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FACULTY OF SOCIAL SCIENCES

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Brexit's Impact on the United Kingdom's Service Specializations in the EU-UK Value-Added Trade Network

Master's Thesis

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Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
3. I fully agree to my work being used for study and scientific purposes.

In Prague on July 31, 2024 Taylar Del Brocco

References

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Abstract

The United Kingdom's (UK) decision to leave the European Union (EU) created widespread uncertainty as to how it would impact the trading relationship between the two markets given the increased interconnectivity and integration in the era of global value chains (GVCs). The United Kingdom has consistently exhibited comparative advantages in high value-added service activities in GVC trade, with the European Union being the largest importer of UK services year-to-year. Moreover, the UK is highly integrated into EU value chains, and the increased non-tariff costs now associated with trade between the two markets contributes to the uncertainty regarding how Brexit will impact the UK's GVC specialization structures in the long term. Using network analysis, this thesis analyzes the UK's position in both the global and EU-UK value-added networks to determine whether or not the nature of trade in services has provided the United Kingdom with some level of resiliency against Brexit shock in its specialized sectors. The proliferation of GVC trade after 2000 has contributed to an overall decline in UK service centrality in both networks. However, Brexit's indirect impacts on EU-UK value chains is evident in the rise in connectivity of Ireland's knowledge-based service sectors relative to the EU market following the referendum.

Abstrakt

Rozhodnutí Spojeného království (UK) opustit Evropskou unii (EU) vyvolalo rozsáhlou nejistotu ohledně toho, jak to ovlivní obchodní vztahy mezi těmito dvěma trhy vzhledem ke zvýšené propojenosti a ekonomické integraci v éře globálních hodnotových řetězců (GVC). Spojené království soustavně vykazuje komparativní výhody v činnostech služeb s vysokou přidanou hodnotou v obchodu GVC, přičemž Evropská unie je každoročně největším dovozcem služeb Spojeného království. Kromě toho je Spojené království vysoce integrováno do hodnotových řetězců EU a zvýšené netarifní bariéry nyní spojené s obchodem mezi těmito dvěma trhy přispívají k nejistotě ohledně toho, jak brexit ovlivní struktury specializace GVC Spojeného království v dlouhodobém horizontu. Tato práce pomocí síťové analýzy analyzovala pozici Spojeného království v globální síti i v sítích s přidanou hodnotou mezi EU a Spojeným královstvím, aby určila, zda povaha obchodu se službami poskytla Spojenému království určitou odolnost vůči šoku z Brexitu v jeho specializovaných sektorech. Rozšíření obchodu GVC po roce 2000 přispělo k celkovému poklesu centrality britských služeb v obou sítích. Nepřímé dopady Brexitu na

hodnotové řetězce mezi EU a Spojeným královstvím jsou však evidentní v nárůstu konektivitu irských sektorů služeb založených na znalostech ve vztahu k trhu EU, který se odehrál v době po referendu.

Keywords

trade in value added, global value chains, GVC, Brexit, EU

Klíčová slova

přidaná hodnota, GVC, globální hodnotové řetězce, mezinárodní obchod, Brexit, EU

Title

Brexit's Impact on the United Kingdom's Service Specializations in the EU-UK Value-Added Trade Network

Název práce

Dopady Brexitu na specializaci Velké Británie v oboru služeb v síti obchodu přidanou hodnotou mezi EU a Velkou Británií

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1. Introduction

The United Kingdom's (UK) 2016 decision to leave the European Union (EU) sparked widespread uncertainty over the future of the EU-UK relationship, with many asking how the United Kingdom's exit from the single market would affect not only its economic performance but also what changes may occur within the European Union and global markets as a result. Prior to the decision to leave, the UK had been highly integrated into European value chains, as the EU was the UK's largest trading partner given its geographic proximity as well as its inclusion in the EU customs union. This deep level of interconnectivity and interdependence is indicative of the rise in trade in intermediate goods and production fragmentation that has defined global trade in the 21st century.

The rise in trade in intermediate goods has coincided with the emergence of global value chains (GVCs) which have contributed to the increased fragmentation of production and participation of more and more countries in global trade networks. The fragmentation of production brought on by GVCs has led to the separation of various processes, services, and activities that are used to produce input and intermediate goods and services, ultimately culminating in the production of final goods or services sold for final consumption. Existing literature estimates that trade in intermediate inputs ranges from roughly 50-60% of total global trade (Cingolani et al., 2017; Gaál et al., 2023; Ibrahim et al., 2021; Lanz & Piermartini, 2018).

As goods flow through the value chain, various activities occur that affect the development, production, assembly, and sale of the final good. These activities are referred to as upstream and downstream activities that occur at either end of the value chain and contribute their own value to the final product. Both upstream and downstream activities contribute the largest shares of added value to the final good. Upstream activities occur in the earlier stages of production and include those such as research and development or design. Downstream activities, on the other hand, occur in the later stages of production when a good is closer to its final product and include services such as distribution or marketing. These activities contribute more added value than traditional manufacturing or assembly activities that occur in the middle of production chains.

One reason for the difference in value-added contributions between upstream, downstream, and midstream activities is the inclusion of high-skilled labor that is more costly than the low-skilled labor used in midstream activities. Manufacturing and assembly services that produce the lowest shares of value-added also require lower investment costs to enter and can therefore be utilized by developing economies to join existing supply chains and reap the benefits of GVC participation without building industries from the ground up (Cingolani et al., 2017; Coveri & Zanfei, 2023; Ibrahim et al., 2021). Conversely, countries who specialize in higher value-added activities are in a position to extract the most benefit from GVC participation. Developed economies like the United Kingdom or the United States tend to specialize heavily in high value-added industries, with the United Kingdom being one of a handful of economies that almost exclusively specialize in high value-added services (Cappariello et al., 2018; Miroudot & Cadestin, 2017).

The fragmentation of production and the increase in trade of intermediate goods has also allowed countries to exploit their own comparative advantages in production capabilities, resulting in restructuring of specializations in activities along the value chain. These characteristics have not only defined the current landscape of international trade but have also contributed to many contemporary issues emerging within international trade. Most notably, the increased specializations have resulted in some countries becoming so integral to the flow of production through the value chain that disruptions in production at these stages can cause debilitating effects to subsequent stages downstream. Additionally, the increase in anti-globalization sentiments and continued trends towards more protectionist trade policies, especially among high-income economies, has prompted additional considerations for the future of global value chains.

