relocation strategy, on employee governance and on the governance modes. The study showed that COVID-19 was not the only external shock that affected firms in GVCs and forced them to change their organisation. Other shocks, such as the energy crisis, the war in Ukraine, Evergreen (2021 Suez Canal obstruction) and the developments in China, all cause firm-level changes. These shocks made it difficult for firms to plan ahead, as they faced a complex, ambiguous and fast-changing environment. The firms indicated that these environmental factors created a sense of urgency and pressure to adapt their organisational activities.

Table 2: Impact of the COVID-19 on GPN; Dep. Variable: Share of Foreign Subsidiaries in Europe

	Total	Sector type						Size		
		High Manuf	Low Manuf	KIS	LKIS	Agric.	Energy and const.	<=50 empl.	50-250 empl.	> 250 empl.
Eastern Europe: most COVID-affected regions	⇩	⇩	-----	⇩	⇩	----	----	⇩	----	-----
Western Europe: most COVID-affected regions	⇩	----	⇩	-----	----	----	----	-----	-----	-----

Note: ---- coefficient not statistically significant
HM - High-Tech Manufacturing
LM - Low-Tech Manufacturing
KIS - Knowledge-intensive Services
LKIS - No Knowledge-intensive Services
AGR - Agriculture
E&C - Energy and Construction
Source: Authors' own elaboration.

Firstly, since the hypothesis that COVID-19 influenced the location choices of multinationals, causing them to reorganize their GVCs and reshore their activities, is supported by the data, we investigated the phenomenon, concentrating on the antecedents and specifics of the process. A common reason underlying the reshoring activities were the diminishing cost advantages of foreign production in that period. However, there were two main reasons why reshoring was a noticeable trend. Relocating production was caused either by technological opportunities stemming from Industry 4.0 advancements or by the external shock and the disruption of supply and demand due to the pandemic. Specifically, companies whose relocation was prompted by the pandemic, supply bottlenecks faced cost rise in the period, as well as demand fell. Consequently, these companies opted to relocate back to their home countries in order to centralize production and avoid unnecessary fixed costs in foreign production plants. In contrast, among companies whose reshoring decisions were not influenced by the pandemic, the rationale for returning home was due to the diminishing significance of low labour costs and higher administrative and logistic costs abroad. Additionally, for these companies, quality and enhanced expertise were equally instrumental in making the reshoring decisions.

The COVID-19 pandemic did have an effect on the reshoring decisions of firms. Reasons behind this were low degrees of capacity utilisation as a result of decreasing demand, or long transportation routes and local lockdowns during the pandemic proved difficult and increased transaction costs. The interruption in the supply of input factors exerted additional pressures and seemed to have made firms slim down their operational processes. Notably,

some companies opted to reshore specifically due to the pandemic's impact, i.e. the choice to reshore would not have been made if not for the pandemic-induced circumstances, which aligns with Verbeke's (2020) findings.

The company perspective on technological opportunities from I4.0 surprisingly reveals that none but one of the studied companies considered the adoption of new digital technologies as a crucial factor in their decision to reshore. This aligns with the research findings of Ancarani, Di Mauro and Mascali (2019), Chiarvesio and Romanello, (2019), Müller, Dotzauer and Voigt (2017), but not with those of Dachs, Kinkel and Jäger (2019). We conclude that for I4.0-enabled reshoring, there has to be a gap in technological endowments/ configurations between the firm's affiliates in the home country and in the offshoring location country. If the gap is not there, the reshoring decision is not grounded in technological reasons.

Secondly, COVID-19 has not only impacted the geographical reconfiguration of the GVCs but also its internal organisation. Respondents indicated that overall COVID-19 altered – to various degrees – three main governance areas, namely the quality of the goods and services that they delivered, the quality of their relationships with external partners, and employee motivation. The degree of the impact varied considerably across GVC governance modes. The analyses show that organisations using the modular form reported most often that they were negatively impacted by COVID-19. Also, the pandemic had a particulary negative effect on relationships with external partners.

As the survey included information about GVCs, the negative impact of COVID-19, and employee strategies, it was possible to relate them. This led to several insights concerning the question of how the pandemic played out for these firm-internal factors. The data revealed a link between human capital investments and their consultation with employee representatives and the severity of the COVID-19 impact. Organizations that suffered more from the pandemic tended to invest more in the human capital of their personnel and consult more often with employee representatives. However, there is no relationship between the negative impact of COVID-19 on employee participation.

We observe minor variations across the different GVC governance modes. The most notable one is that organisations operating in market-mode GVCs are less likely to invest in human capital compared to organisations in the other modes. Organisations operating in modular-mode GVCs, on the other hand, are more likely to invest in upskilling opportunities, consult with personnel, and are more open to share transparent and participatory decision-making processes. Overall, GVC collaboration is strongly related to these employment strategies, but at the same time, the differences do not indicate a significant influence of GVC governance modes on employment strategies in the context of COVID-19. Instead, the level of collaboration in the GVC is more important for explaining the outcomes of employee strategies. The stronger the collaboration, the higher the investment in human capital, the more frequent consultation with representatives, and the more profound participation in decision-making by employees.

Finally, the employment strategies and GVC governance modes explain why the experience of negative impact of COVID-19 is associated with higer levels of organisational performance. Organisations faced with these negative consequences have stronger GVC capabilities and use more advanced employment strategies that enhance human capital and employee participation in decision making, which help them cope with the challenges posed by the pandemic.

COVID-19 had a profound effect on global relations and the need for sustainability, economic security, and health, as reflected by the qualitative study. However, the reform of individual organisations was not directly influenced by the pandemic. Some organisations began to rethink their production activities and whether to keep them in-house or outsource them to other partners, but this was more of a secondary consequence of COVID-19. The pandemic also affected the supply chain and its flexibility, as firms faced longer delivery times due to production disruptions caused by lockdowns and social distancing measures. Nevertheless, the structure of the chains remained largely unchanged by COVID-19.

3. Digital transformation in times of pandemic

Contextual background and research objectives

Services are a key sector of the global economy, accounting for the bulk of GDP in most countries and for a significant share of global trade. According to WTO data, cross-border trade in services (Modes 1 and 2 of services trade) accounted for 22% of total global trade in 2022. The share of services in trade becomes even higher if sales of services through foreign affiliates of multinational companies are added (Mode 3) and services supplied by nationals of one country in the territory of another country (Mode 4). Services have become significantly more tradable as trade costs for financial services, communication services and business services fell by between 30% and 60% between 2000 and 2019, supported by the development of information and communication technology and the growth of air traffic (Benz, Jaax and Yotov, 2022). Digitally deliverable services (DDS), which can be delivered via information and communications (ICT) networks, have been particularly important for services trade expansion. They include ICT services themselves, sales and marketing services, insurance and financial services, professional services, back-office services, research and development (R&D), and education and training services, among others.

In addition, services are traded indirectly as a part of value added embodied in merchandise products (so-called 'Mode 5' of services trade as defined in Cernat and Kutlina-Dimitrova, 2014). Blasquez et al. (2022) show that the foreign IT services content of exports experienced a sharp rise since 2012, which suggests that GVC backward participation is becoming more digitally dependent. Thus, the nature of globalization is changing and a new digital channel of GVC participation is gaining prominence; moreover, this new digital channel is not exclusive to the advanced countries.

At the same time, manufacturing industries are also potentially prone to use digitalization as a means for rebuilding their resilience capabilities. The COVID-19 pandemic disrupted many aspects of supply chain management, but digital systems could have helped to mitigate the impact and enhance resilience. Digital systems for transport management, warehouse management, and managing orders and sales could have enabled supply chain managers to monitor changes and adjust inventory and timings accordingly. Several studies have highlighted the role of digitalisation as a key factor for resilience and recovery in the face of pandemic-induced shocks (e.g. Amankwah-Amoah et al., 2021; Bai, Quayson and Sarkis, 2021; Bigliardi et al., 2023; Bianco et al., 2022; Gereffi, 2020; Hopkins, 2021; Jankowska and Mińska-Struzik 2021; Papadopoulos, Baltas and Balta, 2020; Spieske and Birkel, 2021).

Chapter 3 of this report will, therefore, tackle research questions that relate to the shift in the digitalization level of organisations in the chosen GVC. What we study is the change in the adoption of digital technologies, including solutions used, challenges addressed and companies' strategic shifts in digitalization adoption. The main research questions include:

- whether the pandemic has increased services trade by promoting higher levels of digitalization, improving digital infrastructure and expanding relevant government policies, and
- whether the pandemic pushed firms, especially in automotive and medical equipment GVC, to adopt digitalised production processes and thus change the organisation of their production,

Methods of analysis and data

To meet our objectives and investigate how COVID-19 impacted the digitalization adoption in both service and manufacturing industries and how has thus changed the trade of services, we apply a scope of differentiated methods, including quantitative and qualitative analysis toolkits.

To address the first research question on how the degree of digitalisation of economies and polices restricting services trade impacted countries' trade resilience during the COVID-19 crisis we turn to quantitative tools. We undertake an econometric analysis of the impact of 'digitalisation' on export activities across industries and particularly examine the question of whether the degree of use of digital technologies had a significant impact on the 'resilience' of export activity during the COVID-19 crisis. In order to exploit more detailed information on 'digitalisation' (captured by the different indicators of IT/ITC capital per employee or as a share of total capital) we had to constrain our analysis to trade from European countries. As to the 'resilience' of export flows, we captured this as 'deviation of actual exports from trend exports' or 'deviation of actual exports from a moving average pattern of exports' – (see details of the methodology in Appendix E). Both of these were defined at the industry level. Hence, the idea here was to analyse whether industries which had a higher level of digital equipment or software (per employee or as a share of total capital) reacted differently to the COVID-19 shock than industries which had a lower 'digital-intensity'. To capture the COVID years we had to constrain our analysis to 2020 and 2021; as services trade figures were too scant for 2022. We assume strong heterogeneity amongst services industries (such as travel and transport, on the one hand; and finance, business and professional services, on the other hand). This heterogeneity across service industries and also in relation to other sectors of the economy (manufacturing in particular) will be tested. We shall explore the issue of the relationship between 'resilience' and 'digitalisation' both over a longer period (2005-2022) and, more specifically, for the 'COVID years' (2020 and 2021; because of insufficient detailed service trade data, we could not include the year 2022).

Since one of the limitations often associated with econometric analysis is the lack of ability to include more in-depth remarks that cannot be captured in a quantitative approach, we also apply qualitative research in the form of case study analysis. To explore how Industry 4.0 technologies were adopted during the COVID-19 pandemic and whether the pandemic was a catalyst or a barrier for the ongoing technological transformation, we conducted a qualitative study. We used a grounded theory approach and interviews as our data collection and analysis methods. Grounded theory is a qualitative research approach that is suitable

for studying social phenomena. It is especially useful for new or under-researched topics, such as the effect of the recent pandemic on technological transformation and disruption among businesses. The interviews were held with companies involved in two GVCS: automotive and healthcare equipment manufacturers. The companies that participated in the study had operations located in Poland and Germany and, in some specific cases, in other locations. Details on the sample are included in Appendix F.

We collected and analysed our data in cycles until we reached theoretical saturation. The studies were exploratory, aiming to understand how the pandemic affected the company's industry context, especially in terms of possible disruptions in the digital transformation and the adoption of Industry 4.0 technologies, as well as the barriers, strategies and measures to deal with the technological disruption. We used open, semi-structured interviews (in English and Polish), observations and note-taking as data collection methods. The interviews were based on an interview guide that was designed according to Agee's (2009) recommendations. The interview guide also included a support document that explained the purpose and meaning of each question and provided some sub-questions for further probing. We wrote memos during and after each interview to examine the data from different perspectives (Charmaz, 2003). We did not have any pre-defined hypotheses or answers in our research to avoid bias. To analyze the data, we first transcribed the interviews into text format. We then used the MAXQDA software to assign codes to the texts based on the data. We followed an inductive approach to coding, as it allows for more empirical grounding. We performed open, axial and selective coding to identify themes and categories. Furthermore, also the qualitative study of the organisations in the Netherlands adds some relevant insights relating to digitalization. More details about the methodology used in this particular study can be found in Appendix D.

Findings and discussion

We found that for the short-term analysis of the COVID-19 shock over the years 2020 and 2021, the level of digitalisation in different industries affected their export performance during the pandemic. This was especially true for one of the ICT indicators, namely computing equipment. Industries with more computing equipment had higher actual exports than expected. This effect was caused mainly by manufacturing and not services in general. We also tested for heterogeneity among services industries and the results confirmed that the more digitised the industry (finance/insurance, business and professional services), the more resilient it was to the COVID-19 shock on exports. The other service industries suffered a large drop in exports compared to their trends.

For the longer-run analysis (comprising time series over the period 2005-2021), we confirmed that a higher digitalisation level reduces the impact of shocks on export flows. We also found that the service industries had higher significant parameter estimates than the other industries (all, services and manufacturing, or manufacturing only) for this longer observation period. This means that exports were more stable for the service industries when facing shocks. Moreover, the COVID years 2020 and 2021 had a significant impact on our

long-run analysis. For all industries, we found that digitalisation had a stronger negative association with the ratio of actual to potential/trend exports in these years than in the previous period, 2005-2019. This was especially true for 2020, when the lockdowns and transport disruptions were most severe. However, this pattern did not hold for the services industries as a whole. Moreover, when we examined these interactions for the service industries with high digitalisation, we found that they were able to offset the negative COVID-related effect and even achieve a positive effect in some cases (in the cases of computing capital and communication capital per employee).

When it comes to digitalization level, according to the interviewees, digital transformation was not a consequence of the pandemic. Companies had started to implement Industry 4.0 technologies before COVID-19 broke out. Their choice of technologies was driven by the market demand and requirements, not by the pandemic. However, the pandemic did affect the speed and the priority of technology adoption. The outcome also varied by industry. For instance, many automotive companies used the lockdowns as an opportunity to upgrade their facilities with Industry 4.0 technologies, such as automated production lines and robots. This was a planned activity that stemmed from the need to adapt their manufacturing plants to produce eco-friendly vehicles (e.g. electric cars). The pandemic only influenced the timing of technology implementation for the automotive industry. The market demand changed due to the pandemic, which also affected the medical equipment manufacturing industry. The companies had to adjust their production output to focus on the products that were essential for the COVID-19 response: computed tomography, roentgen, PCV test, protective clothing, etc. The industry also adopted digital solutions that enabled safe distance for the workers (software supporting remote working) and the patients (AI-enhanced cloud solutions to reduce patient-doctor interactions).

The pandemic did not change the direction of digital transformation in the industry, but only the speed. However, it also had an indirect impact on the companies through the market conditions.

According to the interviewees, digitalisation was essential for improving the company's performance and resource management. However, they had different interpretations of what digital shift meant, even within the same industry and while performing similar roles in the global value chains. Companies adopted digitalisation in different ways. The first one involved various Industry 4.0 solutions such as AI-based technologies, automation, big-data analysis or cloud computing to increase their operations' efficiency. These solutions were applied not only to manufacturing but also to other functions such as procurement, sales or back office processes. The technologies adopted were mostly "competence-enhancing" (Tushman & Anderson, 1986), which meant that they built on existing skills and enabled the company to improve its operations without making the previous practices obsolete. As a result, employees also had to up-skill (and less frequently re-skill) to supervise their former tasks. However, Industry 4.0 solutions were seen as 'must-have' solutions that did not create a competitive edge but allowed companies to stay relevant in the market. Big data analysis enabled companies to better coordinate the processes and functions they performed in the global value chain and share information within the company more quickly. Automation

reduces the time and cost of repetitive activities, making the processes more efficient. Cloud computing and software development made the non-manufacturing work more flexible and location-independent. However, in the long term, companies did not view this type of digitalisation as a competitive strategy.

However, digitalisation can not only constitute a way to improve the internal operations of companies but ultimately can become a strategy to create value for their customers if the focus was shifted to the market rather than manufacturing processes. This is what the interviewees understood as the second aspect of digitalisation. They added digital features to their products and services (*servitization*) that could enhance the user's experience by collecting and processing data and providing useful suggestions. The same benefits that digitalisation brought to the companies' efficiency were now transferred to the customers' convenience. The interviewees also noticed a significant change in how they viewed digitalisation, and technology. They realised that digital transformation was not a one-time event but a continuous process and that simply adopting innovative technological solutions was not enough to gain a competitive edge. The widespread availability and affordability of those solutions made digitalisation a necessity rather than an option for many companies.

The qualitative study in the Netherlands confirmed these findings. In particular, most organisations and employees had to work from home using digital tools. However, not all jobs were suitable for remote work and some respondents said that their work continued as usual on an operational level. Another change that was reported was that due to COVID-19 and other environmental shocks, digitization increased the need for better data management to understand the supply chain and the potential for outsourcing tasks and jobs to digital tools.

4. Vaccine Capabilities and Resilience in Europe

Contextual background and research objectives

The COVID-19 pandemic exposed the fragility and danger of relying on global value chains for healthcare. For instance, China was the source of 41% of the world's exports of N95 respirators, and most of the research and production of the mRNA vaccine took place in the U.S. at the beginning of the crisis. Europe faced difficulties in accessing the right vaccines quickly enough, which raised the question of whether Europe was lagging behind and being too dependent on China and the U.S. to supply critical vaccines.

There are several different types of vaccines, but what they have in common is that they teach our bodies' defences how to protect us from disease. Vaccines use the natural abilities of our immune system, which constantly encounters and defends against millions of pathogens. Vaccines are designed to prevent diseases in healthy people, unlike regular drugs that treat existing illnesses. Therefore, vaccines must undergo a lengthy and thorough process of scientific investigation and testing before they can be approved, licenced and distributed. Vaccine trials have to show that a vaccine is both safe and effective in preventing diseases. Before COVID-19 vaccines, it usually took 10 to 15 years to make and approve a new vaccine for human use.

Vaccine production is a long and complex process that usually takes 12 to 36 months before the vaccines can be distributed. Vaccines are complex biological products that require extensive manufacturing and quality control iterations. The quality checks account for up to 70% of the total manufacturing time. The adherence to high-quality standards entails the implementation of specific pharmaceutical quality systems, quality assurance measures and procedures, multiple quality checks at subsequent stages, and appropriate infrastructure as well as satisfactory separation of activities to ensure the vaccine's "identity, purity, sterility, efficacy, and safety" (https://www.vaccineseurope.eu/).