Countries have become more connected than ever before through the processes of political, social, and economic globalization facilitated through international trade, but attitudes toward globalization have shifted, especially in developed, high-income economies. Backlash against economic globalization has coincided with a political shift towards more protectionist and nationalist sentiments in developed nations who have implemented policies pushing back against global integration. The anticipated benefits of globalization in the form of more sustainable and widespread growth and development had very different outcomes among developed and developing countries, and the overall welfare effects of globalization were unequally distributed in both (Srgo & Arthaniti, 2002). Structural transformations like deindustrialization, rising inequality, and increased immigration brought on by globalization have unevenly effected communities in both developing and developed nations. The strongest attitudes against globalization manifesting in communities most effected by internationalization (Walter, 2021). In the United Kingdom, for example, regions with the strongest support for Brexit were working class communities most exposed to “China shock” and rising immigration (Goodwin & Milazzo, 2017; Lawless & Morgenroth, 2016). In recent years, the souring of attitudes towards globalization and further integration has been exacerbated by the fallout of the COVID-19 pandemic and, more recently, the Russia-Ukraine War (Posen & Rengifo-Keller, 2022).

The Brexit vote, a product of such changes in attitudes, was heavily politicized, and proponents latched on to anti-globalization and anti-Europeanization rhetoric. Much of the analysis regarding the conditions surrounding the referendum vote point to migration as a key issue for Brexit proponents (Portes, 2022). Trade negotiations with the EU following the referendum made it clear that any scenario in which the United Kingdom would remain in the single market would also include the maintenance of free-movement policies, similar to Norway or Switzerland’s agreements with the EU. With the UK adamant that free movement was not to be a part of their relationship with the European Union going forward, pre-referendum conditions for access to the single market were no longer possible. Negotiations for the trade agreement between the EU and the UK were long and tense as a result, ultimately culminating in the Trade and Cooperation Agreement (TCA) being signed three years after the referendum.

Although the TCA is by and large a liberal trade agreement with zero tariffs and quotas on bilateral trade between the EU and the UK, the additional barriers to trade due to re-established customs and regulatory borders between the two markets have contributed to higher costs of trade (Freeman et al., 2022). Given the interconnected nature of global value chains and the increased fragmentation of production making up contemporary global trade, these additional costs could have significant long-term effects for both the UK and EU’s trade performance. However, these effects may be disproportionate across both markets given the asymmetry of the EU and the UK bilateral trade relationship, namely in the trade deficit in manufactured goods on behalf of the latter. This, however, is offset by the UK’s large trade surplus in services to the EU, a fact of which makes the analysis of Brexit’s impact on UK services trade in value-added in the EU-UK trade network an interesting topic for research.

2. Research Context

As the first major challenge to European integration, Brexit affords a unique opportunity to explore how policy shocks can affect specialization and trade network structures within the context of highly interconnected global value chains. The value chains of the United Kingdom and the European Union are linked considerably, due to their geographic proximity and longstanding trade relationships established through the United Kingdom's previous inclusion in the EU customs union. The question of how the United Kingdom's exit from the single market has affected not only the structures of the EU-UK value network, but also how it has affected the positions of specialized sectors within the wider network is central to the research context of this thesis. More specifically, this thesis will analyze the effects of Brexit on the UK's observed specializations in high value-added activities, particularly knowledge-intensive service sectors, as well as the overall position of the United Kingdom in both the global and EU value networks.

GVC trade in services as opposed to manufactured goods produces different results when it comes to specialization, mostly because services include far less imports than manufactured goods and are therefore generally less tradable (Hall, 2022; Miroudot & Cadestin, 2017). Due to their positions on either end of the value chain, the value added from services tend to be embodied in other goods, whether they be inputs or final products (Bontadini, 2021; Hoekman & Shepherd, 2015; Miroudot, 2019). The significance of services as a share of global output has also increased significantly in recent decades, with services making up close to 70% of global GDP while only accounting for roughly 20% of traded output (Hoekman & Shepherd, 2015). It is therefore the objective to this research to determine the extent to which value-added contributions and the value network positions of the United Kingdom's service-based sectors have been affected by Brexit given their high shares of domestic inputs and lower tradability. Moreover, the characteristics of trade in services, especially at the value-added level, could be a mitigating factor where the impacts of policy shocks like Brexit on value network positionality are concerned.

2. 1. Hypothesis

This research hypothesizes that the United Kingdom's specialization in high value-added services afforded increased resiliency against impacts of Brexit in the position of its service sectors in the EU-UK value network.

2. 2. Main Methodology

This thesis utilizes a quantitative method of research. The main methodology employed in this research is network analysis. International trade, especially GVC trade, can be analyzed through both a qualitative and a quantitative lens, but the latter affords a more rigorous analysis on the observed effects of qualitative factors like policy decisions that affect trade between nations. By utilizing trade data in the form of inter-country input-output (ICIO) tables, more detailed trade flows in inputs and intermediate goods are able to be captured in the analysis. Input-output tables are central to research in GVC trade and provide the basis for further decompositions in value-added trade indicators. In all, this provides a richer and more complete picture of global trade networks and their evolution in recent decades.

2. 3. Structure of Research

This thesis is organized into seven chapters, with chapters 1 and 2 presenting the introduction and research context, respectively. Chapter 3 presents a review of the existing literature on the topic and outlines the theoretical framework supporting this study's research question and hypothesis. A detailed description of the data and main methodology used in this analysis is provided in Chapter 4. Empirical analysis including the graphical illustrations of the structure of global and EU-UK value networks are presented in Chapter 5. The discussion of results of the analysis, limitations of the study, and avenues for future research are provided in Chapter 6, concluding with the summary of the research and its findings in Chapter 7.

3. Theoretical Framework

This thesis aims to answer the question of whether Brexit had a significant impact on the United Kingdom's specializations in service-based sectors and their position in GVC networks, particularly in relation to its largest trading partner, the European Union. The United Kingdom has traditionally exhibited comparative advantages almost exclusively in service-based industries, both in gross exports and value-added trade (Escaith, 2018). These sectors generally occupy places at either end of the value chain and generally involve much fewer foreign inputs compared to manufactured goods, resulting in higher domestic value-added shares of UK exports.

Given the lower reliance on foreign inputs for service-based sectors, this research suggests that Brexit, although a major turning point for trade and political integration in Europe, would not have significantly impacted the positionality of these sectors in the UK's global value networks. While there may be some reshuffling in supply chains overall, service sectors would be less affected than those relying on inputs from outside the UK. However, given the additional costs associated with trade between the EU and the UK as a result of Brexit, it is also likely that EU value chains will increase their value-added linkages with markets within the customs union, particularly emerging service markets in Ireland and the Netherlands, as well as established service sectors in Germany and France.

The following chapter will explore the existing literature on all aspects of this research topic, including significant distinctions between value-added trade in services versus manufactured goods, the emergence and uses of ICIO data, and the applications of network analysis and centrality in global value chain research.

3. 1. Input-Output tables and value-added measures

The analysis and study of global value chains and their structures has emerged as a significant area in the research on international trade. Subsequently, the use of input-output analysis is a fundamental aspect of empirical research in GVC trade. The dynamics of global trade dominated by GVCs has made the use of traditional trade statistics inadequate in capturing the true supply and demand structures of global trade (Borin & Mancini, 2023; Cappariello et al., 2018; Cingolani et al., 2017). This complex structure led to the seminal development of input-output tables as a way of disaggregating domestic and international trade flows to provide a better understanding of inter-sectoral trade. As global value chains became more dominant, new value-added indicators were added to the input-output decompositions to better account for the increasing fragmentation and expansion of global production networks. Input-output tables have been published by the World Input-Output database (WIOD), the OECD TiVA database, EUROStat FIGARO database, and Eora Global Supply Chain database, among others. Individual countries also publish their own input-output data for domestic inter-sectoral trade flows.

Input-Output tables were first developed by Leontief (1936) and have been the primary tool for analyzing global value chains since their inception. Many subsequent contributions have been made in order to improve the composition and usability of input-output tables since their initial development. The most notable series of contributions began with Hummels, Ishii, and Yi (2001) (hereinafter referred to as HIY (2001)) who introduced the concept of foreign value-added, referred to as *vertical specialization*, that enabled an additional value-added measurement to account for the share of exports that utilized imported inputs. HIY (2001) also pointed out that vertical specialization was facilitated by a reduction in trade barriers that make it easier for inputs and intermediate goods to pass through international borders in the production process. This factor is important to consider when observing the trend towards protectionism and de-integration that is affecting GVCs.

While HIY (2001) was a significant milestone in the study of global value-added trade, subsequent studies addressed some issues with the underlying assumptions. Johnson and Noguera (2012), for example, highlighted the assumption in HIY's (2001) vertical specialization measure that a country's exports were entirely absorbed in foreign final demand, rather than accounting for any share that would be absorbed in the domestic final demand via re-importing inputs in subsequent production processes (Johnson & Noguera, 2012; Jones et al., 2019). This was also echoed by Koopman, Powers, Wang, and Wei (2010), who pointed to the assumption that all imported inputs used in the production of exports in the HIY (2001) model were completely of foreign origin and the model did not account for the share of imported inputs that may have been originally exported and re-imported in a later stage of production.

Given the issues with the assumptions of the vertical specialization model, Johnson and Noguera (2012) built upon the HIY (2001) approach with a method for measuring the structural changes in bilateral trade flows by tracking the ratio of value-added shares to gross exports for each country. They found that changes in fragmentation had been uneven, with some countries and sectors experiencing increases while others, particularly countries with closer proximity to one another and those involved in bilateral trade agreements, experienced a decline in production fragmentation.

Koopman, Powers, Wang, and Wei (2010) introduced a new framework that fully decomposed gross exports, thereby distributing all value-added contributions in exports to their original sources, both at the country and industry level. This new framework was integrated into input-output data and allowed for additional decompositions of gross export data at the country-sectoral level as well as a means of calculating revealed comparative advantages (RCA) in value-added terms rather than the traditional means using gross exports (Jones et al., 2019; Koopman et al., 2010, 2014). Traditionally, RCA indices use gross export data to calculate the ratio of shares of a country's exports in a final good or service to the shares of the good or service in total global exports. However, RCA based on gross export data is insufficient in revealing specializations in intermediate or input goods and services, as traditional trade statistics do not account for the decomposition of such trade flows.[1]

Koopman et al. (2014) developed integral value-added components to identify and account for the sources of double counted items. This was later further clarified by Borin and Mancini (2023) along with subsequent definitions for domestic value added absorbed in final demand, foreign value added (FVA) in exports, and foreign double counted (FDC) items, while also proposing new measures for FVA and FDC that better account for bilateral exports. Borin and Mancini (2023) also introduced additional accounting perspectives including the *sectoral-bilateral* perspective that calculates the value-added content of a country's contribution to the exports between two other countries within a specific sector, the *sectoral-exporter* perspective that calculates the value-added content of total exports within a specific sector, as well as the inverse *importer* and *sectoral-importer* perspectives.

The depth of applications of these value-added measures and input-output analysis in general is robust in the literature. Gurgul and Lach (2016), for example, utilized WIOD input-output tables to examine the role of Central and Eastern European (CEE) economies (mainly new EU members in transition) in the cultivation of European Union comparative advantage in global value chains. They looked at labor productivity and capital efficiency metrics for ten CEE

[1] More detailed uses of value-added and ICIO data in calculating revealed comparative advantages are explored in section 2.2 and section 3.3.

economies in transition from 1999-2009. The highest levels and growth rates for both metrics over the two decades of transition were from the smaller CEE countries, while larger countries like Poland were the main drivers of EU value-added (Gurgul & Lach, 2016). Hagemejer and Ghodsi (2017) similarly used WIOD input-output tables to track the changes in trade patterns among CEE economies in transition through their positions in GVCs. They found that new member states have gone against the increasing trend in the upstream position of all countries, converging their production structures within the CEE group and moving closer to the final consumer (Hagemejer & Ghodsi, 2017).

3. 2. Sector specializations in GVCs

One important emergence within GVC literature has been the distinction between services and manufactured goods when analyzing specializations in intermediate input trade. Measuring comparative advantage within global value chains is much more complex than with traditional trade statistics using gross exports. The original model for comparative advantage developed by Ricardo (1817) remains a significant axiom in the contemporary economic study of trade and provided the basis for further expansions on the concept of comparative advantages and specializations to accommodate the changing nature of global trade. One of the base assumptions of the Ricardo model precludes labor and capital as immobile between countries. Although the trade in intermediates was not an important consideration for Ricardo, the model nonetheless includes important assumptions that do not align with the nature of how global value chains operate, namely in the assumption that labor and capital are immobile between countries. Trade in intermediate and input goods allows countries to trade resources with one another and use these imported inputs in their own domestic production. This is what Bontadini (2021) refers to as the phenomenon that made foreign countries not only export destinations but also “co-producers” of finished goods and services. Additional considerations are therefore needed when attempting to evaluate comparative advantages in value-added trade.

Balassa (1965) developed the seminal method of Revealed Comparative Advantage (RCA) in order to use empirical trade data to “reveal” countries’ specializations in international trade. The Balassa index calculates the ratio of a countries output of a specific product or industry relative to the share of output in the same product or industry in total world exports. If the ratio results in a value between 0 and 1, then the country does not exhibit a comparative advantage in that product or industry, while a value greater than 1 indicates a comparative advantage.

The asymmetry of the intervals between disadvantages and advantages is one of the limitations of this measure, as it indicates a different way of measuring each and makes it difficult to compare indexes over time (Stellian & Danna-Buitrago, 2022). A normalization measure of the original Balassa index can therefore be employed to provide an index that is more general and comparable over time and space (Yu et al., 2009). RCA indices utilized for calculating specializations in GVCs employ the same method as the Balassa index or the normalized Balassa index by using value-added shares in place of gross export data (De Benedictis & Tajoli, 2016; Miroudot & Cadestin, 2017).