As this GVC is so specific, a new term has been coined – the "vaccine club" which refers to a group of countries that have the capacity to produce vaccines - they include China, Germany, India, Russia, the U.K., and the U.S. These countries also manufacture most of the ingredients needed for vaccines. According to trade data from 2017-19 (pre-COVID-19), 88.3% of key vaccine ingredients were imported from other vaccine-producing countries (Evenett et al., 2021). Therefore, many parts of the world are bound to rely on the "vaccine club" countries to overcome COVID-19 or any other virus. The COVID-19 pandemic raised new questions about the vulnerability and flexibility of supply chains that rely on a few offshore locations for cost-effective global production. The issue of resilience became more complicated as different factors at the country level influenced the firm-level responses (Gereffi, Pananond and Pedersen, 2022).

Chapter 4 of this report will, therefore, tackle research questions that relate to Europe's resilience of global value chains (GVCs) in the development and production of vaccines, given the combination of global interconnectedness and a disruptive environment demonstrated by the pandemic. The main research questions include:

- Is Europe becoming too dependent on other global players when it comes to the supply of vaccines, and does it have the right vaccine capabilities to limit such dependence?
- Are there significant gaps in the vaccine value chain in Europe that should be addressed to mitigate the risk associated with future pandemic outbreaks?

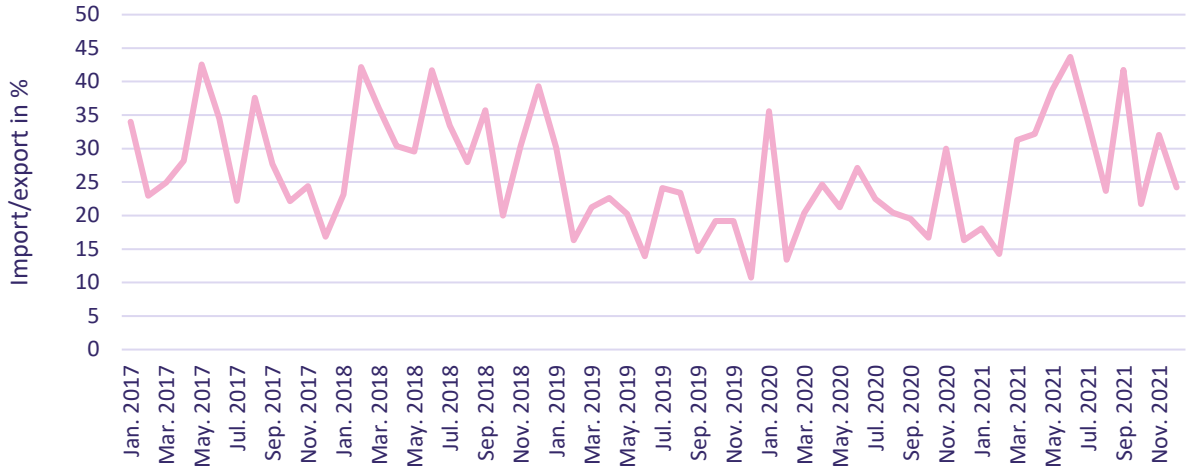
Methods of analysis and data

To assess Europe's role in GVCs for vaccines, we used both primary and secondary data. The secondary data accounted for mainly up-to-date trade data on the pattern of trade on vaccines and ingredients for vaccines before and after the disruptions. This allowed us to prepare the overall assessment of the role of Europe in the global value chains for vaccines, e.g. how Europe is positioned in comparison with China and the U.S. The source of this data is Eurostat, which uses the WTO "HS 6-digit code" to classify the trade flows. The trade flows that are relevant for this analysis are the ones that appear in the WTO Joint Indicative List of Critical COVID-19 Vaccine Inputs, which covers not only the vaccines themselves but also the ingredients required to produce them (OECD, 2022). The primary data included comprehensive expert interviews of the main stakeholders in the value chain for vaccines. These included two leading vaccine researchers, one biotech firm, one large pharmaceutical company, and the Vaccine Europe association (which represents the research-based vaccine companies operating in Europe). We used semi-structured interviews to elicit their views on how Europe fares in various aspects of the vaccine value chain. The main question was how prepared Europe would be for another pandemic scenario. The primary data provided a deeper insight into the vaccine capabilities in Europe compared to other parts of the world.

Findings and discussion

Between January 2017 and November 2021, export of vaccines from Europe is much higher than import to Europe as the share of import over export typically varies between 20-40%, which implies that Europe is producing more vaccines than used in Europe and thereby becoming a net exporter of vaccines (Figure 4). We saw a short spike in imports around January 2020 when the first COVID-19 vaccines were released, but then the share of imports decreased and normalized at the same level as before the pandemic. The reason for the increased imports around January 2020 was that the U.S. companies had a strong start as they were fast in ramping up production - mainly because of Operation Warp Speed). However, as the European companies started production (e.g. BioNTech in Germany, AstraZeneca in the UK and Belgium) and the U.S. companies established production facilities in Europe (e.g. Moderna in Spain and Netherlands, Johnson & Johnson in Italy and Spain) the share of imports went down.

Figure 4: EU's import as a percentage of export on vaccines with the world



Source: own elaboration based on Eurostat.

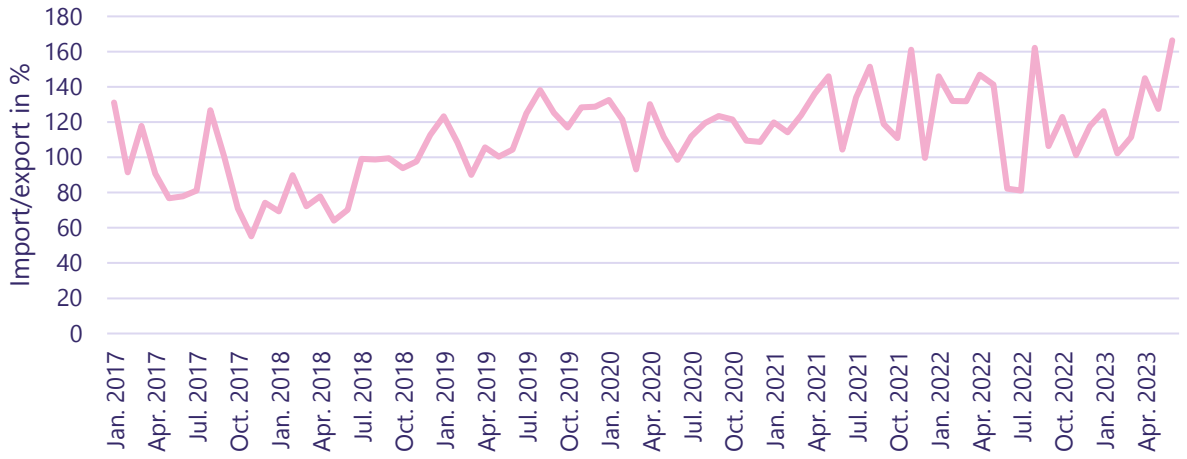
When looking at the absolute values of import and export of vaccines rather than import as a share of export both import and export have increased substantially. The export of vaccines from Europe has increased from approx. Four hundred billion Euro before January 2020 to approx. 800 billion euros afterwards. Similarly, the import of vaccines to Europe has gone up from approx. One hundred fifty billion Euro to approx. 500 billion Euro. Import and export have moved up together rather substantially in absolute value, but relatively import and export have remained rather stable.

Focusing on the many ingredients that go into producing the vaccines provides a slightly more nuanced picture. For each vaccine, many ingredients are needed that are sourced from all over the world. Figures 5 and 6 show the share of import over export for all the vaccine ingredients that go into the two most common COVID-19 types of vaccines used in Europe, the mRNA vaccine and the Viral Vector-based vaccine. In the case of the ingredients for the mRNA vaccine, the share of import over export was just below 100% before January 2020, while it afterward increased to around 120%, indicating that the size of import is slightly higher than the export. The import as a share of export for adenovirus vaccine ingredients was before January 2020 slightly above 100%, while it has increased somewhat more to around 200% in the latest recorded months. As such, in both cases, we see a trend of relative increase in the imports (compared to the exports) after the first COVID-19 vaccine was approved in January 2020.

It is noticeable that while the import share for the vaccines was in the range of 20-40%, the comparable import share for the vaccine ingredients is around 100%. This implies that while Europe is relatively strong when it comes to the development and production of vaccines, it is highly dependent on importing the ingredients that go into the production of the vaccines from other parts of the world.

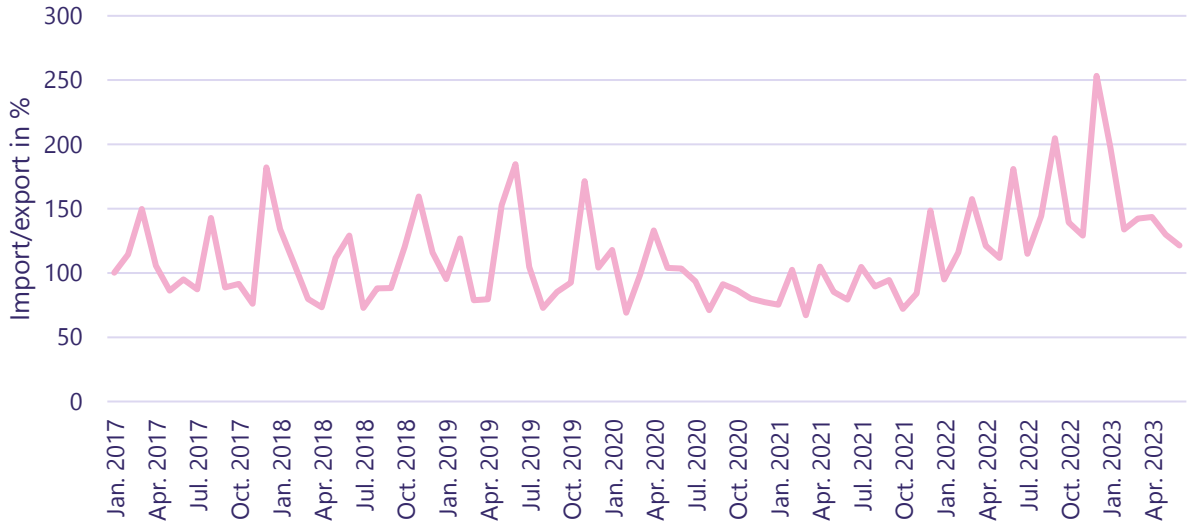
When going deeper into the trade flows for each of the vaccine ingredients, we can observe that for some of the important ingredients, more than 80% of all imports into Europe come from China. Thus, China sticks out as being the key supplier of some of the critical ingredients for producing vaccines like some of the lipid nanoparticles – and this dependency on supplies from China has increased.

Figure 5: EU's import as a percentage of export on vaccine ingredients with the world - mRNA ingredients



Source: own elaboration based on Eurostat.

Figure 6: EU's import as a percentage of export on vaccine ingredients with the world - Adenovirus ingredients



Source: own elaboration based on Eurostat.

Across the interviewees, there is an agreement that COVID-19 was an eye-opener, and many things have changed, not least in Europe, which was not very well prepared for the pandemic and didn't have the institutions and capacity to act fast and agile enough when COVID-19 spread around the whole world. Vaccine research has experienced fluctuations over time; in the late 1990s, promising findings suggested that cancer vaccines could be feasible, leading to a surge of investment from major pharmaceutical companies. However, after many vaccine trials failed, these companies withdrew their funding and left the field to academic institutions and smaller biotech firms. Currently, there is a renewed interest and investment from big pharma in vaccine research, especially in the mRNA vaccine technology that has potential applications for cancer treatment. As a result, vaccine researchers are highly sought-after and scarce in the market.

However, respondents point to significant differences between the U.S. and Europe. The U.S. showed remarkable speed and flexibility in responding to the pandemic, for example, by launching Operation Warp Speed, a $10 billion initiative to fund and accelerate the development and production of four different vaccine candidates. The U.S. also leveraged the collaboration of the government, the private sector, and academic institutions to streamline the approval process. Europe has since adopted some of these best practices and improved its preparedness and response capacity by establishing the Health Emergency Preparedness and Response Authority (HERA) in 2021. HERA has been set up both to prepare better for possible health threats and to manage and coordinate in a crisis phase like the pandemic. EU has thereby created a governance structure that will enable them to prepare better and to act more agile and in a concerted effort in the next pandemic.

The interviewees stressed that Europe is in a much better position today than before the pandemic but also pointed out that much of the money today goes mostly to research on the mRNA vaccine. mRNA vaccines have shown good efficacy against COVID-19, but their performance against other potential pandemic viruses is unknown. Therefore, investment in a diverse range of vaccine technologies is needed without limiting the research to one technology only. One of the challenges in vaccine research is the uneven distribution of resources. Most of the funding from big pharma goes to the vaccine types that have the highest potential for cancer treatment, leaving other vaccine types with less support. This means that the research on other vaccine types is mainly done by universities and some state funding, resulting in a more fragmented and sporadic landscape.

The industry has made remarkable progress in building, filling and finishing vaccine production facilities across Europe. It now has much more capability and capacity to manufacture vaccines than it did before. This enhanced platform will enable Europe to increase its output much more quickly in the future. The existing manufacturing facilities include facilities set up by European and US pharma companies. They have been collaborating in fast scaling up, where, e.g. the European contract manufacturers Lonza and Catalent supply the Moderna vaccine, and Pfizer-BioNTech is teaming up with Sanofi, Novartis, and Merck to scale up production of their vaccine. What remains a problem are the vaccine ingredients. Although most of the more than 200 vaccine ingredients that are needed to make the vaccine are sourced in Europe, firms did experience substantial delays

in deliveries of some of the ingredients during the pandemic. The most severe bottleneck, however, was with the components imported from China. These components are rare and hard to find elsewhere, and their delivery time increased from days to months during the crisis. Companies tried to find other sources, but none of them met our quality standards. During the pandemic vaccine producers complained about a series of input shortages such as lipids, bioreactor bags, filtration pumps, and other equipment and raw materials that were in short supply.

Although the orchestration of combined capabilities thus far has been admirable, the complexity of the vaccines constitutes a risk for the future resilience of the vaccine value chain. This complexity is the result of the combination of the specialized ingredients, the large number of suppliers involved, and the locational spread of the suppliers across many countries. The combination of these factors makes the vaccine value chain vulnerable to disruptions. This vulnerability also includes a geopolitical dimension, with several suppliers located in China, and could therefore entail increased future dependency on China, which is not desirable from a European policy perspective. Vulnerability in the value chain is not purely a future risk but has already manifested itself during and after the pandemic. The expert interviews refer to several incidents during recent years where supply shortages of ingredients have caused delays in research and production processes. This raises the question of whether and how measures can be applied to mitigate this risk, for example, under the auspices of the EU's Open Strategic Autonomy policy. This could include, for example, replication of production capabilities for specialized ingredients within Europe to prevent future supply problems. The establishment of slack resources and capabilities will require contributions from industry as well as from public authorities.

5. Summary of key findings

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

- To address COVID-related shortages, many governments reached for trade policy – limiting exports and making critical imports easier, through lowering tariffs, cutting bureaucracy and removing previously imposed anti-dumping duties and other restrictions. In the first half of 2020, the COVID-19 crisis resulted in the significant rise in trade barriers, affecting ca. 90 countries. These actions were not in line with the WTO's rules and disregarded the World Bank's advice on how to use trade policy to tackle the pandemic-related issues.
- The reorganization of global production was to some extent influenced by the COVID-19 pandemic. Although the average effect of COVID-19 on the foreign subsidiaries' share was negligible, proving that EU MNEs did not immediately reconfigure their operations, some discrepancies are observed when looking at the Western and Central and Eastern Europe separately. Specifically, CEE headquartered MNEs increased their overall foreign subsidiaries' share but only by focusing on non-European locations. On the other hand, MNEs based in the most COVID-affected regions of Western Europe opted for a different path, reducing their overall foreign subsidiaries' share.
- As part of the GVC reconfigurations some companies used reshoring, nearshoring and friendshoring strategies. However not all decisions related to these practices were directly caused by the COVID-19 pandemic. Some firms leveraged the technological opportunities arising from Industry 4.0 developments, while others were motivated mostly by external factors, including geopolitical tensions and pandemic itself. Specifically, firms that suffered from the pandemic reported higher operations costs and lower demand in their overseas markets. Thus, relocating was intended to streamline their production and eliminate the unnecessary fixed costs in foreign locations.
- Generally, digitalisation leveraged industries' export resilience to the COVID-related shock. Both short- and long-term, manufacturing industries were the ones where this dependence was most observable. One of the reasons for such outcome are significant discrepancies on how COVID-19 and lockdowns affected certain services industries (e.g. travel/tourism and transport services) and how they responded in adopting digital solutions.
- In some industries, such as automotive and healthcare equipment manufacturing GVCs, digital transformation accelerated. However the changes and solutions that were adopted were mostly initiated in the pre-pandemic period. The COVID-19 forced companies to accelerated their digital shift, however did not influence the digital pathway firms had been pursuing. At the same time, I4.0 technologies are mostly seen as a 'must-have' solutions rather than competitive advantage, unless the technology is used as servitization.

- Against expectations, companies adopted a much diversified approach when it comes to R&D expenditures with 1,195 out of 2,859 studied firms in Austria increasing their R&D expenditures by at least 10%. In terms of performance, firms that had a low R&D intensity before the crisis had on average better results than firms with high R&D intensity. Also, firms that claimed more public funding for their R&D expenditures performed much better during the crisis than firms with less or no public funding.
- Digitalisation and funding are also key issues for vaccine GVC which is of key importance for creating and maintaining resilience capacity in Europe should another pandemic happen. Vaccine production plants across Europe have made remarkable progress in their development, equipment and operation, increasing their ability and capacity to produce vaccines compared to the pre-pandemic situation. Both European and US pharma companies have expanded their involvement in this area. Yet, sourcing the vaccine ingredients is still a difficulty that has no immediate solution. So is the allocation of funds in vaccine manufacturing, which is mostly focused on the research on the mRNA vaccine only.
- Finally, COVID-19 also affected the employee management and relationships among MNEs. On one hand, in automotive and heartcare equipment manufacturing, digital shift mostly resulted in up-skilling or re-skilling processes and companies rarely reached for lay-offs to cope with the lockdowns. However, in other industries companies acted differently depending on their GVC mode (market, modular, relational, captive, hierarchical) – companies in market-mode GVCs were less invested in developing their HR, while modular-mode GVCs provided more engaged in their employee management by providing development opportunities.

6. Policy implications

Increasing state intervention in many key markets calls for a better understanding of the state's role. As a result of geopolitical tensions and technological rivalry, regulatory interventions, including trade restrictions, have continued to increase (GTA, 2023), whereas 'facilitatory' policies involving huge subsidies to key priority industries, like semiconductors and electric vehicles, have expanded rapidly across the globe, including in the United States (Luo & Van Assche, 2023) and the European Union (Ragonnaud, 2023).

This report shows that trade policy interventions were numerous and widespread during the pandemic, yet in the PPE sector, they were almost entirely focused on final goods. Governments largely ignored trade in intermediate products. Nevertheless, we note a significant increase in trade in the targeted products. This implies that there are limits to the capacity of governments to restrict trade in the face of major shifts in demand. However, we also note an evolution in trade over time, with an increase in intermediate goods trade. This suggests that one effect of these interventions was to encourage trade in the inputs to PPE, stimulating the diversification of the GVC, particularly in the EU. Therefore, states' willingness to impose emergency restrictions on some parts of the value chain could encourage firms to reassess their GVCs so as to diversify disruption risks. In today's unstable geopolitical context, firms seem likely to consider such risks in their decisions on GVC structures going forward. Our findings also highlight the tendency of governments to focus on high-profile final goods in a crisis rather than their intermediate inputs. This relative openness at lower levels of the GVC can further facilitate restructuring.

Furthermore, our research suggests an apparent disconnection between the declared objective of reshoring for example, in the French programme and the actual aims of the funded projects under the reshoring objective. It seems that government financial support for GVC restructuring might not always be aimed at that purpose. Although there were many projects on reshoring, they were not the majority. The actual effect of the projects analysed on the geography of the GVCs targeted will only become evident over time. Still, for most, their short-term objectives did not seem to be primarily focused on shifting the country of production. These findings hold for the initial projects supported under the first French recovery plan. Since then, large-scale EU (and national) programmes to foster autonomy in key priority sectors like chips (Ragonnaud, 2023) and batteries (Arroyo & Coletti, 2023) have intensified. Recent interventions include €20bn subsidies for chipmaking in Germany (Alkousaa & Mukherjee, 2023) and up to €1.5bn in state support for just one battery factory in France (Henley, 2023). Facilitatory actions such as these are larger and more production-oriented than what we investigated in this study, reshaping supply chains to a far greater degree. Later, WPs will need to explore how this evolving landscape of 'facilitatory' state actions affects the geography of EU GVCs.

In our discussion of how the pandemic has affected global value chains and trade, we also addressed the issue of vaccine production in relation to the EU's policy of Open Strategic Autonomy. The dilemma of how to ensure security and competitiveness is still valid. Our findings indicate that since most of the active ingredients in the COVID-19 vaccines were

developed in Europe, it is clear that Europe has a high level of competence in vaccine development. Compared to the U.S. and China, Europe lagged in institutional setup. While the U.S. and China could mobilise internal resources more quickly, Europe could not take bold steps like Operation Warp Speed initiated by the U.S., which took some risks away from the individual companies, allowing them to scale up their operations more quickly. Several initiatives have been taken in Europe to expand research capacities and manufacturing facilities so that similar health crises can be handled in the future (e.g. HERA). Concerning the future, the warning signals are related more to the EU's debate on Open Strategic Autonomy and China's reliance on vaccine ingredients. As we need to maintain research and competencies on other vaccine technologies, another concern might be the disproportionate focus on mRNA vaccines, which currently attract the most attention and funding. Considering the scale of disruptions caused by the pandemic, demand and supply chain resilience has increasingly become a key strategic pillar with significant policy implications.

The above findings contribute to the debate on the role of EU value chains in the EU industrial policy (Amighini et al, 2023). Moreover, our study on MNEs added a regional perspective to this debate. Our research on MNEs representing various industries proves that the adjustment strategies implemented after the COVID-19 shock differed in EU regions more severely affected by the pandemic, so tailor-made regionally differentiated policy measures aimed at supporting MNEs while bouncing back after the shock are essential. Many EU-MNEs tend to bring back or maintain the most knowledge-intensive segments of the production chain in the EU, thus contributing to improving the potential for innovation, research, and technological development of the EU. Reshoring manufacturing activities strengthens the EU's manufacturing industry, which still represents the most significant contributor to the non-financial business economy in terms of employment (23%) and value-added (29%). Already in November 2020 in its resolution of on a New Industrial Strategy for Europe, the European Parliament called for action to strengthen supply chains, stating that shortening or altering them to the EU's neighbourhood and Africa could have a positive effect on their sustainable, green, inclusive and resilient economic growth (2020/2076(INI)). Our fidings confirm that the expected change is indeed happening. What has to be stressed however is that the reshoring of manufacturing activities and the provision of knowledge-intensive services is specific to MNEs headquartered in Western EU regions. MNEs headquartered in Central and Eastern EU regions delocalised production activities more often in low-tech manufacturing and low-knowledge-intensive sectors. The above discrepancy may further contribute to the still-existing gap between member states regarding their potential for innovation and research. Thus, policy measures need to consider that discrepancy to add to the cohesion of the whole EU. Additionally, the projected policies need to consider the war in Ukraine, which may further impact the Central Eastern EU MNEs and their delocalisation decisions. The Russian invasion of Ukraine clearly manifested the vulnerability of GVCs, thus the delocalisation decisions on the side of EU companies sometimes facilitated by COVID-19 pandemic, need to be analysed as potential remedy strategy against the disruption of GVCs in EU companies. The need to develop more collaborative ties with local partners is nowadays even more visible, especially in the food

sector but not only (https://cor.europa.eu/en/news/Pages/NAT-Santiago.aspx). Thus, implementing solutions that trigger and support the emergence of collaborative ties among local partners and between them and MNEs hosted in their markets is not to be overappreciated.

Continuing the theme of GVC, it becomes evident that the GVC governance mode matters. Our research revealed that organisations operating in market-mode GVCs are less likely to invest in human capital than in other modes. That is important from the perspective of the development of employees' digital capabilities, among others. Those capabilities further translate to the digital maturity of firms and the digital readiness of the whole society, which further determines the economy's resilience against such shocks as pandemics. Organisations operating in modular-mode GVCs are more likely to invest in schooling, consult with personnel, and are more participatory. Thus, policy measures facilitating collaboration within GVC and enhancing employment strategies may add to the organisation's resilience. Furthermore, our study found that modular-mode GVCs are more likely to exploit digital tools. Based on these results, we conclude that policy measures may positively affect resilience simultaneously in two ways – supporting the adoption of digital tools by organisations collaborating within GVCs and supporting those collaborative ties among international partners and with employees.

The argument is often raised that digitalisation reshapes the demand for labour, which may result in layoffs of workers with low digital capabilities. Our research highlighted that human resources are still key for companies, even in the digital transformation era. Firms still prefer to upskill and invest in developing the competencies of their employees rather than lay them off. So, supportive measures and means may be developed both by businesses themselves as well as by governments. While the latter may address the developmental solution simultaneously to organisations and individuals.

Upgrading digital skills is vital because, as it came out from the research on MNEs while coping with a shock, the lack of digital capabilities may trigger reshoring decisions from low-labour-cost to high-labour-cost countries. Thus, that may further deepen the developmental gap and digital divide between the low-labour cost and high-labour cost countries. Such a conclusion brings the notion of digital readiness even higher in the research agenda. The study on the impact of the COVID-19 pandemic on international trade flows revealed that services suffered more than goods and proved substantial differences among different types of services. It was due not only to border closures (pivotal for such services like tourism) but broadly taken to the capability of particular service types to provision via digital means determined by countries' digital readiness. Thus, policy measures dedicated to upgrading digital readiness by developing digital skills may increase the resilience of companies and whole economies. It may also help in the implementation of the EU industrial strategy (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en).

To increase resilience, we need to monitor the digital transformation within particular economies. A clear message on the digital transformation in Europe, more precisely in the European Union, provides the Digital Economy and Society Index (https://digital-

strategy.ec.europa.eu/en/policies/desi). The digital divide between developed and developing countries is still visible, particularly regarding access to broadband services, e-commerce platforms, quality of infrastructure and legal framework. Further digital transformation may support the resilience of export activity in periods of shocks. While some services may be more negatively affected in unforeseen situations, other service types prone to digitalisation may easily maintain pre-shock sales levels. Multidimensional, multilevel measures to improve the digital readiness of EU economies are needed to make Europe competitive globally and enhance Europe's Open Strategic Autonomy. Those measures may support the efforts to close the gap between the Central and Eastern EU and Western EU economies.

7. Next TWIN SEEDS steps

The TWIN SEED's investigation of GVCs does not end here. The WPs that follow focus on the specific aspects of recent and emerging trends in GVCs and their impact on: employment and inequality (WP3), environment (WP4) and finally growth, productivity and competitiveness (WP5). The reorganization of GVCs that followed the challenges highlighted in WPs 1-2, has involved both the restructuring of activities and the re-allocation of tasks and functions across space, with important implications for jobs, working conditions, and inequalities. WP3 will aim to provide a detailed and comprehensive analysis of the different influences GVCs may exert on regional labour market scenarios and outcomes, such as employment, the composition of the labour force, wages, job quality and working conditions, by using national/regional data at industry- and employee-level at the highest possible level of disaggregation. The general objectives of WP4 will be the quantification and evaluation of the environmental impacts, in terms of changes in carbon emissions, circular production, and transfers of sustainable business practices from MNEs. Finally, we expect that the changing geography of GVCs will lead to delineating winners and losers. Some countries, regions and firms will become key hubs, while others will lose out and become more peripheral. The WP5 analyses will examine the effects of these changes on productivity of GVCs and the competitiveness of MNEs, as well as on firm-level risks and resilience.

WPs 3-5 that follow this report are therefore complementary to the analyses presented here. They explore in more detail specific focus areas that are crucial to contemporary European society.

8. References

Agee, J. (2009). Developing qualitative research questions: a reflective process. *International Journal of Qualitative Studies in Education*, 22(4), 431–447.

Alkousaa, R., & Mukherjee, S. (2023, July 25). *Germany earmarks 20 billion euros in subsidies for chip industry*. Reuters.

Amankwah-Amoah, J., Khan, Z., Wood, G., & Knight, G. (2021). COVID-19 and digitalisation: the great acceleration. *Journal of Business Research*, 136, 602-611.

Amighini, A.A., Maurer, A., Garnizowa, E., Hagemajer, J., Stoll, P-T., Dietrich, M., Roy, R., Skowronek, A., & Tentori, D. (2023). *Global value chains: Potential synergies between external trade policy and internal economic initiatives to address the strategic dependencies of the EU*. Policy Department for External Relations, Directorate General for External Policies of the Union, PE 702.582.

Ancarani, A., Di Mauro, C. & Mascali, F. (2019). Backshoring strategy and the adoption of Industry 4.0: Evidence from Europe. *Journal of World Business*, 54(4), 360–371.

Arroyo, F., & Coletti, M. (2023, July 24). *Batteries: L'UE cherche l'équilibre entre ouverture aux marchés et souveraineté technologique*. The Conversation.

Ashenbaum, B. (2018). From market to hierarchy: An empirical assessment of a supply chain governance typology. *Journal of Purchasing and Supply Management*, 24(1), 59–67.

Bai, C., Quayson, M., Sarkis, J. (2021). COVID-19 pandemic digitisation lessons for sustainable development of micro- and small-enterprises, *Sustainable Production and Consumption*, 27, 1989-2001.

Benz, S., Jaax, A., & Yotov, Y.V. (2022). *Shedding Light on the Drivers of Services Tradability over Two Decades*. OECD Trade Policy Paper n°264.

Bianco, D., Bueno, A., Filho, M. G., Latan, H., Miller Devós Ganga, G., Frank, A.G., & Chiappetta Jabbour, Ch. J. (2023). The role of Industry 4.0 in developing resilience for manufacturing companies during COVID-19. *International Journal of Production Economics*, 256.

Bigliardi, B., Bottani, E., Casella, G., Filippelli, S., Petroni, A., Pini, B., & Gianatti,E. (2023). Industry 4.0 and COVID-19: Evidence from a case study. *Procedia Computer Science*, 217,1803-1809.

Blázquez, L., Díaz-Mora, C., & González-Díaz, B. (2022). Slowbalisation or a "New" type of GVC participation? The role of digital services. *Journal of Industrial and Business Economics*, 50, 121–147.

Borgen, N. (2016). Fixed Effects in Unconditional Quantile Regression. *Stata Journal*, 16(2), 403–415.

Cernat, L., & Kutlina-Dimitrova, Z. (2014), *'Thinking in a Box: A 'Mode 5' Approach to Service Trade'*. DG TRADE Chief Economist Notes, No 2014-1.

Chiarvesio, M. & Romanello, R. (2019). *Industry 4.0 Technologies and Internationalization: Insights from Italian Companies*. In International business in the information and digital Age,; van Tulder, R., Verbeke, A., Piscitello, L., Eds.; Progress in international business research, volume 13; Emerald Publishing Limited, 357–378.

Curran, L., Eckhardt, J., & Lee, J. (2021). The trade policy response to COVID-19 and its implications for international business. *Critical Perspectives on International Business*, 17(2), 252–320.

Curran, L., Nadvi, K., & Campling, L. (2019). The influence of tariff regimes on global production networks (GPNs). *Journal of Economic Geography*, 19(4), 873–895.

Dachs, B., Drach, A., 2019. Forschung und Entwicklung von Unternehmen in langfristiger Perspektive: Starkes Wachstum, alte Akteure. *Perspektiven der Wirtschaftspolitik*, 20, 340–351.

Dachs, B., Kinkel, S., & Jäger, A. (2019). Bringing it all back home? Backshoring of manufacturing activities and the adoption of Industry 4.0 technologies. *Journal of World Business*, 54(6)

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building From Cases: Opportunities And Challenges. *Academy of Management Journal*, 50(1), 25–32.

Evenett S.J., Hoekman B., Rocha N. & Ruta M. (2021). *The COVID-19 vaccine production club: Will value chains temper nationalism?* World Bank Group, Policy Research Working Paper 9565.

Evenett, S., Fiorini, M., Fritz, J., Hoekman, B., Lukaszuk, P., Rocha, N., Ruta, M., Santi, F., & Shingal, A. (2022). Trade policy responses to the COVID-19 pandemic crisis: Evidence from a new data set. *The World Economy*, 45(2), 342–364.

Firpo, S., Fortin, N. M., & Lemieux, T. (2009). Unconditional Quantile Regressions. *Econometrica*, 77(3), 953–73.

Fortune (2020). *75% of companies report coronavirus has disrupted their supply chains*. Retrieved from: https://fortune.com/2020/03/11/75-of-companies-report-coronavirus-has-disrupted- their-supply-chains/.

Fratocchi, L., & Di Stefano, C. (2020). Industry 4.0 technologies and manufacturing back-shoring: a European perspective. *Acta IMEKO*, 9(4), 13-20.

Gereffi, G. (2020). What does the COVID-19 pandemic teach us about the global value chains? The case of medical supplies. *Journal of International Business Policy*, 3, 287-301.

Gereffi, G., & Fernandez-Stark, K. (2016). *Global value chain analysis: A Primer*. Center on Globalization, Governance & Competitiveness

Gereffi, G., Pananond, P., & Pedersen, T. (2022). Resilience Decoded: The Role of Firms, Global Value Chains, and the State in COVID-19 Medical Supplies. *California Management Review*, 64(2), 46–70.

Gkeredakis, M., Lifshitz-Assaf, H. & Barrett, M. (2021). Crisis as opportunity, disruption and exposure: Exploring emergent responses to crisis through digital technology. *Information and Organisation*, 31(1).

Golini, R., De Marchi, V., Boffelli, A., & Kalchschmidt, M. (2018). Which governance structures drive economic, environmental, and social upgrading? A quantitative analysis in the assembly industries. *International Journal of Production Economics*, 203, 13–23.

GTA. (2020). *The COVID-19 Pandemic: 21st Century Approaches to tracking trade policy responses in real-time: Methodological Note*. Global Trade Alert.

Hopkins, J.L. (2021). An investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia. *Computers in Industry*, 125.

Jankowska, B., & Mińska-Struzik, E. (2021). *The adoption of Industry 4.0 solutions as a remedy against the pandemic crisis – the case of Polish companies*. In E. Mińska-Struzik, & B. Jankowska (Eds.), Toward the "new normal" after COVID-19 – a post-transition economy perspective (211–222). Poznań University of Economics and Business Press.

Jean, S., & Vicard, V. (2020). Relocaliser, réindustrialiser: Dans quels buts. La Lettre Du CEPII, 410, 1–4.

KPMG (2020). *Branża motoryzacyjna w Polsce – Raport kwartalny Q3 PZPM i KPMG*. Retrieved from: https://www.pzpm.org.pl/Publikacje/Raporty.

Luo, Y., & Van Assche, A. (2023). *The rise of techno-geopolitical uncertainty: Implications of the United States CHIPS and Science Act*. Journal of International Business Studies (in press).

McGuire, S. (2014). Global value chains and state support in the aircraft industry. *Business and Politics*, 16(4), 615–639.

Miroudot, S. (2020). Reshaping the policy debate on the implications of COVID-19 for global supply chains. *Journal of International Business Policy*, 3(4), 430–442.

Müller, J. Dotzauer, V., & Voigt, K.-I. (2017). Industry 4.0 and its Impact on Reshoring Decisions of German Manufacturing Enterprises. *Supply Management Research,* 165–179.

Nasih, M., Wardani, D.A.K., Harymawan, I., Putra, F.K.G. & Sarea, A. (2022). COVID-19 exposure: a risk-averse firms' response. *Journal of Financial Reporting and Accounting*, ahead-of-print.