Value-added shares can be used to determine comparative advantages in sectors that contribute a significant share of value-added output to gross exports. Timmer et al. (2013) developed a metric called "GVC income" that accounts for value-added contributions to gross exports from individual sectors as well as the embodied contributions in other domestic sectors' value-added outputs. This concept is important when considering the nature of trade in services as well as their value-added contributions. Services are typically traded indirectly, with their value-added output embodied in the value of other goods, including both final products and intermediates (Miroudot, 2019).

Specialization in value-added activities at either end of the value chain can also be significantly leveraged to reap the most benefit from GVC participation. Downstream specializations, for example, allow for more control over the setting of final prices (De Benedictis & Tajoli, 2016). Lanz and Piermartini (2018) explore the role of transportation infrastructure on the development of comparative advantage along the value chain. As value increases downstream, efficient transportation in delivering intermediate and final goods to their end destinations becomes more inelastic, thereby making efficient transportation infrastructure and cross-border customs procedures vital for leveraging downstream specializations (Lanz & Piermartini, 2018). Not only is efficient infrastructure important, but the location of downstream production as well. As value increase downstream, the trade cost elasticity decreases making centrally located markets with efficient transportation infrastructure important for maximizing the benefits from the production of final goods. While the current trade agreement between the EU and the UK is tariff-free, the added costs in non-tariff barriers like increased lead times due to customs and regulatory border checks affects the ability of both the UK industries and their EU trading partners to leverage the benefits of their GVC specializations.

Re-industrialization policies that aim to reshore GVCs to be serviced by domestic industries also impact how countries gain and maintain comparative advantages in GVC trade. Peneder and Streicher (2018) investigated whether developed economies can regain comparative advantage within fragmented production processes through re-industrialization policies. They concluded that while the loss of comparative advantage drives de-industrialization, de-industrialization by way of GVC participation does not necessarily lead to a decline in specialization and competitiveness. This is key in relation to the stability of specialization structures among the United Kingdom and its significant trading partners. Re-industrialization policies focusing on specialized services that enhance comparative advantage in manufacturing (e.g. R&D or customer services) can increase the productivity growth of these services, which in turn contribute to an increase in the income share of manufacturing without sparking a race-to-the-bottom of global de-industrialization (Peneder & Streicher, 2018). However, the aim of Brexit policy-makers did not appear to be enhancing their service sectors, and were largely forgotten in EU-UK trade agreement negotiations (Du & Shepotylo, 2022).

Specializations in GVCs are generally categorized in products or functions, as the latter is differentiated by low and high value-added activities in the value chain, such as manufacturing and assembly, and R&D and marketing, respectively. More importantly, functional specialization categorizes all value-added activities as services, so it is unsurprising that all countries would exhibit a comparative advantage in some value-added services (Timmer et al., 2019). In order to avoid confusion with these definitions of functional specialization, this thesis will refer to service specializations as those in high value-added, knowledge-intensive service activities.

The role of services in global value chains is understudied relative to the trade in manufactured goods. Consensus in the existing literature surrounding service specialization in GVCs characterizes services as (1) less tradable than manufactured goods (Bontadini, 2021) and (2) utilizing less foreign inputs to produce their output (Miroudot, 2019; Miroudot & Cadestin, 2017).

In the United Kingdom, specialization in services impacts the competitiveness of manufacturing sectors that rely on the integration of service activities at various stages of production (Du & Shepotylo, 2022; Miroudot, 2019). Furthermore, shocks to economic activity that rely heavily on production and trade in services have far reaching effects for not only those sectors, but also the sectors in which large shares of value-added are being contributed. This is not only in the domestic inter-sectoral trade flows, but cross-border as well, with the European Union being a significant importer of UK services (Giammetti, 2020; Hall, 2022).

3. 3. Network Analysis

Network analysis has become a popular analytical tool within international trade research, especially since the emergence of global value chains and the increased rate of international production fragmentation. Network analysis methodology originates from the sociology discipline, primarily developed for the study of social networks. It has been employed across many different disciplines, including computer science, political science, and economics. The application of network analysis for economics is relatively new and underutilized, primarily residing in the study of global value chains and value-added networks.

Network analysis combines statistics and graphic visualization to analyze the significance of various entities in a connected network. The connections between each entity are referred to as edges while the entities themselves are referred to as nodes. Networks can be either directed or undirected. Undirected edges indicate a relationship or link between nodes, but there is no subsequent directional relationship that exists between them. In directed networks, however, the edges are characterized by a directional flow, either forwards, backwards, or both. Undirected networks are commonly used in social network analysis, where the connections between individuals do not typically require a directional distinction. However, global value chains and value-added trade networks are usually represented as directed networks due to the flow of value-added inputs from one country or sector to another.

The number of connections associated with a given node in the network is referred to as the degree. Degrees can be used to assess a node's significance in the network based on the number of connections it possesses. In a directed network, degree can be further decomposed into in-degree and out-degree measurements, in which the degree of a node is based on the number of edges linked to that node that possess a specific directional quality (i.e. "in" or "out"). Degree is a significant element of network graphs as it is most often used to determine the importance of a node within a network. This concept is referred to as centrality and is one of the primary measures used in network analysis to assess the overall structure of the network and the relative importance of each node. Subsequently, there are many different ways of measuring centrality in network analysis. Degree centrality, as previously mentioned, is the simplest and therefore most common.

Not only has participation in global value chains been shown to be beneficial in the literature, but there is also a significant area of research that focuses on the importance of countries' positions, or centrality, within the network for production optimization. Criscuolo and Timmis (2018) illustrated the differing results of productivity shock diffusions between key hubs and periphery nodes, showing that more central hubs in the network have a much greater influence on aggregate GDP due to their increased connectivity via direct and indirect linkages to other nodes in the network (Criscuolo & Timmis, 2018). Cingolani et al. (2017) showed that not only should a country's position within the network be considered important, but also its centrality at the various stages of the production process. They determined that developing countries tend to have higher centrality in the upstream and midstream stages while developed economies tended to have higher centrality in downstream activities (Cingolani et al., 2017). The additional measure of centrality within the various stages of production, namely upstream, midstream, and downstream activities, rather than centrality in the network as a whole provided additional insights into the competitiveness of countries participating in these value chains. Moreover, considering each stage in production as its own value network allowed for more nuanced specializations to be revealed via the centrality within the network at each stage.

De Benedictis and Tajoli (2016) utilized network analysis to map the structural changes in Italy's sectoral comparative advantages in order to provide additional insight into how centrality in global value chains affects production specialization. This study utilized Italy's revealed specializations in two key industries (leather and footwear and machinery) in relation to the country's overall position in the gross trade network to determine whether gross trade centrality corresponds with large shares of value-added in key specialized sectors. Decreases in eigenvector centrality scores for Italy's overall position in global trade over time indicated the country did not adapt to the changes in global trade and became more distant from the main players in the network, with trade flows connecting Italy to more peripheral markets rather than more central ones (De Benedictis & Tajoli, 2016).