Nassimbeni, G., Sator, M., Wan, L., Ancarani, A., Di Mauro, C., Mascali, F., Barbieri, P., Di Stefano, C., Fratocchi, L., Iapade, L., & Orzes, G. (2019). *Reshoring in Europe: Overview 2015–2018*. Luxembourg: Publications Office of the European Union.

OECD (2022). *Global Supply Chains at Work: A Tale of Three Products to Fight COVID-19*. OECD: Paris.

Papadopoulos, T., Baltas, K.N., & Balta, M.,E. (2020). The use of digital technologies by small and medium enterprises during COVID-19: Implications for theory and practice. *International Journal of Information Management*, 55.

PZPM (2021). *Automotive industry report 2020/2021*. Retrieved from https://www.pzpm.org.pl/en/Automotive-market/Reports/PZPM-Automotive-Industry-Report-2020-2021.

Ragonnaud, G. (2023). *The EU chips act: Securing Europe's supply of semiconductors*. European Parliament Research Service.

Rios-Avila, F., & Maroto, M. L. (2022). Moving Beyond Linear Regression: Implementing and Interpreting Quantile Regression Models with Fixed Effects. *Sociological Methods & Research* (in press).

Rutkowski, E. (2021). *Medical Devices and Equipment in Poland*. Retrieved from: https://www.trade.gov.pl/wpcontent/uploads/2021/08/PPE_PL_Medical-Devices-and-Equipment-in-Poland-Report-2021.pdf.

Santos Silva, J., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics*, 88(4), 641-658.

Spieske, A., & Birkel, H. (2021). Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. *Computers & Industrial Engineering*, 158.

Strange, R. (2020). The 2020 COVID-19 pandemic and global value chains. *Journal of Industrial and Business Economics*, 47(3), 455-465.

Tate, W. L. (2014). Offshoring and reshoring: U.S. insights and research challenges. *Journal of Purchasing and Supply Management*, 20(1), 66–68.

Tushman, M. L., & Anderson, P. (1986). Technological Discontinuities and Organizational Environments. *Administrative Science Quarterly*, 31(3), 439-465.

UNCTAD. (2021). *World investment report 2021: investing in sustainable recovery*. United Nations New York.

Van Thiel, S. (2014). *Research methods in public administration and public management: An introduction*. Routledge.

Verbeke, A. (2020). Will the COVID-19 pandemic really change the governance of global value chains? *British Journal of Management*, 31(3), 444–446.

World Bank. (2020). *Do's and Don'ts of Trade Policy in the Response to COVID-19*. World Bank. https://doi.org/10.1596/33516.

WTO. (2020a). *Responding to the COVID-19 Pandemic with Open and Predictable Trade in Agriculture and Food Products*.

WTO. (2020b). *Trade in Medical Goods in the Context of Tackling COVID-19*. WTO iLibrary. https://www.wto-ilibrary.org/content/papers/27095819/1/read.

Yotov, Y. V., Piermartini, R., Monteiro, J. A., & Larch, M. (2016). *An advanced guide to trade policy analysis: The structural gravity model*. Geneva: World Trade Organization.

8. Technical appendices

Appendix A: Evaluating restrictions imposed by key exporters – the case of PPE

Trade restrictions only have major impact on GVCs if they affect important suppliers. Banning exports of PPE from countries that have little or no production will not affect global supply. In our more detailed analysis of the trade policy context, we therefore focused on the restrictions imposed by key exporters. We included all exporters who represented more than 1% of global trade in PPE and its intermediate products prior to the pandemic (based on ITC TradeMap figures) and identified whether and how they had restricted trade in those goods during the pandemic. For this latter analysis we used mainly the GTA database, which provides the best details of the timelines of the various measures, but we cross referenced these details with those in the ITC database to ensure coherence and complete coverage.

In terms of the key exporters of PPE reported in Table A.1, many imposed restrictions on exports, although most were relatively short lived and many only targeted facemasks, rather than all PPE. China, the most important global source of PPE, briefly imposed an export licensing scheme in April, before shifting to certification requirements (ostensibly to ensure quality levels). The next most important global exporter, Germany, briefly banned exports of PPE, before moving in mid-March 2020 to the common EU licensing system, which itself only lasted until the end of May.

The key exporter with the most restrictive and long-lasting trade regime was the US. Their ban on five key PPE products (nine HS product codes including protective clothing and two different types of face masks) only expired in June 2021, although there were some exceptions allowed (OECD, 2020a). Several key exporters vacillated between bans and restrictions over a period of several months. India was the key exporter with the most variable regime. Their regulations changed 10 times in as many months, oscillating between banning exports, imposing quotas and licensing. Although India was one of the countries most heavily affected by the pandemic, such an unpredictable policy environment was clearly not conducive to trade.

Table A.2 presents restrictions on PPE intermediate inputs. These results are very different to those in final products. Very few of the most important exporters of intermediate inputs restricted trade. Korea banned exports of melt-blown plastic (MBP) used to make medical grade masks for several months, while Taiwan briefly included mask filters in their trade restrictions, before concentrating only on masks. The longest running restrictions was India's ban on exports of non-woven fabric (NWF), an important input for many types of PPE.

Table A.1: Trade restrictions by key exporters of PPE – 2020-2022

	% of average trade	Restrictions	Date started	Date ended	Nature
China	27.4	yes	01/04/2020	24/04/2020	Export licensing PPE. After removal retained new certification requirements
Germany	11.8	yes - national and EU	04/03/2020	25/05/2020	Banned export of PPE, then required export licensing
United States of America	8.3	yes	03/04/2020	30/06/2021	Banned export of 5 PPE products
Italy	5.3	yes - national and EU	26/02/2020	25/05/2020	Export licensing PPE
France	4.2	yes - national and EU	04/03/2020	31/05/2020	Banned mask exports and Export licensing PPE
Netherlands	3.2	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Japan	2.5	no			
India	2.5	yes	31/01/2020	06/10/2020	Banned PPE export then imposed license and export quota. Regulation changed 10 times in 10 months.
Mexico	2.4	no			
United Kingdom	2.1	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Belgium	2.1	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Poland	2.1	yes - national and EU	20/03/2020	25/05/2020	Export licensing PPE
Korea	1.9	yes	26/02/2020	11/12/2020	Restricted then banned then restricted face mask exports
Czech Republic	1.9	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Taiwan	1.8	yes	24/01/2020	30/06/2020	Banned face mask exports, then required licences, then banned again
Hong Kong	1.8	no			
Spain	1.7	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Austria	1.5	yes - EU	15/03/2020	25/05/2020	Export licensing PPE
Canada	1.4	no			
Thailand	1.4	yes	05/02/2020	04/02/2022	Banned face mask exports
Jordan	1.4	yes	20/02/2020	20/04/2020	Banned face mask exports
Switzerland	1.0	yes	25/03/2020	22/06/2020	Export licensing PPE

Source: Authors' elaboration based on GTA and ITC databases.

Table A.2: Trade restrictions by key exporters of PPE intermediates - 2020-2022

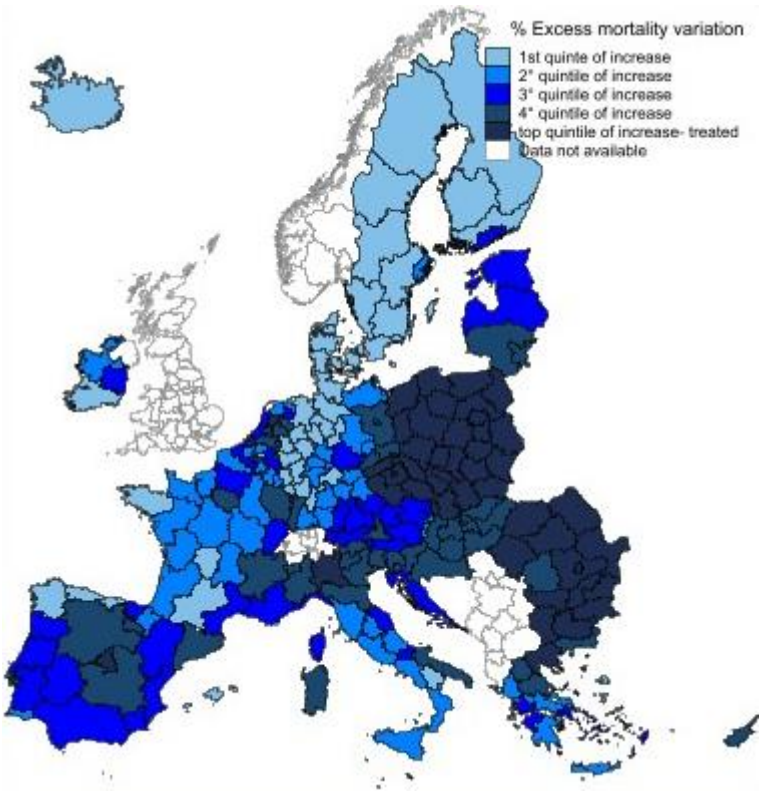
	% of trade	Restrictions	Date started	Date ended
China	13.9	no		
Germany	11.6	no		
United States of America	8.4	no		
Italy	6.5	no		
Korea	4.2	yes - ban MBP	06/03/2020	05/08/2020
France	3.6	no		
Belgium	3.2	no		
Poland	3.2	no		
Spain	2.8	no		
Netherlands	2.8	no		
Czech Republic	2.7	no		
Austria	2.4	no		
Taiwan	2.4	yes - ban filters	24/01/2020	23/02/2020
Thailand	2.3	no		
Japan	2.2	no		
Türkiye	2.2	no		
India	1.8	yes - ban NWF	19/03/2020	14/08/2020
Malaysia	1.7	no		
United Kingdom	1.6	no		
Singapore	1.6	no		
Canada	1.5	no		
Mexico	1.5	no		
Slovakia	1.2	no		
Hong Kong	1.1	no		
Hungary	1.0	no		
United Arab Emirates	1.0	no		

Source: Authors' elaboration based on GTA and ITC databases.

Appendix B: Evaluating regional disparity of the pandemic severity

Simple descriptive statistics pointed to the presence of heterogeneity in the geographical distribution of both our variables of interest, i.e. the severity of the COVID-19 pandemic and EU MNEs headquarters, as indicated by Figures B.1 and B.2. In particular, Figure B.1 clearly indicates a large concentration of regions with the highest excess mortality (>80th percentile of the distribution) in the EU Central and Eastern European member states. We used this geographical difference as an identification strategy to construct the group of treaties and controls, as explained later in this document.

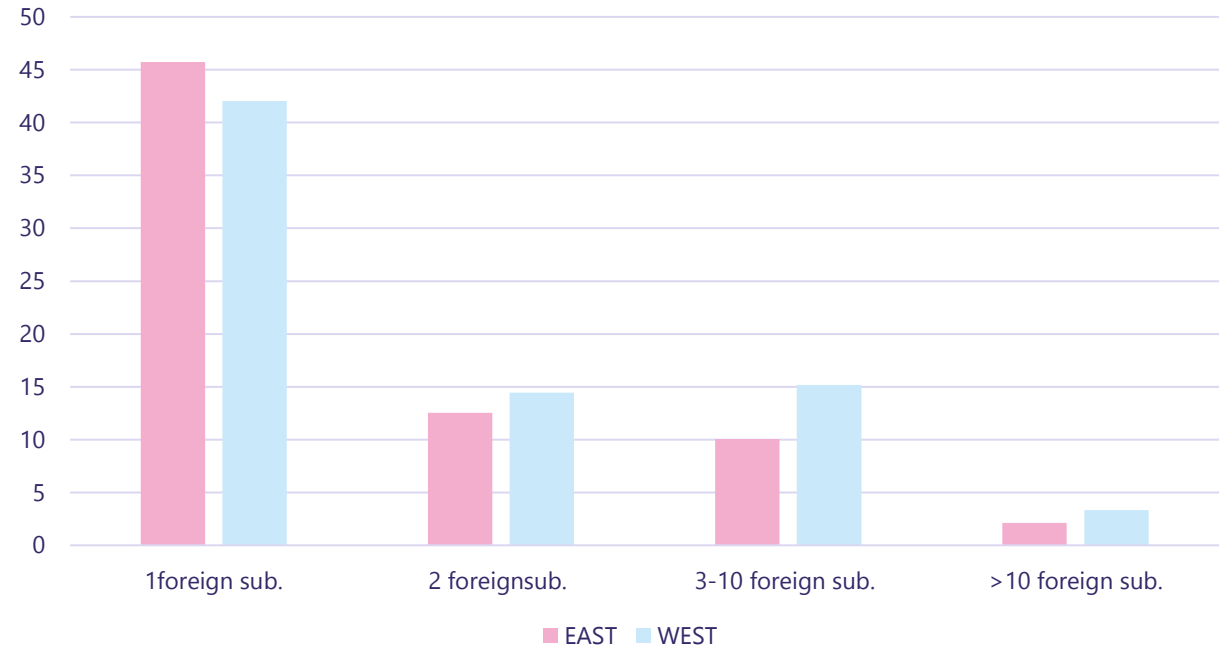
Figure B.1: Excess mortality by regions – year 2021



Source: Authors' elaboration.

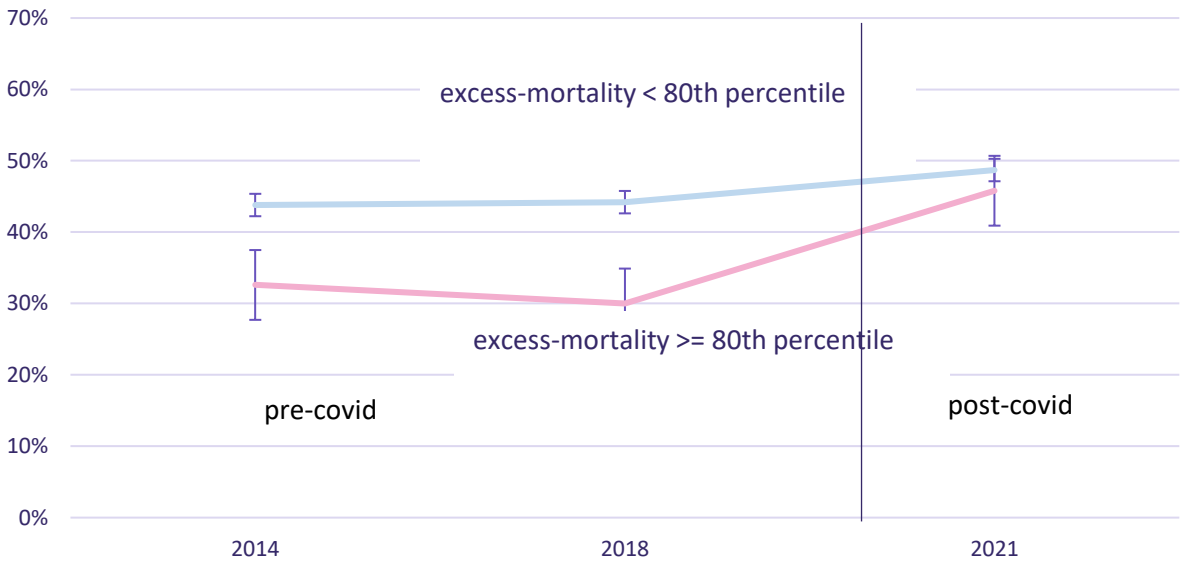
Figure B.2, instead, compares the size of GPNs driven by EU MNEs headquartered in Western and Eastern EU member states. On average, multinational companies located in Western European countries controlled a higher number of foreign subsidiaries compared to their counterparts in Eastern EU countries, indicating that GPNs driven by multinational companies headquartered in Western EU member states may be more complex and geographically dispersed than those driven by MNEs originating from Eastern EU countries. Given the existence of these deep differences between Eastern and Western EU member states, we decided to investigate the impact of COVID-19 on the reorganization of GPNs separately for the two areas.

Figure B.2: Percentage of MNEs by number of foreign subsidiaries



Source: Authors' elaboration.

Figure B.3: Average share of foreign subsidiaries – MNEs in Eastern Europe

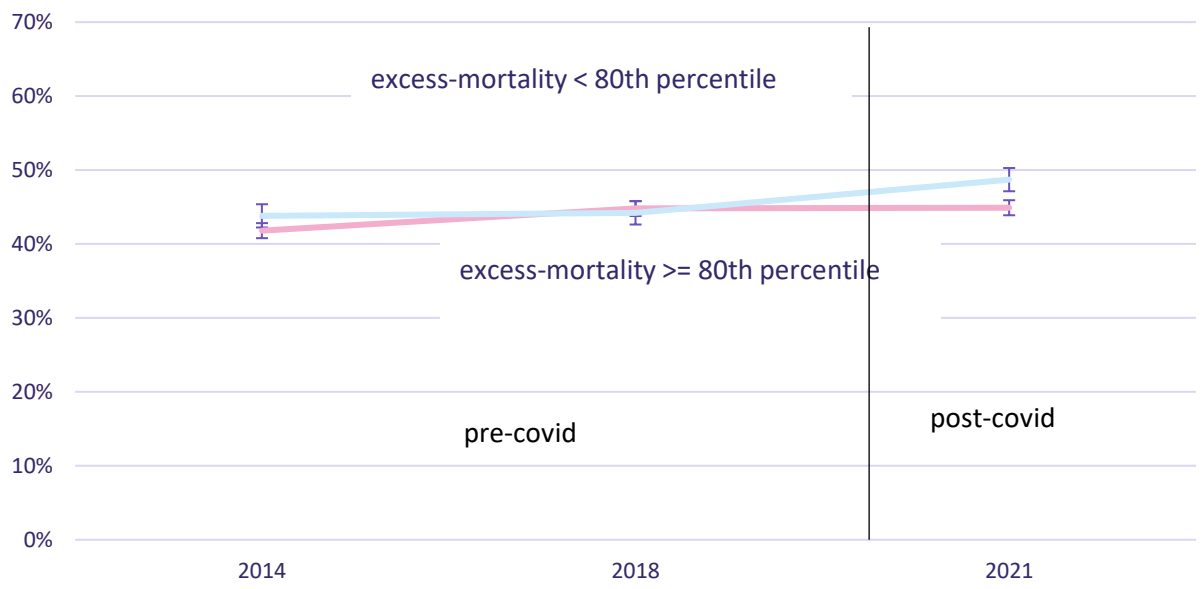


Source: Authors' elaboration.

Figures B.3 and B.4 compare the average share of subsidiaries controlled by MNEs headquartered in regions most and least affected by COVID-19 in Eastern and Western

Europe, respectively. The two graphs show different trends. Indeed, in Eastern Europe MNEs headquartered in the regions most affected by the pandemic had, before COVID, an average share of foreign subsidiaries well below that of multinational companies headquartered in the least affected regions; after COVID, however, these shares were quite similar. In contrast, in Western European countries, MNEs located in the most and in the least affected regions behaved similarly before the pandemic and differently after it. Overall, the figures indicate that there is a pre-COVID parallel trend in both Eastern and Western Europe.[2]

Figure B.4: Average share of foreign subsidiaries – MNEs in Western Europe



Source: Authors' elaboration.

The coronavirus disease pandemic represented a sudden and unexpected shock that affected all the economies differently. Its impact on the re-organization of global production networks, and therefore, on the geographical dispersion of MNEs activity, may be heterogeneous across regions. In this analysis, we did not explore the factors that may have influenced the propagation of the virus, but we were interested in evaluating whether and to what extent the regional disparity of the pandemic severity has affected the MNEs' location decisions. To investigate this effect, we compared the regions most affected by COVID-19 with regions less affected by the virus. Following theoretical predictions, we have no priors on the impact of the pandemic on the reorganization of MNEs' GPNs.

We constructed treatment group by using information on the distribution of excess mortality across space in 2021. In particular, we considered a region (or a country) as treated if it was

[2] The t-tests confirm that the means of the share of foreign subsidiaries for treated and intreated MNEs are not statistically different in 2014 and 2018, in both Eastern and Western Europe.

exposed to COVID-19 more than others, i.e. if it had a percentage of excess mortality that exceeded the 80th percentile in 2021.

We estimated the following equation:

$$Y_{isrt} = \alpha_{isrt} + \beta_1 TREATED_{rt} * Post_t + \tau_t + \mu_i + \sum_{s=1}^{n} \delta t_s + \theta X_{it} + \varphi R_{rt-2} + \varepsilon_{isrt} \quad (1)$$

where "*isrt*" denotes the *i*-th MNE in sector *s*, observed at time *t*, headquartered in region *r*. *Y* is the outcome variable, *TREATED* is a dummy for the treated regions, and *Post* is a dummy equal to 1 in the year 2022. τ_t are year dummies included to control for common macroeconomic global shocks, μ_i are firm fixed effects, and $\sum_{s=1}^{n} \delta t_s$ are sectoral trends, which have been added to control for the existence of unobserved ongoing restructuring processes in specific industries.[3] *X* is a control variable at the firm level, i.e. the (log of the) number of employees in the headquarters, and *R* is a vector of control variables at the regional level, which includes the unemployment rate, the population density and the average manufacturing wage, in log form and lagged two years to avoid endogeneity issues; ε is the error term.[4] We are interested in the estimation of the coefficient β_1 which represents the impact of the pandemic on MNEs' internationalization decisions.

Besides the size of a company, other factors may affect MNEs' strategic choices, as, for example, the degree of internationalization. Operating in an international environment, indeed, implies high entry fixed costs, whose burden reduces as the degree of internationalization increases since firms become more experienced in doing business abroad. Therefore, one may expect that highly internationalized firms may be more willing to change the foreign location of their production facilities than companies with a low degree of internationalization. To control for this potential heterogeneity, we estimated equation (1) using the Unconditional Quantile Regression (UQR) technique as suggested by Firpo et al. (2009), which enabled us to determine how the pandemic affected the overall or unconditional distribution of the outcome[5].

This method simplifies the estimation of unconditional effects using Recentered Influence Functions (RIF) associated with small changes in the covariates (Rios-Avila and Maroto, 2022). The RIF for the unconditional quantiles was defined as follows:

$$RIF(Y_{isrt}, q_\tau, F_Y) = q_\tau + \frac{\tau - 1\{Y_{isrt} \leq Q_\tau\}}{f(q_\tau)} \quad (2)$$

[3] Indeed, policy measures and pressures to relocate production facilities have been already occurring in strategic sectors (UNCTAD, 2021).

[4] The unemployment rate, instead, has been used to proxy the macroeconomic conditions of the regions of origin of MNEs, whereas the population density variable proxies the degree of urbanization of the region. It is an indirect measure of urbanization externalities. The average manufacturing wage is a proxy of the labour costs.

[5] This approach differs from Conditional Quantile Regression (CQR), where quantiles are defined conditional on the covariates.

where q_τ is the τ-th decile of Y, $1\{.\}$ is an indicator function for whether the observation Y_{isrt} is below Q_τ and $f(q_\tau)$ is the density function of Y evaluated at the decile q_τ, and F_Y is the distribution function[6]. Using the implementation suggested by Rios Avila (2019), we applied an OLS estimator to the following regression equation in which the dependent variable is the RIF (eq. (2)):

$$RIF(Y_{isrt}, q_\tau, F_Y) = \alpha_{isrt} + \beta_1 TREATED_{rt} * Post_t + \tau_t + \mu_i + \sum_{s=1}^{n} \delta t_s + \theta X_{it} + \varphi R_{rt-2} + \varepsilon_{isrt} \quad (3)$$

where the notation is the same as in eq. (1). Though quantile functions are nonlinear, this approach enabled us to apply a within transformation to control for firm fixed-effects, as discussed in Borgen (2016) and Rios-Avila and Maroto (2022).

In order to detect potential heterogeneity at both geographical (Western vs. Eastern EU member states) and sectoral levels, we adopted a full interaction approach, interacting the Treated variable with specific dummy variables. As for sectoral heterogeneity, industries were classified, starting from the two-digit NACE code, into High-Tech Manufacturing, Low-Tech Manufacturing, Knowledge Intensive Services, Less Knowledge Intensive Services, Agricultural, and Energy and Construction.

The COVID-19 pandemic was also characterized by different policy responses. In order to better understand the role of these policy measures, we also interacted the treatment variable, i.e. excess mortality, with the stringency index discussed in the previous section. In particular, we constructed a dummy variable equals to one if the stringency index of a given country was above the EU median, and zero if the index was below the median.

[6] Since our dependent variables have values of zero at the bottom of the distribution, the coefficient of interest can only be estimated from the 30th percentile.

Table B.1: Impact on Share of Foreign subsidiaries - estimation results

VARIABLES	(1) Share of Foreign subsidiaries	(2) Share of European subsidiaries	(3) Share of Foreign subsidiaries	(4) Share of European subsidiaries
Treated*Post	-0.0002	-0.0228***		
	(0.0103)	(0.00741)		
Treated*Post*East			0.0646***	-0.0372***
			(0.0166)	(0.0129)
Treated*Post*West			-0.0371***	-0.0147*
			(0.0124)	(0.00832)
N. of employees (log)	0.00921***	0.00457***	0.00921***	0.00457***
	(0.00151)	(0.00112)	(0.00150)	(0.00112)
Unemployment rate (log)t-2	-0.0904***	-0.0197**	-0.0848***	-0.0209**
	(0.0104)	(0.00814)	(0.0104)	(0.00822)
Average wage (log) t-2	0.129***	0.0501**	0.0886***	0.0590**
	(0.0293)	(0.0230)	(0.0302)	(0.0240)
Population density (log) t-2	-0.00294	0.000900	-0.00179	0.000646
	(0.00714)	(0.00546)	(0.00711)	(0.00547)
Constant	1.034***	0.482***	0.881***	0.515***
	(0.108)	(0.0851)	(0.111)	(0.0891)
Firms fixed effect	yes	yes	yes	yes
Sectoral trend	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes
Observations	26,514	26,514	26,514	26,514
R-squared	0.793	0.863	0.793	0.863

Note: The impact of Covid is measured by the percentage variation in the average number of deaths in the last two years with respect to the average number of deaths in the previous five years, at regional level (Treated). Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' elaboration.

Table B.2: Unconditional Quantile regression

VARIABLES	(30) Share of foreign subsidiaries	(40) Share of foreign subsidiaries	(50) Share of foreign subsidiaries	(60) Share of foreign subsidiaries	(70) Share of foreign subsidiaries	(80) Share of foreign subsidiaries	(90) Share of foreign subsidiaries
Treated*Post*East	0.344***	0.256***	0.249***	0.147***	-0.163***	-0.0479***	-0.0226***
	(0.0474)	(0.0350)	(0.0368)	(0.0213)	(0.0380)	(0.00919)	(0.00530)
Treated*Post*West	-0.129***	-0.0612**	-0.0675**	-0.0413***	-0.0691**	-0.0155**	-0.0159**
	(0.0377)	(0.0266)	(0.0272)	(0.0152)	(0.0339)	(0.00714)	(0.00629)
N. of employees (log)	0.0315***	0.0206***	0.0160***	0.00487***	0.00683*	-0.000949	-0.000948*
	(0.00484)	(0.00344)	(0.00341)	(0.00188)	(0.00410)	(0.000759)	(0.000536)
Unempl. rate	-0.335***	-0.204***	-0.156***	-0.0817***	-0.0318	-0.0118**	-0.00920**

(log) t-2							
	(0.0309)	(0.0220)	(0.0219)	(0.0124)	(0.0253)	(0.00555)	(0.00446)
Average wage (log) t-2	0.173*	0.136**	0.159**	0.0892**	0.152**	0.0464***	0.0464***
	(0.0915)	(0.0645)	(0.0659)	(0.0370)	(0.0767)	(0.0172)	(0.0172)
Pop. density (log) t-2	-0.0119	-0.00499	-0.00726	-0.00446	-0.00298	0.000682	0.000682
	(0.0216)	(0.0141)	(0.0137)	(0.00784)	(0.0170)	(0.00431)	(0.00431)
Constant	1.378***	1.126***	1.214*a**	1.027***	1.220***	1.187***	1.089***
	(0.332)	(0.234)	(0.236)	(0.133)	(0.277)	(0.0679)	(0.00960)
Firms fixed effect	yes	yes	yes	yes	yes	yes	yes
Sectoral trend	yes	yes	yes	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes	yes	yes	yes
Observations	26,514	26,514	26,514	26,514	26,514	26,514	26,514
R-squared	0.503	0.583	0.694	0.709	0.801	0.854	0.858

Note: The impact of Covid is measured by the percentage variation in the average number of deaths in the last two years with respect to the average number of deaths in the previous five years, at regional level. Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' elaboration.

Table B.3: Heterogeneity by sector

VARIABLES	(1) Share of foreign subsidiaries	(2) Share of European subsidiaries
Treated*Post*High Manuf*EAST	-0.0446	-0.0707*
	(0.0501)	(0.0397)
Treated*Post*Low Manuf*EAST	0.0763*	-0.0232
	(0.0412)	(0.0301)
Treated*Post*KIS*EAST	0.0423	-0.0483**
	(0.0300)	(0.0240)
Treated*Post*LKIS*EAST	0.0783***	-0.0399**
	(0.0231)	(0.0181)
Treated*Post*Agriculture*EAST	0.248***	-0.00641
	(0.0720)	(0.0420)
Treated*Post*Energy & Costruction *EAST	0.0853	0.0131
	(0.0685)	(0.0414)
Treated*Post*High Manuf*WEST	-0.108**	0.00900
	(0.0479)	(0.0371)
Treated*Post*Low Manuf*WEST	-0.119***	-0.0551*
	(0.0452)	(0.0330)
Treated*Post*KIS*WEST	-0.0280*	-0.0111
	(0.0167)	(0.0104)
Treated*Post*LKIS*WEST	-0.0247	-0.0157
	(0.0242)	(0.0163)
Treated*Post*Agric. *WEST	0.00874	0.0378
	(0.0656)	(0.0552)
Treated*Post*Energy & Construction*WEST	-0.0173	-0.0178
	(0.0498)	(0.0398)

Observations	26,514	26,514
R-squared	0.794	0.863

Note: The impact of Covid is measured by the percentage variation in the average number of deaths in the last two years with respect to the average number of deaths in the previous five years, at regional level (Treated). The regressions also include control variables, a constant term, firms fixed effects, sectoral trend, and time dummies, as in the basic specification. Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors' elaboration.

Table B.4: Heterogeneity by MNEs size

VARIABLES	(1) Share of foreign subsidiaries	(2) Share of European subsidiaries
Treated*Post*<=50employees*EAST	0.0670***	-0.0426***
	(0.0187)	(0.0141)
Treated*Post*<=50<employess<=250*EAST	0.0414	-0.0312
	(0.0371)	(0.0267)
Treated*Post *>250employees*EAST	0.0759	-0.00310
	(0.0517)	(0.0426)
Treated*Post *<=50employees*WEST	-0.0422***	-0.0124
	(0.0153)	(0.0101)
Treated*Post *50<employess<=250*WEST	-0.0551	-0.0228
	(0.0337)	(0.0208)
Treated*Post *>250employees*WEST	-0.00980	-0.0182
	(0.0233)	(0.0169)
Observations	26,514	26,514
R-squared	0.793	0.863

Note: The impact of Covid is measured by the percentage variation in the average number of deaths in the last two years with respect to the average number of deaths in the previous five years, at regional level (Treated). The regressions also include the set of control variables, and of fixed effects, as specified in the basic regression equation. Robust standard error in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' elaboration.

Table B.5: Excess mortality vs Stringency index

VARIABLES	(1) Share of foreign subsidiaries
Treated*Post * Stringency above median	-0.0345***
	(0.0123)
Treated*Post * Stringency below median	0.0613***
	(0.0167)
Observations	26,514
R-squared	0.793

Source: Authors' elaboration.

Appendix C: Reshoring strategy – sample breakdown

Table C.1: Overview of the interviewed firms

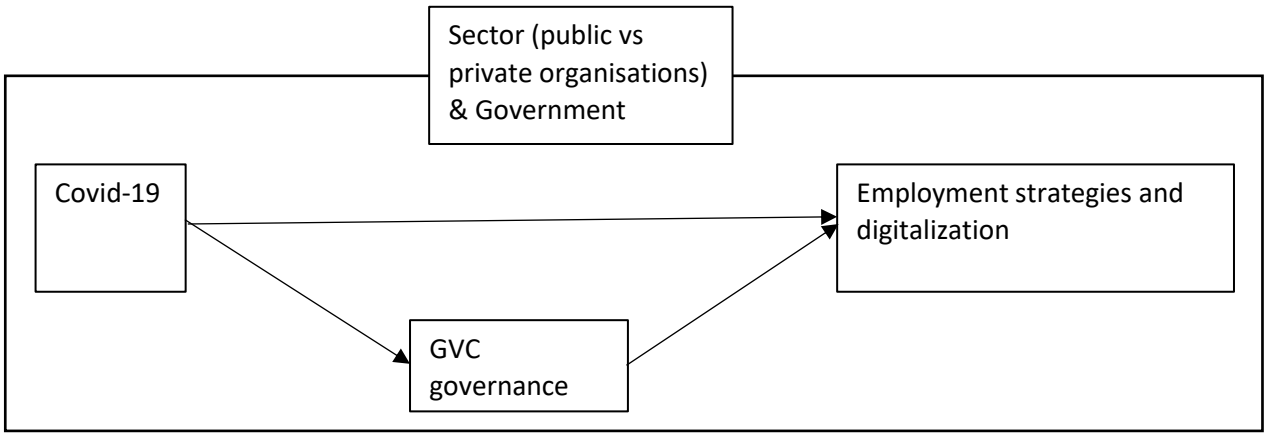
Name, year of foundation, HQ	Business ownership	Presence in countries	Industry	Technological intensity	Firm Size	Offshored Country	Reshored Country
Company A, 2019, Austria	Partnership ownership	Austria, Germany	Cycling industry	Low-tech	Small	China	Germany
Company B, 2019 Austria	Sole proprietorship	Austria	Textile industry	Low-tech	Small	China	Bulgaria
Company C, 1880, Austria	Sole proprietorship	Austria, Germany, Slovakia, U.S., México, China	Metal processing industry	High-tech	Large	Slovakia	Germany
Company D, 1983, Austria	Sole proprietorship	Austria, Czech Republic, UK, Australia, U.S.	Entertainment industry	High-tech	Large	India	Austria
Company E, 1925, Switzerland	Partnership ownership	Austria, Argentina, Australia, Bolivia, Brazil, Bulgaria, Chile, China, Germany, Ecuador, Finland, France, India, Italy, Japan, Cameroon, Canada, Columbia, Kuwait, Malaysia, México, Nether-lands, Nigeria, Norway, Peru, Poland, Rumania, Saudi Arabia, Sweden, Switzerland, Singapore, Spain, Slovakia, Spain, South Africa, South Korea, Taiwan, Thailand, Turkey, Hungary, United Arab Emirates, U.S.	Mechanical engineering industry	High-tech	Large	Czech Republic	Austria

Source: Authors' elaboration.

Appendix D: GVC governance and Covid-19, methodology and outcome

To explore firm-level organisational changes of GVCs in response to the pandemic we used a conceptual model to structure the results (Figure D.1). The impact of Covid-19 on GVC governance and employment strategies were assessed with qualitative and quantitative data.

Figure D.1: Conceptual model



Source: Authors' elaboration.

Qualitative study

To gain more insight into firm-level organisational changes caused by COVID-19, a qualitative case study was conducted using semi-structured interviews aimed at collecting data from different organisations, who are part of a GVC. Questions were formulated following the insights of McGuire (2014), Gereffi & Fernandez-Stark (2016), Fratocchi & Di Stefano (2020) and (Golini et al., 2018). More precisely, we asked questions related to GVC governance modes following the theoretical framework of McGuire (2014) who builds further on the insights of Gereffi & Fernandez-Stark (2016). Furthermore, we asked questions about COVID-19 as well as digitization as contextual elements and how this impacts their organisation and management. Hereby we used insights from the research of Golini et al. (2018). We also deep-dived further in the latter topic by focusing on choice of partners and motives to back-shore, near-shore or off-shore following the literature of Fratocchi & Di Stefano (2020). Finally, we explored which other factors impact firm-level organisational changes by using a more general focus on contextual elements. To gain more insight into the different organisations we also did website-scraping and used internal documents to prepare for each interview.