While gross trade statistics like those utilized in De Benedictis & Tajoli (2016) provide a holistic picture of gross trade flows in various sectors, the value-added flows included in input-output tables offer richer applications for network analysis in global trade research. Early implementations of network analysis using input-output data focused on adapting the methodology of social network analysis to be applicable in input-output networks (Soyyiğit & Boz, 2017;

Vittucci Marzetti & Montresor, 2009). Criscuolo & Timmis (2018) provide a significant work in GVC network analysis by utilizing OECD ICIO data to map key hubs in global value chains through the implementation of eigenvector centrality. More recently, De Paolis et al. (2022) applied advanced random-walk based centrality measures to input-output networks in the United States to identify key sectors at the local, regional, and country levels (DePaolis et al., 2022).

3. 4. Brexit and UK GVC participation

Since the 2016 referendum in the United Kingdom, both the political and economic effects of Brexit have been widely studied and analyzed with many predictions made in the immediate aftermath of the vote as to how such effects would materialize for both the UK and its trading partners. Brexit was championed initially by the United Kingdom Independence Party (UKIP), whose platform advocated for the UK's independence from the bureaucratic decision-making of the European Union. UKIP's platform focused on the lack of autonomy in economic (particularly trade) policy decisions and more controversial anti-migration stances. After being absorbed into the leading Conservative Party platform during the general election campaign in 2015, the referendum was held on 23 June 2016 resulting in a narrow margin of 51.9% voting in favor of the United Kingdom leaving the European Union. The UK subsequently confirmed the results of the referendum by notifying the EU of its plans to withdraw on 29 March 2017, with the ultimate exit occurring on 31 January 2020.

The three-year interim period between 2017-2020 was one in which negotiations between the United Kingdom and the European Union sought to define what the trading relationship would look like after the UK's imminent exit from the EU. Negotiations for a new trade agreement were initially intended to conclude on 29th of March 2019. However, they were ultimately extended due to a lack of agreement over a number of issues. The United Kingdom and European Union eventually signed the EU-UK Trade and Cooperation Agreement (TCA) on 31st of December 2020 after a one-year post-exit transition period.

Much of the research on Brexit's impact on the UK's GVC participation and overall trade performance was conducted during the interim negotiating period at which time there was a high-level of uncertainty regarding the future of the trade relationship between the EU and the UK. As a result, many of the studies conducted during this time modeled several potential scenarios that could have resulted from the negotiations. Most notably, a "no deal" scenario in which the EU and the UK did not reach an agreement, and the UK would move under "Most Favored Nation (MFN)" tariff rates with no preferential trade agreement in place was widely modeled in post-referendum literature. While this scenario did not eventually come to pass, the studies nonetheless modeled the potential tariff and non-tariff trade barriers that may have impacted both markets as a result. The United Kingdom's shares of exports to the European Union were large and the former's exposure to the latter was extremely high, indicating the EU was both an export destination for UK exports and a pass-through destination for exports bound for other foreign countries (Cappariello et al., 2018; Ijtsma et al., 2018). Consequently, a "no deal" scenario would have had significantly negative effects on UK exports, both to final destinations in the EU and elsewhere.

Literature dedicated specifically to the United Kingdom's GVC participation was minimal prior to Brexit. Understandably, following the results of the 2016 referendum, numerous studies emerged, assessing the role of the United Kingdom in GVCs, particularly the degree to which the UK relied on EU value chains for their exports, and vice versa. The bilateral trade relationship between the UK and EU was somewhat unbalanced prior to Brexit, with the EU being an important import destination for the UK, while its significance as an export destination had been steadily declining (Giammetti, 2020). Likewise in value-added and GVC participation, although the United Kingdom remained highly integrated into global and European value chains at the time of Brexit (Ali-Yrkkö & Kuusi, 2019; Mulabdic et al., 2017), its overall participation in GVCs had been steadily declining leading up to the referendum (Ijtsma et al., 2018).

The United Kingdom has consistently exhibited GVC specialization in high value-added sectors on either end of the value chain, particularly in high-skilled, knowledge-based services (Bontadini, 2021; Cappariello et al., 2018; Miroudot & Cadestin, 2017; Mulabdic et al., 2017). The differences in composition between services and manufactured goods impacts not only how each is traded, but also how trade policy affects the output of each. Manufactured goods are subject to WTO tariffs, while services are not. However, the way in which services are embodied in the value of exported goods subjects services to both indirect costs from the good's tariff as well as costs of non-tariff barriers (Vandenbussche et al., 2022). Since the UK has a stable comparative advantage in service-based activities, the ability to study the impact of protectionist trade policies affords a unique opportunity to assess the empirical effects on service-based specializations that is understudied in the literature.

While the UK had already been experiencing a steady decline in GVC integration in the period leading up to the referendum, many of the UK's potential trading partners and the countries intended to be courted into trade agreements post-exit were serviced by supply chains that moved through EU hubs (Ijtsma et al., 2018). Bilateral trade agreements with such countries, therefore, were projected to produce only a marginal benefit under the UK's "Global Britain" strategy. Additionally, the cost of manufacturing inputs in the UK would have been more affected by tariffs as a result of a Brexit "no deal" than the corresponding cost in the EU (Giammetti, 2020). This is largely due to the fact that the United Kingdom has a significant trade deficit in manufacturing and goods relative to the EU (Du & Shepotylo, 2022; Posen & Rengifo-Keller, 2022).

The United Kingdom's exclusion from the EU's customs union as a result of Brexit is a significant factor that would be expected to contribute to the impact of Brexit on its position in the EU value-added network. The economic benefits and drawbacks of membership in customs unions like the single market was originally explored in Viner (1950). Viner theorized that customs unions would both create trade within the union and divert trade among non-member countries. Customs unions create conditions for freer, more liberal trade between the countries involved in the union by removing the regulatory costs of cross-border trade, but this also creates conditions of increased competition outside of the customs union as non-member countries face the additional costs associated with cross-border trade with member countries, particularly tariffs (Viner, 1950).

The exclusion from the customs union as a result of Brexit places the United Kingdom in a position where trading within the bloc becomes more difficult and more costly due to the additional barriers it now faces. Trading with countries outside of the EU may be more accessible for the United Kingdom than while under EU membership, but the added complexity of the value chains to which the United Kingdom are integrated into means servicing those value chains still requires trade with the bloc (Ijtsma et al., 2018; Mulabdic et al., 2017).

The United Kingdom's strong trade performance in services is linked to the depth of PTAs signed by the EU with external countries while the UK was a member, which allowed for UK services trade to more than double during its membership (Mulabdic et al., 2017). Not only is the EU an important destination for UK gross exports, both as a final destination and a pass-through to external markets, but it is also a significant importer of UK services. In fact, the growing trade deficit in manufactured goods between the UK and EU is almost entirely offset by the UK's export surplus of services to the EU (Du & Shepotylo, 2022; Giammetti, 2020; Rowthorn & Coutts, 2004). In order to avoid the additional costs of trading with the United Kingdom post-Brexit, the share of UK value-added embodied in EU output is anticipated to decline as a result of Brexit. As a result, EU importers would likely look to other providers of services typically received from the UK within their own market, particularly Ireland. However, given the high domestic value-added content of services, the UK's value-added contributions are expected to remain relatively stable post-Brexit (Miroudot, 2019).