We interviewed different stakeholders from diverse private and public sector organisations, located in the Netherlands. We used criterion and random sampling (Van Thiel, 2014) to

select respondents that were able to give us more insight into the topic of research. To select the final respondents, we had an open interview with two leaders of a public-private network of different firms and organisations that collaborate in GVCs. Via these contact persons we were able to contact our respondents. The only criterion we used was that the organisation they work participated in a GVC and, that they personally had a management function in the organisation so that they could provide us insight into the strategic choices of the organisation. Following GDPR (General Data Protection Regulation) rules and regulations, all respondents are anonymized, and their interview was transcribed confidentially in an ad-verbatim manner. An overview of respondents can be found in table D.1.

Table D.1: Respondents profiles

Respondent	Type of organisation	Sector
1 – Male	B2B energy supplier	Private
2 – Male	Municipality	Public
3 – Male	Municipality	Public
4 – Male	Port	Hybrid
5 – Male	Network focusing on sustainability	Private
6 - Female	Supplier of energy & Gas	Public
7 – Male	Engineering company	Private
8 – Male	Civil engineering	Private
9 – Male	Automotive - Bike	Private
10 - Male	Organic grower & distributor	Private
11 - Female	Construction company	Private
12 - Male	Ministery	Public
13 - Male	Sustainable energy supplier	Private
14 - Male	Ministery	Public
15 - Male	Municipality	Public

Source: Authors' elaboration.

Finally, to analyse all data (interviews and a minor number of relevant documents), a three-step coding process in Atlas.Ti was conducted by two researchers independently. By having the data coded by two independent researchers, we can report more reliable and more valid results (O'Connor & Joffe, 2020). In a first step all transcripts were uploaded to Atlas.TI and coded in an open manner. To enhance reliability of coding, we conducted a comparative code-document analysis. In a second step, axial coding was used by comparing the different codes with the purpose of the interviews, based on the literature discussed in the theoretical research model. The coding scheme was once again optimized in a deductive and inductive manner via discussions between the first and second researcher. While some codes were merged, others were deleted, and the majority stayed the same. In the end, 14 code groups were used containing 101 subcodes in total. Based on these codes, during step 3, selective

coding was used to finalize the analysis and to select data that illustrates the main findings. An overview of the different codes can be found in Table D.2.

Table D.2: Overview of the main codes

Concept – main codes	1e subcode (non obligatory)	2e subcode (non obligatory)	3e subcode - Values
Information - organisation	Dominant/core activity Complexity activity?		
GVC participation	Perception GVC participation Purchase Sale		Stand-alone company Part of a network Purchasing -The Netherlands Purchasing- outside the Netherlands - but EU Purchasing outside the EU Sales B2B Sales B2C Sales Netherlands Sales outside the Netherlands - but EU Sales outside EU
Technological impact	Speed Impact		High/low Massive/small
Governance modes - Based on the topics discussed we can distinguish these at the end of the analysis	• Hierarchy • Captive • Relational • Modular • Market		
Nearshoring/ backshoring/offshoring	Motives	Backshoring Offshoring Nearshoring	Delivery time Costs Societal impact Government incentives (home country/town
Government/ public organisations	EU Netherlands/ ministries Local city/ organisations	Rules & regulations Support Collaboration Market mechanisms	

Source: Authors' elaboration.

Quantitative study

A survey was conducted among 978 organisations in the Netherlands (a response rate of 54 per cent), from different sectors (both private and public) and varying in size. The questionnaire consisted of around 100 questions about international trade, GVC governance, employment strategies, and performance.

A selection of organisations is made based on their responses to questions about importing and exporting goods and services. If the answer to one of these four questions was "yes", the organisations is considered to have international partners. The remainder of the analyses focuses on these selected organisations (n = 373). Of these organisations, 3 percent is active in the agricultural sector, 30 percent in the industry, 49 percent in the service sector, and 18 percent is active in the public sector. 44 percent of the organisations have between 1-49 employees, 40 percent has between 50 and 249 employees, and 16 has 250 and more employees). The GVC dataset contains a number of concepts that are measured with multiple items (Table D.3).

Table D.3: Overview of the main concepts and items used in survey

Concept	Items	α
Performance	Goods and services of good quality Made a profit Low sickness leave Sufficient personnel Committed personnel Motivated personnel	.730
Human capital	Learning and development Organisation-specific training Employability Yearly budget for training Stimulates peer learning Inventory of learning needs	.928
Consultation	Member of an employer organisations Cooperates with labour unions Union membership	.819
Participation	Influencing organisational policies Suggestions for improvement Choose location of work	.633

Source: Authors' elaboration.

Measuring GVC governance modes

To assess GVC governance, the approach of Ashenbaum (2018) was followed, which aims to operationalize Gereffi et al.'s (2005) governance types. Based on three underlying dimensions (transaction complexity, codification ability and supply base capabilities), this classification consists of the following modes of governance. Next to the five common types, Ashenbaum (2018) also investigates three additional ones – which logically follow from the three dimensions – that have a low level of complexity (Table D.4). In the analyses, the focus is on the five common types and the other three serve as a point of reference.

Table D.4: Overview of governance modes. Adopted from Ashenbaum (2018)

Governance type	Complexity of transactions	Ability to codify transactions	Capabilities in the supply-base
Market	Low	High	High
Modular	High	High	High
Relational	High	Low	High
Captive	High	High	Low
Hierarchical	High	Low	Low
Developmental	Low	High	Low
Disconnected weak	Low	Low	Low
Disconnected strong	Low	Low	High

Source: Authors' elaboration.

The survey extended Ashenbaum (2018) by having 3 questions for each dimension (rather than 1-3). While the measures for codifiability and supply-base ability are largely similar, though extended, the measure of complexity deviates somewhat by focusing on complexity as a characteristic of the products or goods provided by the organisation as it adds to the specificity of the transactions required and thus leads to more complex interactions in the GVC. A principal component analysis shows that the items belong to different dimensions.

The classification was constructed in the same way as Ashenbaum (2018). After constructing the dimensions, these are transformed into dichotomous variables (high = above the mean value of the scale). These dummy variables are then used to construct the governance types (Table D.5).

Table D.5: GVC dimensions and items

GVC dimensions	Items
GVC codification	Similar technology used in the sector Accepted technological standards Buying complete goods or services
GVC capacity	Agreements are fulfilled Stable supply and demand Exchange of knowledge and skills
GVC complexity	Complex goods and services Unique goods and services Specific knowledge required

Source: Authors' elaboration.

Using logistic regression analyses, we investigated whether and to what extent the modes of governance differ with regard to the impact of the COVID19-pandemic. Table D.6 shows that the main differences are found with respect to the relations with external partners. Organizations using the modular and the hierarchical modes of governance report that the relations where negatively impacted by COVID-19.

Table D.6: Logistic regression analyses of three indicators of negative impact of COVID-19

	Quality			Relations			Motivation		
	b	s,e,	p	b	s,e,	p	b	s,e,	p
Intercept	-2,724	1,197	0,023	-1,911	1,026	0,063	-2,390	0,984	0,015
Mode of governance									
Market	0,022	0,520	0,966	0,320	0,461	0,487	-0,275	0,407	0,499
Modular	0,961	0,436	0,028	1,175	0,387	0,002	0,139	0,349	0,691
Relational	1,258	0,505	0,013	0,706	0,442	0,110	0,023	0,400	0,953
Captive	-0,280	0,829	0,736	0,271	0,588	0,645	-0,533	0,563	0,344
Hierarchical	-0,253	0,690	0,714	1,118	0,516	0,030	0,684	0,482	0,156
Control variables									
Absorptive capacity	-0,038	0,140	0,786	-0,040	0,123	0,743	0,086	0,115	0,456
Escalation prevention	0,193	0,168	0,252	0,115	0,137	0,402	0,145	0,126	0,252
Government support	0,040	0,108	0,715	0,038	0,094	0,681	-0,004	0,086	0,966
HWPW - human capital	-0,099	0,194	0,609	0,035	0,159	0,824	-0,014	0,143	0,922
HPWP - consultation	0,672	0,159	< ,001	0,267	0,124	0,031	0,255	0,113	0,024
HPWP - participation	-0,215	0,178	0,225	-0,098	0,154	0,523	-0,084	0,139	0,549
Organization size	0,055	0,056	0,323	0,048	0,050	0,337	0,062	0,045	0,169
Permanent contracts	-0,359	0,117	0,002	-0,125	0,097	0,197	-0,038	0,088	0,668
Fulltime contracts	-0,049	0,108	0,649	-0,144	0,093	0,120	-0,063	0,084	0,453
Nagelkerke R^2		0,339			0,230			0,151	

Source: Authors' elaboration.

Next, the relationship between GVC governance modes and employment strategies were investigated (Table D.7).

Table D.7: OLS regression analyses of three employment strategies

	Human capital			Consultation			Participation		
	b	s.e	p	b	s.e.	p	b	s.e.	p
(Intercept)	1.898	0.228	0.001	1.545	0.264	0.001	3.468	0.199	0.001
Negative impact of Covid-19	0.623	0.172	0.001	1.042	0.199	0.001	0.360	0.150	0.017
Mode of governance									
Market	0.075	0.209	0.719	0.360	0.242	0.138	0.374	0.182	0.040
Modular	1.026	0.160	0.001	0.618	0.186	0.001	1.351	0.139	0.001
Relational	0.850	0.191	0.001	0.020	0.222	0.927	1.293	0.166	0.001
Captive	0.831	0.284	0.004	0.544	0.329	0.099	1.049	0.247	0.001
Hierarchy	0.663	0.248	0.008	0.242	0.287	0.398	1.143	0.215	0.001
Control variables									

KWP	0.141	0.020	0.001	0.168	0.023	0.001	-0.053	0.017	0.002
organisatie_vastcontract	0.188	0.044	0.001	0.080	0.051	0.114	0.171	0.038	0.001
organisatie_voltijdscontract	0.035	0.044	0.430	0.056	0.051	0.270	-0.006	0.038	0.882
Adjusted R^2		0.346			0.307			0.244	

Source: Authors' elaboration.

Finally, a mediation analysis was conducted with an overall indicator of the negative impact of COVID-19 (having a score of 1 if an organization experienced a negative impact regarding quality, relationships, or employee motivation) as the independent and organizational performance as the dependent variables. As mediating variables, a summary score of the three employment strategies and the three sub-dimensions of GVC governance were added. The analyses were controlled for permanent contracts, full-time contracts, organization size, and economic sector. In the control model (model 1), there is a positive and statistically significant relationship between the negative impact of COVID-19 and organizational performance. Hence, a negative impact is associated with higher performance. Model 2 provides an exaplanation. Adding employment strategies and GVC governance, the effect of COVID-19 is no longer statistically significant. The relationship is mediated by employment strategies and GVC capacity, indicating that the organisations that were negatively impacted by COVID-19 were also the ones having these characteristics which helped them to sustain their performance.

Table D.8: Mediation analysis of organizational performance in relation to GVC governance and employment strategies and the negative impact of COVID-19

Dependent variable	Independent variable	Model 1			Model 2		
Performance		b	s.e.	p	b	s.e.	p
	Negative impact of Covid-19	0.425	0.151	0.005	0.074	0.131	0.572
	Employment strategies				0.349	0.047	0.000
	GVC codification				-0.045	0.042	0.289
	GVC capacity				0.215	0.046	0.000
	GVC complexity				0.111	0.036	0.000
Employment strategies							
	Negative impact of Covid-19				0.791	0.152	0.000
GVC codification							
	Negative impact of Covid-19				0.347	0.156	0.026
GVC capacity							
	Negative impact of Covid-19				0.506	0.150	0.000
GVC complexity							

	Negative impact of Covid-19	0.393	0.196	0.046

Adjusted R^2 of model 1: 0.073; Adjusted R^2 of model 2: 0.349;

Source: Authors' elaboration.

Appendix E: Resilience and digitalization in services exports – methodology and estimations

We conduct an econometric analysis to determine whether the resilience in services exports during the pandemic and subsequent lockdowns can be attributed to varying degrees of digitalization across sectors and countries (Table E.1). To achieve this, we employ data on three types of ICT assets: computing assets I_{kjt}, communication assets C_{kjt}, and software and databases SD_{kjt} for sector j in country k in year t, as compiled from the EU KLEMS database. Since there is a large heterogeneity across sectors and countries in terms of the size of the sectors, two indicators of ICT assets per employee (i.e. respectively $I^L_{kjt}, C^L_{kjt}, SD^L_{kjt}$) or share of ICT assets per total assets (i.e. respectively $I^K_{kjt}, C^K_{kjt}, SD^K_{kjt}$) in a sector is calculated. Annex Figures E.3-E.5 (for ICT assets per employee) and Figures E.6-E.8 (for ICT assets as shares of total capital assets) shows the calculation of these two sets of indicators for total manufacturing and a range of services industries.

Table E.1: List of sectors included in the estimations for each column

NACE	Sector	All	Selected	Selected-Services	Manufacturing
A	Agriculture	1	0	0	0
B	Mining	1	0	0	0
C10-C12	Food products, beverages and tobacco	1	1	0	1
C13-C15	Textiles, textile products, leather and footwear	1	1	0	1
C16-C18	Wood and products of wood and cork and paper	1	1	0	1
C19	Manufacture of coke and refined petroleum and chemical products	1	1	0	1
C20	Manufacture of coke and refined petroleum and chemical products	1	1	0	1
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	1	1	0	1
C22-C23	Manufacture of non-metallic mineral products	1	1	0	1
C24-C25	Manufacture of metals	1	1	0	1
C26	Manufacture of computer, electronic and optical products	1	1	0	1
C27	Manufacture of electrical equipment	1	1	0	1
C28	Manufacture of machinery and equipment n.e.c.	1	1	0	1
C29-C30	Manufacture of transport equipment	1	1	0	1
C31-C33	Manufacturing nec; repair and installation of machinery and equipment	1	1	0	1
E	Electricity, gas, steam and air conditioning supply, water, and sewage	1	0	0	0
F	Construction	1	0	0	0
G	Wholesale and retail trade; repair of motor vehicles	1	0	0	0
H49	Land transport and transport via pipelines	1	1	1	0
H50	Water transport	1	1	1	0
H51	Air transport	1	1	1	0
H53	Postal and courier activities	1	1	1	0

I	Accommodation and food service activities	1	1	1	0
J61	Telecommunications	1	1	1	0
K	Financial and insurance activities	1	1	1	0
M	Professional, scientific and technical activities	1	1	1	0
N	Administrative and support service activities	1	0	0	0
R-S	Other service activities	1	0	0	0

Source: Authors' elaboration.

Moreover, given the disruptions in trade across numerous sectors and countries during the COVID-19 lockdowns, particularly in 2020, we introduce a measure to capture the deviation of actual exports x_{kjt} from their potential levels $\dot{x}_{kjt}$. This export utilization measure, denoted as $\tilde{x}_{kjt}$, is constructed as $\tilde{x}_{kjt} = x_{kjt}/\dot{x}_{kjt}$. The potential levels can be measured in two ways: either as the moving average of the past two values plus the current value, denoted as $\dot{x}_{kjt}^{ma}$, or by using the past value of the variable multiplied by its period-averaged growth rate from 2005 to 2019, denoted as $\dot{x}_{kjt}^{tr}$, and constructed as follows for the years 2020 to 2022[7]:

$$\dot{x}_{kjt}^{tr} = x_{kjt-1}\left(1 + \left(\frac{\sum_{t=2006}^{2019} \frac{x_{kjt} - x_{kjt-1}}{x_{kjt-1}}}{2019 - 2006}\right)\right) \quad (1)$$

The equation used for the estimation of the pattern and determinants of the export utilization measure thus defines is as follows:

$$\tilde{x}_{kjt} = exp\left[\alpha_0 + \alpha_1 I_{kjt-2} + \alpha_2 C_{kjt-2} + \alpha_3 SD_{kjt-2} + \alpha_4 II^x_{kjt-2} + \omega_{kj} + \omega_t + \varepsilon_{kjt}\right] \quad (2)$$

Where $\tilde{x}_{kjt}$ is the export utilization measure defined earlier; II^x_{kjt-2} represents the share of intermediate inputs relative to total exports for sector j in country k in year $t-2$; ω_{kj} denotes country-sector fixed effects that control for technological differences within the sample; ω_t signifies time-fixed effects that account for global shocks in each year; ε_{kjt} is the well-behaved robust standard error; and other variables are as previously defined.

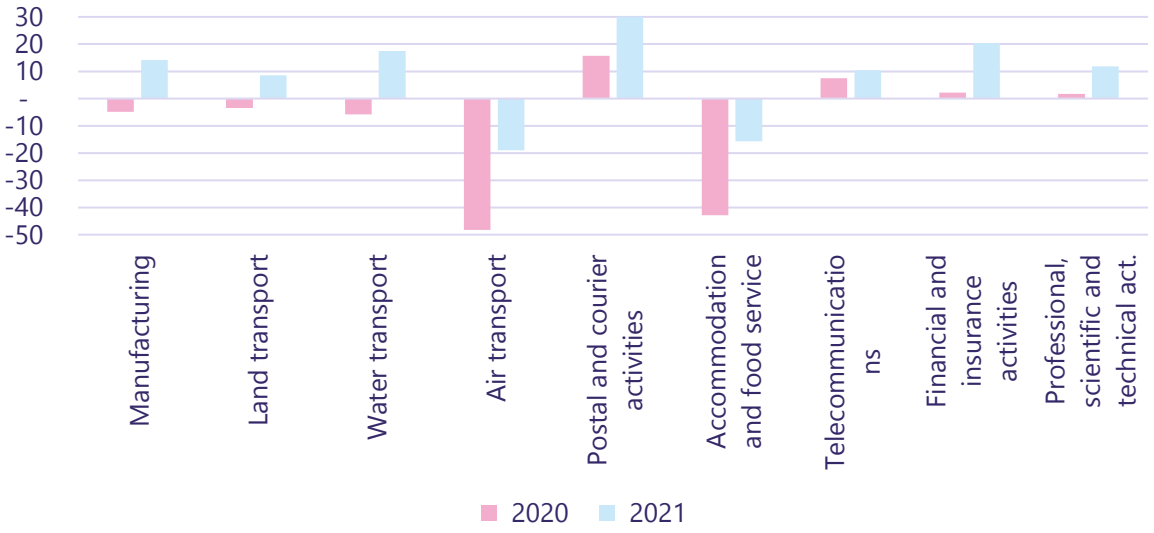
Given that the dependent variables take non-negative values and are skewed around unity, we follow the existing literature (Santos Silva and Tenreyro, 2006; Yotov et al., 2016) and employ the Pseudo Poisson Maximum Likelihood (PPML) model to obtain statistically robust results. As our focus is on the resilience of sectors that are intensive in ICT, we introduce an interaction term between the independent variables and a dummy variable. This dummy variable d_{ict} is specific to ICT-intensive sectors, which are limited to the following: Telecommunications (J61), Financial and Insurance Activities (K), and Professional, Scientific, and Technical Activities (M).