4. Methodology

4. 1. Data

This study utilizes inter-country input-output tables developed and published by the Organization for Economic Co-operation and Development (OECD). Inter-country input-output tables are typically organized into a matrix structure representing a world economy with *i* countries and *j* sectors. The rows are broken down by the countries and sectors supplying intermediate inputs. The corresponding columns are broken down by the countries and sectors using the inputs in production of final demand. Each cell in the matrix, therefore, represents the value of the intermediate trade flows in each country and sector. The right-most columns indicate a breakdown of the final use in the form of consumption and investments by households, governments, and firms, along with a summation of the total use of the intermediate goods supplied by each country-sector pairing. The bottommost rows indicate the inverse relationship, with a summation of total value added from each country-sector pairing utilizing the intermediate goods in production of final demand and their gross outputs. Due to the structure of the input-output matrix, total use and gross outputs for each country-sector pairing are assumed to be equivalent.

The basic structure of the OECD inter-country input-output tables is a symmetrical matrix of value-added flows between countries and sectors. The structure is summarized in **Figure 1**. The OECD data consists of value-added trade flows for 45 sectors[2] in 76 countries, including an additional aggregate element for the rest of the world (ROW). The data is presented in millions of US dollars ($) at basic prices. The trade flows of intermediate inputs for each country-sector pairing are represented in the blue section in **Figure 1**. The final demand is broken down into subsequent categories for each country and is represented in orange. The subsequent categories are household consumption, non-profit consumption, government expenditures, gross fixed capital, inventory changes, and direct purchases abroad. Output at basic prices is in the final column and row in the table and is represented in gray. The total output for the country-sector pairings in each row is the sum of the total supply for each country-sector pairing and the share of each sector realized in final demand for each country. The total output for the country-sector pairing in each column is an aggregation of the total use for each country-sector pairing minus any

[2] A complete list of all 45 sectors from the OECD ICIO data can be found in **Table 2** of **Appendix A**

taxes and subsidies on intermediate and final goods as well as the total value added for each country-sector pairing.

Figure 1: Inter-country input-output table structure

			Intermediate Use							Final Demand (Household, non-profit, government, gross fixed capital, inventory changes, direct purchases abroad)			Output at basic prices
			Country 1			...	Country 77			Country 1	...	Country 77	
			Sector 1	...	Sector 45		Sector 1	...	Sector 45				
Supply of intermediate inputs	Country 1	Sector 1											
		...											
		Sector 45											
	...												
	Country 77	Sector 1											
		...											
		Sector 45											
Taxes less subsidies on intermediate and final products													
Value added at basic prices													
Output at basic prices													

Source: Adapted from OECD. (2023) OECD Inter-Country Input-Output Tables, http://oe.cd/icio

Value-added flows are characterized by forward and backward linkages. Forward linkages are associated with the supply of intermediate goods that are exported to other countries for production uses further along the value chain. Conversely, backward linkages are defined as the country's intermediate imports for further use in subsequent production chains. The decomposition of value-added in forward and backward linkages is also calculated using two unique accounting approaches, source and sink-based, in order to prevent the double-counting of inputs re-entering markets in which they had been previously exported in another intermediate form. Source-based accounting counts the value-added at the moment of first export, while sink-based counts the value-added of the input at the very last import before the input is fully absorbed in final demand. The DVA decompositions used in this thesis utilize the source-based approach in order to account for the domestic share of value-added in gross exports for each country and sector.

Following Galindo-Rueda and Verger (2016), the 45 sectors included in the OECD ICIO data are aggregated into sector groupings based on the R&D intensity of each sector. The sectors are split based on whether the production activity of each sector is manufacturing or non-manufacturing and the ratio of R&D to value-added within each sector (Galindo-Rueda & Verger, 2016). Galindo-Rueda and Verger (2016) original divided the OECD sectors into five sector groupings (high, medium-high, medium, medium-low, and low R&D intensity industries), but Bontadini (2021) used the R&D intensity methodology to aggregate the sectors into four groups: knowledge-intensive business services, high-tech manufacturing, low-tech manufacturing, and natural resources (Bontadini, 2021). This thesis utilizes the Bontadini (2016) categorization of OECD sectors in the analysis of GVC networks.

The most significant limitation with the OECD ICIO data is the availability of the latest published dataset. The OECD last published ICIO data for 2020, which makes analyzing the impact of the post-Brexit EU-UK trade agreement, TCA, incredibly difficult if relying exclusively on the OECD ICIO data. In order to combat this limitation, this thesis utilizes the FIGARO ICIO tables published by EUROstat in an additional analysis that expands the time series of the study past 2020. EUROstat's FIGARO database is published on a time series of T-2 years, with T being the year the tables are published, meaning the latest available table offers data for 2022. The FIGARO input-output tables follow a similar structure to the OECD tables with a supply-use matrix for each country-sector pairing. The data is presented in millions of euros (€) at basic prices as opposed to millions of dollars ($) at basic prices in the OECD tables.

The FIGARO data differs slightly from the OECD data regarding countries and industries included in the dataset. While the OECD data offers a composite for 76 countries including the ROW aggregate, FIGARO data is limited to the current 27 EU member states and their 18 main trading partners[3] with an additional aggregate for the rest of the world (also referred to as ROW). FIGARO data is less useful when analyzing the wider global network in comparison to the OECD as fewer countries are included in the dataset. Therefore, this limits the breadth of the global network. However, the availability of the FIGARO data post-2020 is very useful for analyzing the subsequent changes in the EU-UK value network.

The classification of industries in the FIGARO data follows NACE revision 2 which also differs slightly from the OECD sectoral classifications based on ISIC revision 4. For example, transportation activities in OECD sector 28 and various professional and scientific activities belonging to OECD sector 38 that are disaggregated into five distinct sectors in the FIGARO data. While FIGARO and OECD ICIO tables utilize different industry classifications, both NACE revision 2 and ISIC revision 4 are able to be cross-referenced in order to aggregate the sectors from both datasets into the previously established sector groupings based on R&D intensity.

4. 2. Network Analysis

Network analysis utilizes both statistics and visualization to show the structure of various networks and the relationship between participants in the network. Applications of network

[3] The EU's main trading partners according to EUROstat are Argentina, Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Norway, Russia, Saudi Arabia, South Africa, South Korea, Switzerland, Türkiye, the United Kingdom and the United States

analysis are vast and inter-disciplinary. Network analysis is presented visually as network graphs that illustrate the participants in the network and their associated linkages. Various statistical methods are employed on the graph data to test the networks modularity, clustering coefficients, node centrality, and community detection. For the purposes of this study, centrality is the primary network indicator assessed.

4. 2. 1. Network Graphs

The structure of network graphs is commonly represented in mathematical terms as an adjacency matrix with a dimension of $N \times N$, where a value of 0 or 1 is given for each ordered pair of (N_i, N_j) that indicates the absence (0) or presence (1) of an edge connecting nodes i and j. The symmetry of an adjacency matrix depends on whether the network is undirected or directed. Undirected networks have a symmetrical adjacency matrix in which the row and column values are reciprocated for each pairing.

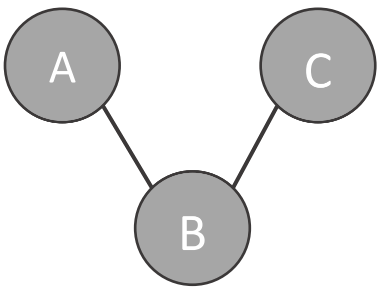
Edge lists or adjacency lists are also used in network analysis to store graph data. Edge lists are simply a representation of all edges in the network in list format. The main difference between adjacency matrices and lists is the structure, with lists comprising a minimum of three elements of necessary information for directed graphs: source node, target node, and edge weight. Edge lists are more compact than adjacency matrices and consume less memory storage than the latter (Singh, 2012). Due to this advantage, edge lists were used in this thesis to build the network visualizations from the input-output data by creating source and target nodes from the supply and use dimensions of the input-output matrices.

Figure 2a. presents a stylized undirected network of three nodes and its associated adjacency matrix A. Nodes A and B are connected, so the matrix indicates a value of 1 from A to B as well as from B to A. In a directed network, however, the corresponding adjacency matrix is asymmetrical. **Figure 2b.** provides the same example of a stylized network with three nodes, but this time with directed edges indicating in and out flow connections among the nodes. Once again, nodes A and B and nodes B and C are linked, but the edge between A and B is reciprocal, indicating both an in and out flow from each node to the other. On the other hand, the edge connecting B to C is unreciprocated and indicates an outflow only from B to C (or, conversely, an inflow to C from B). The adjacency matrix, therefore, indicates a value of 1 for the pairing from B to C and 0 for the pairing from C to B. In this example, the adjacency matrix is measuring the out-degree of each node. If we were to assess the in-degree of each node, the adjacency matrix in **Figure 2b.** would indicate a value of 1 for the pairing from C to B and a value of 0 for the pairing from B to C.

Similarly, the edge lists for each network indicates the source node, the target node it shares an edge with, and the weight of the edge (in this case 1). Note that for the directed network, the edge list indicates only two distinct source nodes (A and B), while the target nodes have three. This provides the same directional information as the adjacency matrix without having to stipulate the in or out direction of the linkage. The direction on the edge is built into the structure of the list.

Figure 2: Undirected (a) versus directed (b) network graphs and their corresponding adjacency matrices and edge lists.

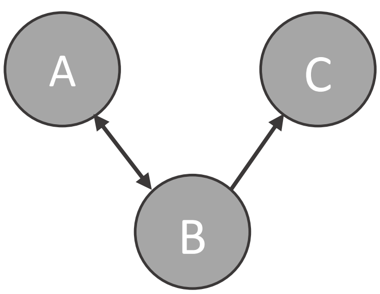
(a)



$$A = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Source	Target	Weight
A	B	1
B	C	1
C	B	1

(b)



$$A = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

Source	Target	Weight
A	B	1
B	A	1
B	C	1

Source: Adapted from Criscuolo & Timmis (2018) and Singh (2012)

4. 2. 2. Centrality Metrics

An essential element of network analysis is the measure of centrality. Centrality is used to determine the importance of a particular node in a network and there are many different ways of measuring centrality in network analysis. The method of calculating centrality is based on a number of different factors, including the characteristics of the network as well as the specific research question being asked in the study. While there exist numerous methods of determining centrality in network analysis, this section provides explanations of those most appropriately applied to the United Kingdom and EU value networks: degree, closeness, betweenness, and eigenvector centrality. The equations for each centrality measurement in this section are drawn from Rodrigues (2019).

The concept of degrees was briefly touched on in the previous section detailing the characteristics of network graphs. Degree centrality is the most straightforward measure of centrality in network analysis as it calculates the significance of nodes in the network based on the number of edges connected to each node. Degree centrality is most commonly used in undirected networks where the edges do not represent a directional link between nodes. Directed graphs further decompose degree centrality into in-degree and out-degree centrality in which the importance of nodes is calculated based on the number of inward or outward connections, respectively. Using the mathematical representation of a network in the form of the adjacency matrix A, the degree centrality of node i can be calculated as follows by the sum of all elements of row i in A,

$$C_D(i) = \sum_{j=1}^{n} A_{ij}$$

where A_{ij} = 1 when an edge connecting nodes i and j is present, and n is the number of nodes in the network. In and out degree centrality is calculated in a similar fashion in which A_{ij} = 1 when there is an inward or outward edge between nodes i and j, respectively.

Since degree centrality measures only the edge connections of each node, highly or more densely connected nodes may not be located in the center of the network (Rodrigues, 2019). Therefore, degree centrality can be useful as a local centrality measure for clustering or community detection applications. For the study of global value chains, there are more nuanced measures of centrality that provide a better reflection of countries and respective sectors' positions and importance within value networks. However, in- and out-degree centrality is still a useful measure for preliminary analysis in detecting important nodes for forward and backward linkages in the value chain.

Closeness centrality defines the importance of nodes in a network in terms of the shortest distance that connects the nodes i and j, also referred to as the shortest path. This can also be defined as the average distance between each node to all other nodes in the network (Rodrigues, 2019). Closeness centrality is defined mathematically as,

$$C_C(i) = \frac{n}{\sum_{j=1}^{n} d_{ij}}$$

in which d_{ij} is the sum of edges on the shortest path connecting nodes i and j, and n is the total number of nodes in the network. The total number of nodes in the network is then divided by the sum of all shortest distances from node *i* to all iterations of *j*.

Degree and closeness centrality are similar measures in directed networks, as both take into account the directional flow of edges – in- and out-degree and in- and out-closeness (Valente et al., 2008). This measure of centrality is used to trace how quickly information is able to spread through the network from any given node and is an important measure in determining the influence of nodes on the network as a whole.

In the context of GVCs and other global trade networks, closeness centrality is important in assessing a country's access to other countries or other production resources and how efficiently it is positioned to connect with other hubs. A country with high closeness centrality indicates its value-added activities are more compact and therefore able to capitalize on the reduced costs of moving goods and services to other markets (Guan et al., 2020). At the sectoral level, closeness centrality can also shed light on which industries are more condensed between upstream and downstream activities and would therefore have more influence on the flow of inputs or intermediate goods or services.

For the United Kingdom, a central position in its global value network would provide an even greater incentive to pursue a break from the European Union and the corresponding customs union. They both would have been well-positioned in the network to pursue trade agreements independent from the EU given its ability to leverage their degree of connectivity in the global network. However, if the UK was not in such an advantageous position and instead relied instead on more highly connected markets, then such autonomous trade policy goals may not have been as successful given the level of influence (or lack thereof) over the rest trade network.