[7] Figures E.1 and E.2 in the Annex present – for the aggregate of export flows from European economies – the calculations of these two methods of calculating 'export utilisation' indicators for the years 2020 and 2021 for total manufacturing and a sub-set of services industries which are also used in our econometric estimates.

As the export data span from 2005 to 2022, while the EU KLEMS data are only available up to 2019, we include two lags for the independent variables. Additionally, we divide the sample for analysis into two distinct periods: the 'long' period, which includes years from 2005 to 2021, and the 'short' period, which encompasses only the COVID-19 era from 2019 to 2021. The estimation results for these two samples are presented in separate tables below. For the long period, both calculations of the export utilization measures are included as dependent variables. However, for the short period, only the measure using the previous growth rates — defined in equation (1) — will be used. For the long period analysis, the independent variables are interacted with three time-dummies: one dummy for the period prior to COVID defined by d_{2005}^{2019}; the other dummy indicates the years 2020 and 2021 separately that are respectively define as d_t^{2020}, and d_t^{2021}.

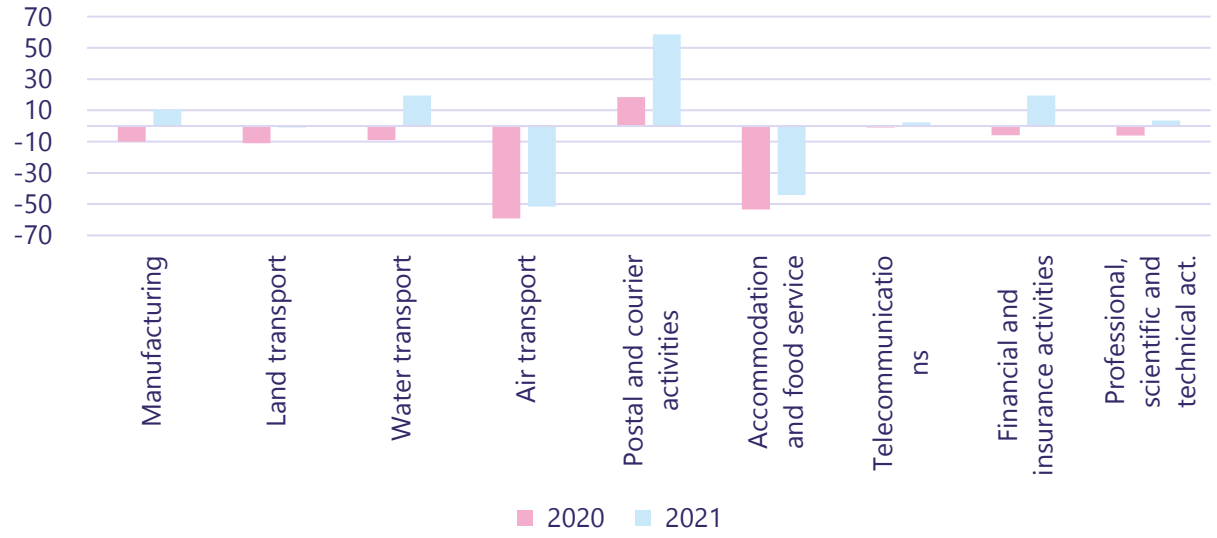
Furthermore, separate regressions will be estimated using different sets of sectors within the sample for analysis. Lastly, in one set of regressions, ICT assets are defined per employee, while in another, they are defined per total asset (capital stock derived from GFCF data).

Figure E.1: Exports deviation from moving average - across countries in sample



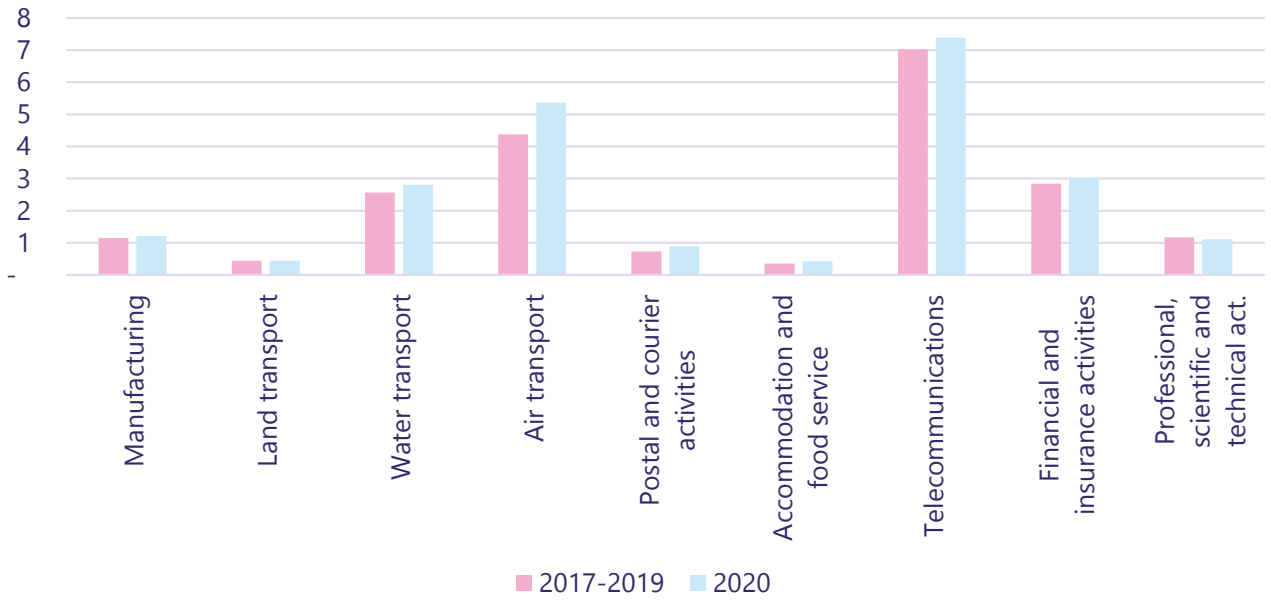
Source: Authors' elaboration based on EU KLEMS.

Figure E.2: Exports deviation from trend - across countries in sample



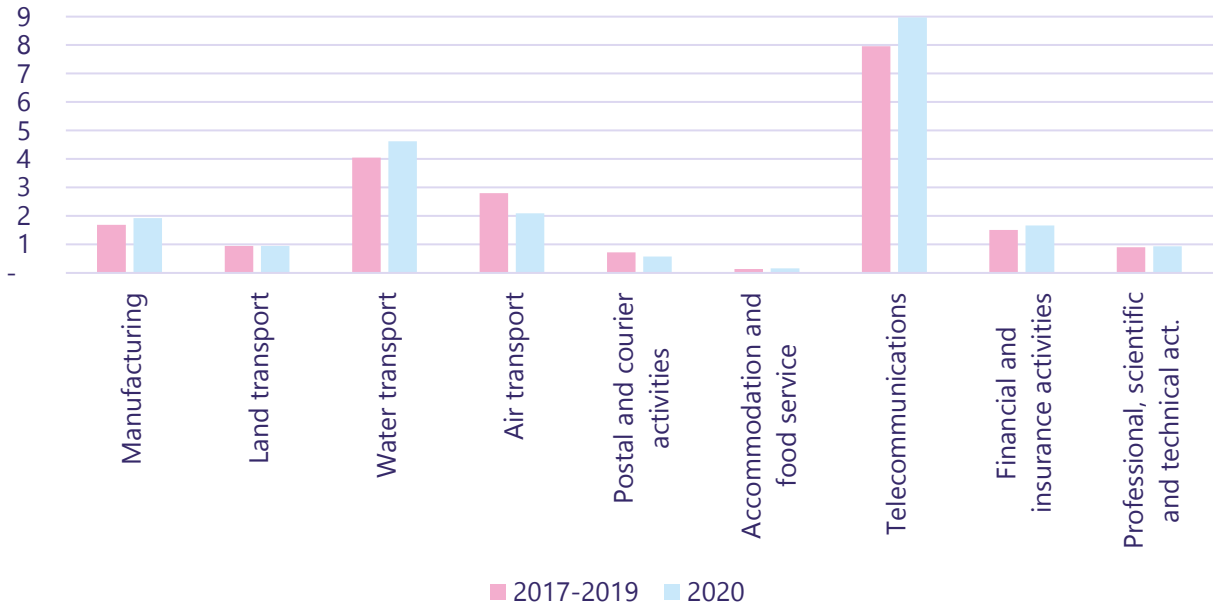
Source: Authors' elaboration based on EU KLEMS.

Figure E.3: Computing capital per employee



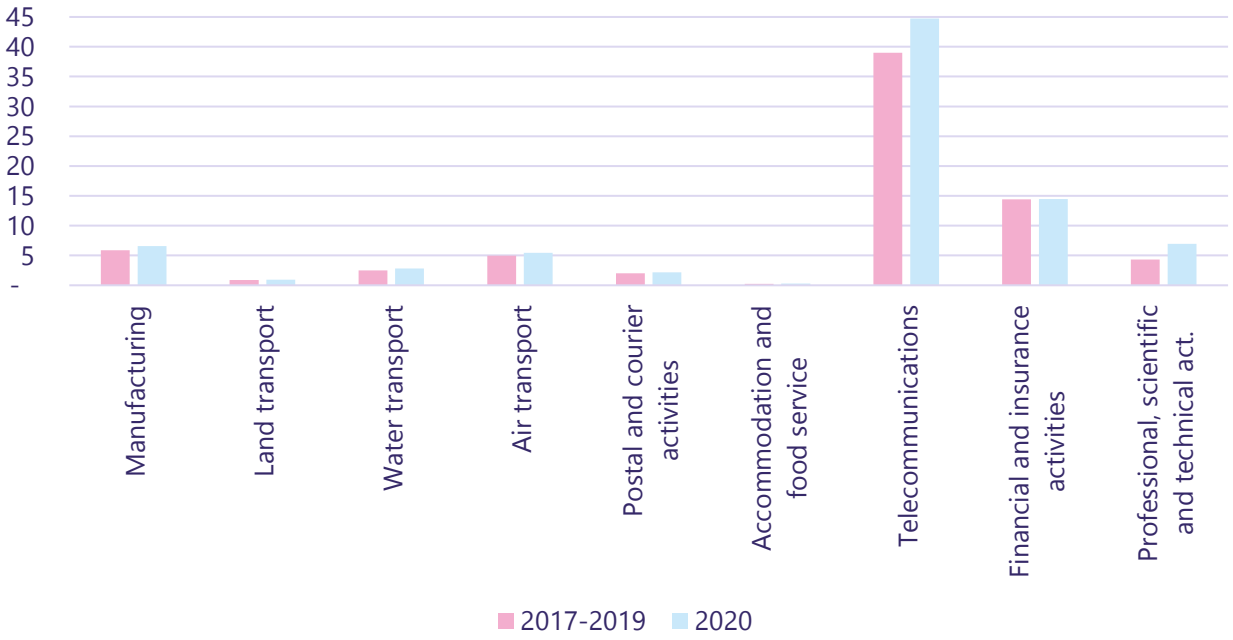
Source: Authors' elaboration based on EU KLEMS.

Figure E.4: Communication capital per employee



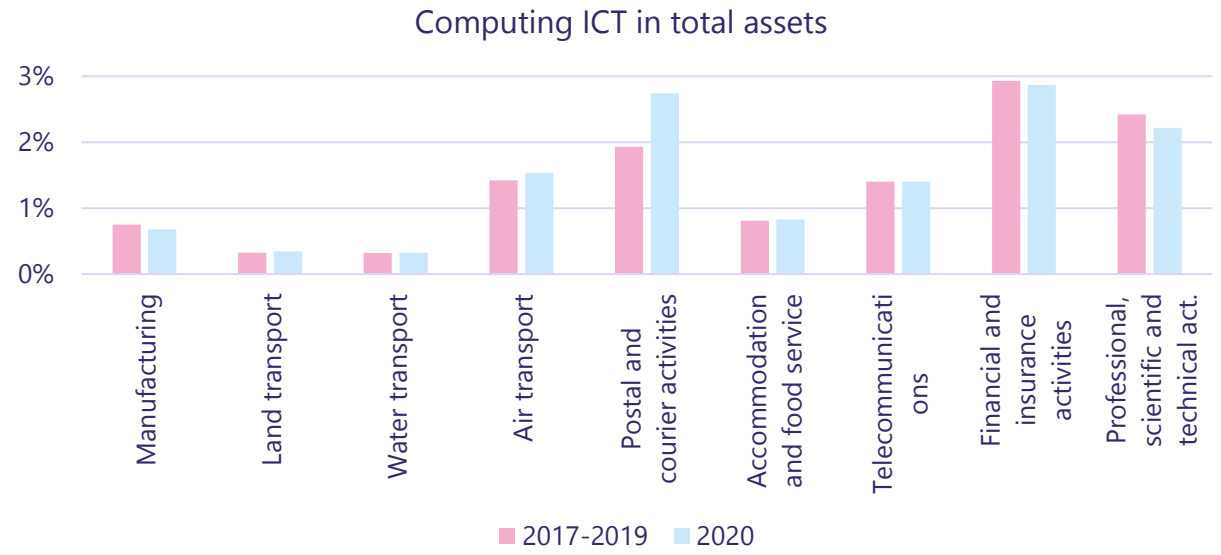
Note: for clarity, the values for Telecommunications service ssector is divided by 10.
Source: Authors' elaboration based on EU KLEMS.

Figure E.5: Software and databases capital per employee



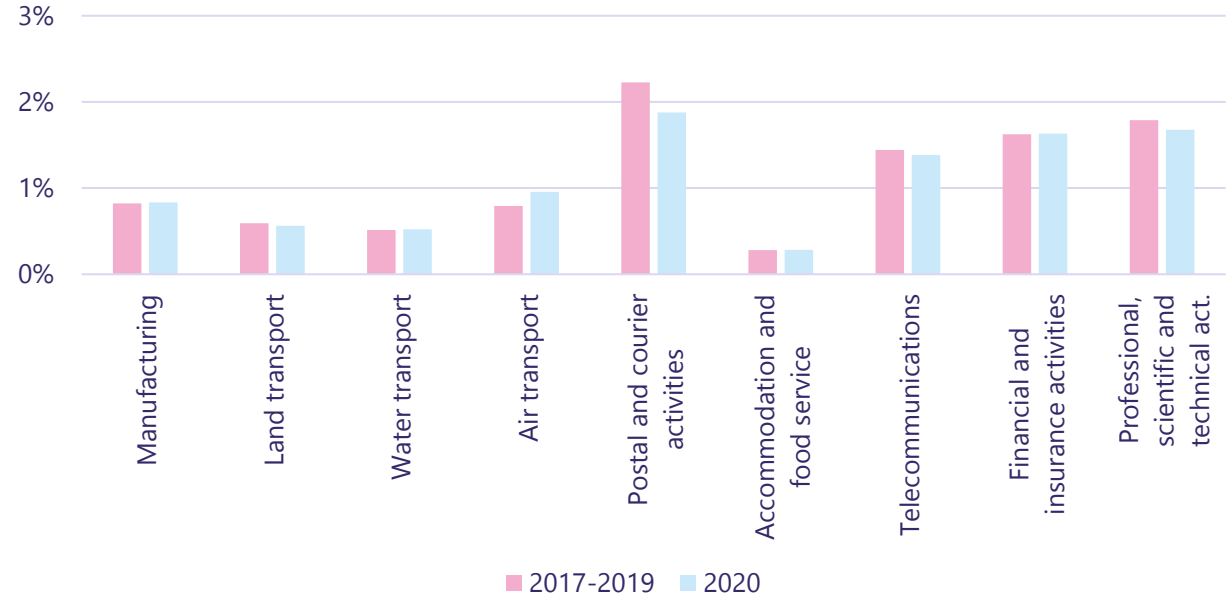
Source: Authors' elaboration based on EU KLEMS.

Figure E.6: Share of computing capital in total capital



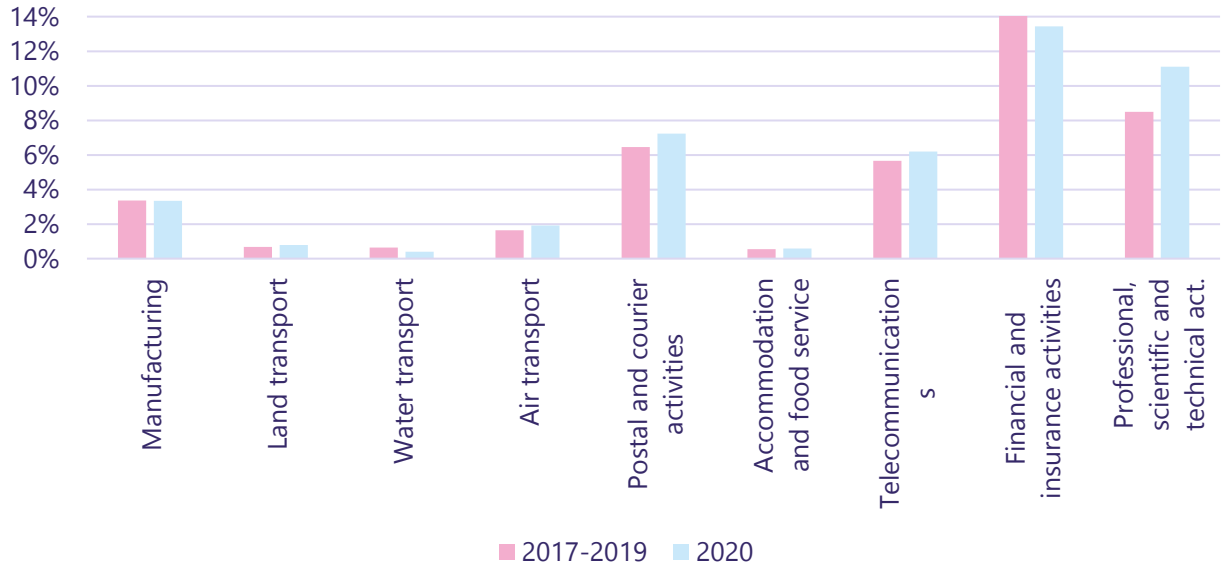
Source: Authors' elaboration based on EU KLEMS.

Figure E.7: Share of communication capital in total capital



Note: for clarity, the values for Telecommunications service ssector is divided by 10.
Source: Authors' elaboration based on EU KLEMS.

Figure E.8: Share of software and databases capital in total capital



Source: Authors' elaboration based on EU KLEMS.

Table E.2: Short-term analysis: PPML estimation results on the export utilization measure during period 2020-2021

Dependent variable: $\dot{x}_{kjt}^{tr}$	All	Selected	Manufacturing	Selected-services-1	Selected-services-2
I_{kjt-2}^{L}	0.033***	0.037***	0.039***	-0.00066	-0.13***
	(0.0077)	(0.0075)	(0.0071)	(0.014)	(0.017)
C_{kjt-2}^{L}	0.015	-0.0048	0.022*	-0.0039	-0.038**
	(0.011)	(0.0072)	(0.013)	(0.0047)	(0.015)
SD_{kjt-2}^{L}	0.0029	0.0053	0.010	-0.0047	-0.13***
	(0.010)	(0.0081)	(0.011)	(0.0070)	(0.038)
II_{kjt-2}^{x}	-0.000090	0.00089***	0.029*	0.00099***	0.0013***
	(0.00021)	(0.00019)	(0.017)	(0.00019)	(0.00013)
$d_{ict} \times I_{kjt-2}^{L}$					0.16***
					(0.020)
$d_{ict} \times C_{kjt-2}^{L}$					0.030*
					(0.017)
$d_{ict} \times SD_{kjt-2}^{L}$					0.13***
					(0.039)
$d_{ict} \times II_{kjt-2}^{x}$					-0.0055***
					(0.0011)
Constant	-0.037	-0.018	-0.18**	0.12**	0.34***
	(0.062)	(0.048)	(0.083)	(0.058)	(0.050)
Observations	1046	751	559	192	192
Pseudo R-Sq	0.057	0.037	0.028	0.063	0.064
AIC	2103.3	1515.2	1144.9	380.1	388.0
BIC	2128.1	1538.3	1166.5	396.4	417.3

Source: Authors' elaboration.

Table E.3: Long-term analysis: PPML estimation results on the export utilization measure during period 2007-2021

Dependent variable: $\dot{x}_{kjt}^{tr}$	All	Selected	Manufacturing	Selected-services-1	Selected-services-2
$d_{2005}^{2019} \times I_{kjt-2}^{L}$	-0.0053***	-0.0073***	-0.0035	-0.011***	-0.038***
	(0.0018)	(0.0019)	(0.0026)	(0.0024)	(0.013)
$d_{t}^{2020} \times I_{kjt-2}^{L}$	-0.0098**	-0.0085*	0.0016	-0.012***	-0.019***
	(0.0041)	(0.0045)	(0.0028)	(0.0044)	(0.0015)
$d_{t}^{2021} \times I_{kjt-2}^{L}$	-0.0071***	-0.0072***	-0.0053*	-0.0084***	-0.0074***
	(0.0017)	(0.0014)	(0.0029)	(0.0015)	(0.00095)
$d_{2005}^{2019} \times C_{kjt-2}^{L}$	0.00027	0.00016	-0.0018	0.00018	0.0095
	(0.00052)	(0.00050)	(0.0019)	(0.00060)	(0.0070)
$d_{t}^{2020} \times C_{kjt-2}^{L}$	0.00044	0.00031	-0.0048*	0.00018	-0.0021
	(0.00052)	(0.00050)	(0.0028)	(0.00064)	(0.0071)
$d_{t}^{2021} \times C_{kjt-2}^{L}$	0.00020	0.00016	0.0039	0.00017	-0.0020
	(0.00051)	(0.00048)	(0.0028)	(0.00062)	(0.0063)
$d_{2005}^{2019} \times SD_{kjt-2}^{L}$	0.00023	0.00027	0.00024	0.0012	-0.0011
	(0.00022)	(0.00021)	(0.00020)	(0.0014)	(0.010)
$d_{t}^{2020} \times SD_{kjt-2}^{L}$	0.00089	0.00063	-0.00045	0.0026*	-0.029*
	(0.00057)	(0.00052)	(0.00062)	(0.0016)	(0.016)
$d_{t}^{2021} \times SD_{kjt-2}^{L}$	0.00048	-0.00044	-0.00030	0.00015	-0.028***
	(0.00047)	(0.00039)	(0.00043)	(0.0014)	(0.011)
II_{kjt-2}^{x}	0.000051**	0.000055**	0.000036*	0.00020***	0.00027***
	(0.000024)	(0.000023)	(0.000019)	(0.000070)	(0.000022)
$d_{2005}^{2019} \times d_{ict} \times I_{kjt-2}^{L}$					0.036***
					(0.013)
$d_{t}^{2020} \times d_{ict} \times I_{kjt-2}^{L}$					0.024***
					(0.0046)
$d_{t}^{2021} \times d_{ict} \times I_{kjt-2}^{L}$					0.0048
					(0.0047)
$d_{2005}^{2019} \times d_{ict} \times C_{kjt-2}^{L}$					-0.0096
					(0.0070)
$d_{t}^{2020} \times d_{ict} \times C_{kjt-2}^{L}$					0.0019
					(0.0072)
$d_{t}^{2021} \times d_{ict} \times C_{kjt-2}^{L}$					0.0017
					(0.0063)
$d_{2005}^{2019} \times d_{ict} \times SD_{kjt-2}^{L}$					0.0028
					(0.010)
$d_{t}^{2020} \times d_{ict} \times SD_{kjt-2}^{L}$					0.031**
					(0.016)
$d_{t}^{2021} \times d_{ict} \times SD_{kjt-2}^{L}$					0.029***
					(0.011)
$d_{ict} \times II_{kjt-2}^{x}$					-0.00020**
					(0.000087)
Constant	0.040***	0.043***	0.039***	0.048***	0.048***
	(0.0048)	(0.0042)	(0.0041)	(0.014)	(0.017)
Observations	5677	4173	3223	950	950
Pseudo R-Sq	0.005	0.004	0.004	0.004	0.005
AIC	11603.0	8507.8	6563.7	1964.7	1983.6
BIC	11676.1	8577.5	6630.6	2018.1	2085.6

Appendix F: Automotive and medical equipment GVCs' digitalization shift: data sample and method description

The pandemic has had a severe impact on the European automotive industry, which was already a vital sector of the EU economy before the crisis. The industry contributed 7% of the EU's GDP and employed 6% of its workforce. However, the pandemic disrupted the supply chains of the industry, especially from Asia and China, where most of the components came from. This led to huge losses and production challenges for the industry. The industry experienced its worst sales drop in history in 2020, with only 78.8 million vehicles sold (the lowest since 2011). However, sales rebounded by 30% y/y in the first half of 2021 (KPMG, 2020, PZPM, 2021). The European automotive industry is facing a difficult situation due to COVID-19.

Likewise, according to Rutkowski (2021), Europe ranks second in the global medical devices market. The COVID-19 pandemic has highlighted the value of medical devices for the entire European community. Some groups of medical devices (e.g. ventilators and oxygen concentrators) faced temporary shortages and enormous demand, revealing their vital role in the health care system and in preserving and improving patients' lives. In Europe, medical devices contributed to combating the virus on a large scale, at every stage, from diagnosis to treatment. The COVID-19 pandemic has also brought significant challenges to the medical equipment industry, despite its overall positive impact on the sector. Contrary to common belief, the industry has experienced tremendous stress and disruption. Due to shifts in health care system priorities and organisational issues in most European countries, elective procedures were cancelled or delayed. This led to less use of medical devices during surgeries and a substantial decline in sales for their manufacturers. The shock was quite severe, as in the first year of the pandemic, the number of planned medical procedures dropped by up to 80-90 per cent in European countries with the highest COVID-19 impact on the population (Rutkowski, 2021). On the other hand, various in-vitro diagnostic devices and related products gained popularity in the market due to COVID-19 diagnosis and treatment, resulting in a significant increase in revenues for their manufacturers.

Therefore, the qualitative study was conducted with the participation of the 12 top executives representing eight companies from the automotive and medical equipment sectors from May 2023 until August 2023. The industrial background of the top executives participating in the study was pre-defined purposefully. The COVID-19 pandemic severely impacted both sectors, thus creating a good laboratory for studying the inhibiting or facilitating role of that pandemic for digital transformation in companies. The interviewees were to possess different top management positions and were assured of anonymity and confidentiality to reduce bias and increase the reliability of the results. The typical interview lasted around one hour. We aimed to conduct interviews with top executives representing entities that varied across the following aspects:

- domestic versus foreign subsidiaries,
- age of the company,

– diversity of value-creating processes (from inbound logistics through manufacturing to marketing and after-sale services).

Following the OECD guidelines related to foreign direct investment, as a foreign subsidiary, we defined an entity where the involvement of a foreign investor amounts to a minimum of 10% ownership stake. The company size categories were determined according to the European Union, with firms that employed fewer than 50 people being defined as small enterprises, those with 50–249 employees as medium-sized enterprises, and those with 250 or more employees as large enterprises. As far as the value-creating activities are concerned, we referred to the concept of the Porterian value chain and the whole set of activities from research and development, production of materials, production of components, production/assembly of final products (addressed to final consumers or users), sales and marketing and on- and after-sales services (service). The detailed list of top executives representing the firms under the study is presented in Table F.1.

Once the transcripts were analysed we mapped the main categories and their connections. This helped us group similar concepts and define the core category and higher-level categories. The analysis revealed three groups of factors that affect how companies adopt Industry 4.0 technologies when dealing with the pandemic challenges. We found 40 codes in the open-coding stage, then we narrowed them down to seven codes based on the open codes and moved to the selective-coding stage, which led to 3 core categories that we used to develop and suggest the theory (Table F.2).

Table F.1. Interviewee profile

Interviewee ID	Industry	Domestic v. foreign subsidiary	Age of the company	Value creating activities
1	Automotive	Foreign subsidiary	30 years	• Research and development • Production of materials • Production of components • Production/assembly of final products
2				
3				
4				
5				
6	Automotive	Foreign subsidiary	21 years	• Research and development • Production of materials • Production of components • Production/assembly of final products • Sales and marketing
7	Automotive	Domestic	14 years	• Research and development • Production/assembly of final products • Sales and marketing • On- and after-sales services (service)
8	Automotive	Domestic	32 years	• Research and development • Production of materials • Production of components • Production/assembly of final products • On- and after-sales services (service)

9	Medical equipment	Foreign subsidiary	18 years	• Sales and marketing • On- and after-sales services (service)
10	Medical equipment	Foreign subsidiary	31 years	• Production of materials • Production of components • Production/assembly of final products • Sales and marketing • On- and after-sales services (service)
11	Medical equipment	Foreign subsidiary	16 years	• Production of materials • Production of components • Production/assembly of final products • On- and after-sales services (service)
12				

Source: Authors' elaboration.

Table F.2: Emergent selective codes and their correspondence with axial and open codes

Open codes	Axial codes	Selective codes
(1) innovations (2) Industry 4.0 (3) technological advancement	(A) Technological changes (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 21, 24, 27, 33, 34, 40)	Digitalisation (A, B, C)
(4) digital shift (5) software	(B) Innovations (1, 2, 3, 4, 10, 11, 12, 13, 14, 21, 37)	Organisation (D, E)
(6) Hardware	(C) Competence (7, 8, 9, 14, 18, 19, 35)	Ecosystem (F, G)
(7) competitive advantage (8) effectiveness (9) efficiency	(D) Internal structures (15, 16, 17, 18, 19, 20, 22, 23, 24, 26, 27, 35, 39)	
(10) artificial intelligence (11) robotization (12) automatisation of processes (13) Big data analysis (14) servitisation	(E) Internal communication (16, 18, 19, 22, 23, 32)	
(15) Global value chain role (16) internal structure (17) subsidiary (18) local initiatives (19) top-down initiatives (20) restructuring	(F) External environment (25, 28, 29, 30, 31, 32, 33, 34, 36, 38)	
(21) cybersecurity (22) international markets (23) reshoring (24) Substituting entities (25) supply shortages (26) employee turnover (27) sources of financing (28) legal restrictions (29) Global challenges (30) COVID_19 pandemic (31) Governmental policies (32) Industry profile (33) competitors (34) customer needs (35) human resources	(G) Disruptions (21, 25, 29, 30, 38, 40)	

(36) Partnerships in the market (37) green solutions (38) Lockdowns and mobility restrictions (39) geographical dispersion (40) opportunities		

Source: Authors' elaboration.

Appendix G: The creative response to Covid-19: R&D, internationalisation – method and data analysis results

We analysed firm-level data from Statistics Austria for the period 2019-2021. The database is compiled from the results of three different surveys: Austrian structural business statistics (Leistungs- und Strukturerhebung), R&D survey, and data on imports and exports at firm level. These data sets have been matched at the firm level and include 2,859 firms which reported R&D activities for 2019 and 2021.

The analysis proceeds in two steps: firstly, we divided the sample into different sub-groups that helped us highlight the heterogeneity in the data and understand the changes observed between 2019 and 2021; secondly, we employed descriptive statistics and regressions to link these changes to external factors.

Firms are categorized twofold:

- by the percentage change of R&D expenditures between 2019 and 2021 (high growth, medium growth, no growth, medium losses, or significant losses in R&D expenditures) and
- by absolute R&D expenditures and R&D intensity (R&D expenditures divided by turnover) (Dachs and Drach, 2019):
    - Moderate R&D performers with a R&D intensity of less than 7% (the mean intensity across all firms).
    - R&D professionals with an R&D intensity of more than 7% and less than 2.5 Mio EUR R&D expenditures which is the mean of R&D expenditures.
    - R&D Leaders with R&D intensities of 7% and more but less than 50%, and R&D expenditures of more than 2.5 EUR.
    - R&D Centers with R&D intensities of 50% or more and R&D expenditures of more than 2.5 EUR.

These four classes account for the heterogeneity among R&D active firms in Austria. Besides manufacturing and services firms where investing in R&D is a strategy to increase competitiveness, the Austrian business sector also includes a number of firms that provide R&D as their main product. Examples are found among technology-intensive start-ups or specialized suppliers of knowledge. Moreover, some research and technology organizations including AIT, but also corporate R&D centers affiliated to foreign multinationals are incorporated as enterprises.

Table G.1: Quantiles of firms according to their change in R&D expenditures between 2019 and 2021

	Firm size	R&D intensity			R&D expenditures	Turnover	Public funding	Funding from abroad	Basic research	Exports	imports
Quantiles	Average no of employees	2019	2021	Change, %points	Change in, %	Change, %	Share on total R&D	Share on total R&D	Share on total R&D	share of turnover	Share of turnover
1	116	9.9%	3.8%	-6.2%	-6.3%	1.6%	18%	2.6%	7.4%	54%	42%
2	230	12.2%	8.2%	-4.0%	-2.1%	1.5%	16%	3.0%	6.7%	55%	38%
3	193	1.4%	0.8%	-0.6%	0.3%	0.4%	15%	3.8%	6.1%	51%	35%
4	194	2.4%	3.6%	1.2%	3.3%	6.1%	16%	2.3%	5.4%	48%	36%
5	149	11.0%	14.9%	3.9%	39.9%	13.9%	17%	2.4%	6.5%	51%	43%
Total	176	7.4%	6.3%	-1.1%	7.0%	4.7%	16%	2.8%	6.4%	52%	39%

Source: Authors' elaboration based on R&D survey by Statistics Austria.

Table G.2: Groups of firms according to R&D intensity and absolute R&D expenditures between 2019 and 2021

	No of firms	R&D intensity			R&D expenditures	Turnover	Public funding	Funding from abroad	Basic research	Exports	imports
Group		2019	2021	Change, %points	Change in, %	Change, %	Share on total R&D	Share on total R&D	Share on total R&D	share of turnover	Share of turnover
Moderate R&D	1232	0.02%	0.04%	0.02%	10.7%	0.1%	11.3%	1.1%	5.0%	52%	32%
R&D Professionals	1347	12.22%	9.67%	-2.56%	5.0%	9.7%	20.8%	3.4%	7.6%	54%	49%
R&D Leaders	190	0.18%	0.16%	-0.02%	-0.3%	0.1%	10.5%	5.9%	4.3%	53%	24%
R&D Centers	90	52.91%	54.23%	1.32%	1.2%	3.2%	25.1%	11.2%	11.8%	17%	17%
Total	2859	7.36%	6.26%	-1.10%	7.0%	4.7%	16.1%	2.8%	6.4%	52%	39%

Source: Authors' elaboration based on R&D survey by Statistics Austria.

Table G.3: Regression results

Indipendent variable	Coefficient	Std. err.	t	P>|t|	[95% conf interval]	
Log of employees	-36.8132	5.7467	-6.410	0.000	-48.083	-25.543
Share of public funding	0.9053	0.4453	2.030	0.042	0.032	1.779
Sh. of funding from abroad	7.6866	18.1157	0.420	0.671	-27.840	43.213
Share of research	0.5008	0.2066	2.420	0.015	0.096	0.906
Change in turnover	0.0002	0.0009	0.250	0.806	-0.001	0.002
Share of imports	0.0007	0.0040	0.160	0.871	-0.007	0.009
Group: R&D Professionals	-135.7158	21.3962	-6.340	0.000	-177.676	-93.756
Group: R&D Leaders	-57.2953	27.3924	-2.090	0.037	-111.015	-3.576
Group: R&D Centers	-119.4516	40.1573	-2.970	0.003	-198.204	-40.699
_cons	226.5903	30.8492	7.350	0.000	166.092	287.089

Note: Base case - Moderate R&D performers
Source: Authors' elaboration based on R&D survey by Statistics Austria.