Another metric of centrality, betweenness centrality, measures a nodes position and significance in the network by calculating the number of times the node appears on the shortest path between two distinct nodes. In effect, a node with high betweenness centrality acts as a bridge between a considerable number of nodes in a network and therefore is similarly influential in the flow of information and resources across the network.

Betweenness centrality is simply the ratio of the number of shortest paths between two distinct nodes that pass through a given node and the total number of shortest paths between the two distinct nodes. For any given node i, betweenness centrality can be calculated as follows,

$$C_B(i) = \sum_{i \neq j \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}}$$

in which j and k represent two distinct nodes in the network other than i, $\sigma_{jk}(i)$ is the number of shortest paths between j and k that pass through i, and σ_{jk} is the total number of shortest paths between nodes j and k in the network.

Betweenness centrality is a useful metric when analyzing global value networks. It can reveal which industries in which countries are crucial intermediaries in the flow of goods and services along the value chain. For the UK specifically, high betweenness centrality would indicate an important position in bridging the value chains of other countries which would once again be influential in pursuing trade agreements outside of the EU. Conversely, a country with high betweenness centrality indicates negative consequences for the wider network from disruptions originating both within and from outside the country. A country that acts as a bridge for a significant portion of the network could critically hinder the flow of goods and services should any disruptions affect its ability to facilitate trade. Low betweenness, however, indicates a country that exists on the periphery of the network and would be dependent on other more central markets to access inputs or other goods and services.

A node's centrality can also be measured through the relative importance of the other nodes to which it is connected to in the network. Nodes that may not have as many linkages to the rest of the network can still have high importance via its connections with other highly connected nodes. This measure of centrality is known as eigenvector centrality. When accounting for eigenvector centrality, nodes on the periphery of the network with the same number of edges may have different levels of importance based on the connections those nodes have with other nodes in the network and the importance of those other nodes to which they are connected to.

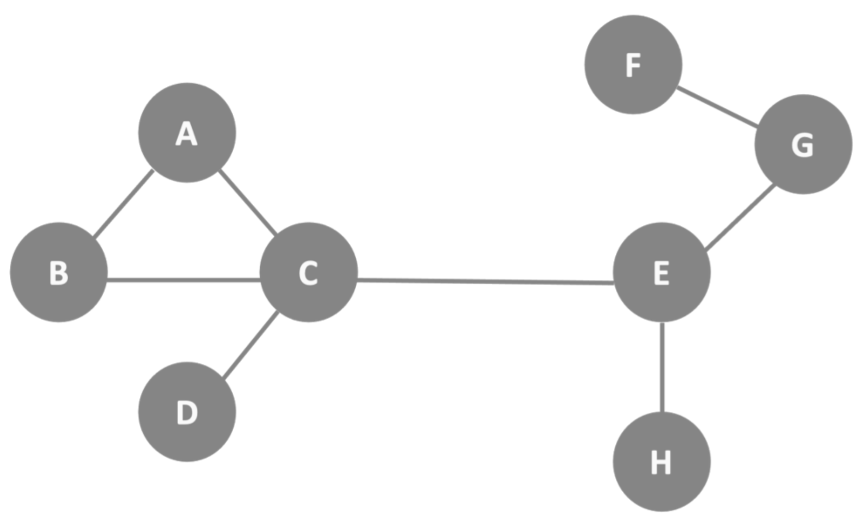
Within GVCs, eigenvector centrality can be a powerful tool to determine which countries and sectors are trading with important intermediaries in the network, Moreover, the relative nature of eigenvector centrality means it can capture the multiple linkages that exist between pairs of industries, particularly in service sectors where inputs can be supplied and used at several stages in production chains (Criscuolo & Timmis, 2018).

Eigenvector centrality has a more complex calculation method than the previous centrality measures explored above. The eigenvector centrality for node *i* can be calculated as follows,

$$C_E(i) = \frac{1}{\lambda}\sum_{j=1}^{n} A_{ij} C_E(j)$$

where λ is a constant reflecting the dominant eigenvalue in the network. **Figure 3** presents an example of a stylized undirected network with eight nodes labeled A-H. Nodes D, F, and H are all periphery nodes in the network, but because of node D's connections with node C, a highly connected node, it would theoretically have a higher eigenvector centrality value than the other periphery nodes, F and H. It is important to note that nodes located in the center of the network will typically present the highest eigenvector centrality values in the network. However, unlike in degree centrality measurements, eigenvector centrality allows for a more dynamic assessment of centrality due to the considerations for the network as a whole and the other important connections associated with each node rather than accounting exclusively for the direct linkages of each.

Figure 3: Hypothetical trade network



Source: Adapted from Rodrigues (2019)

4. 3. Revealed comparative advantage

Revealed comparative advantage is a metric used to measure a country or sector's competitiveness against other countries production performance in a given product or industry. Revealed comparative advantage is inspired by Ricardian trade theory originating from David Ricardo's original concept of comparative advantage that states trade patterns between countries are governed by each country's relative productivities. Revealed comparative advantage was developed to "reveal" these difficult to observe productivity differences using available trade data. Revealed comparative advantage is useful in piercing the veil of relative productivity among nations, but the metric has some limitations, mainly in the inability to factor in additional variables such as tariffs or trade agreements that would affect a country's export productivity (UNTCADstat, n.d.).

The method of revealed comparative advantage was first developed by Balassa (1965). The Balassa index is the ratio of country i's exports in sector k relative to the world export shares of the same sector k. A country would exhibit comparative advantages if the resulting value exceeded 1 in a range from $1 > \infty$ (Stellian & Danna-Buitrago, 2022). Conversely, a country would exhibit a disadvantage in the productivity of sector k if the resulting value was between $0 > 1$, with 1 being the comparative advantage neutral position indicating an absence of advantages or disadvantages (UNTCADstat, n.d.). The Balassa (1965) index is notated as follows,

$$BRCA_{ik}^{X} = \frac{X_{ik}}{\sum_k X_{ik}} \Big/ \frac{X_{wk}}{\sum_k X_{wk}}$$

in which X_{ik} represents the share of total exports of country i in sector k, X_{wk} is the share of world exports in sector k and $\sum_k X_{wk}$ is the sum of all world exports in each sector.

Gross exports, however, do not tell the complete story when it comes to value-added trade, as some sectors can produce a share of value-added that is subsequently embodied in the exports of another sector. In order to reveal which sectors may have a significant share of total output, the Balassa index can be adapted by replacing gross exports (X) with domestic value-added shares of gross exports (DVA) as follows,

$$BRCA_{ik}^{DVA} = \frac{DVA_{ik}}{\sum_k DVA_{ik}} \Bigg/ \frac{DVA_{wk}}{\sum_k DVA_{wk}}$$

in which DVA_{ik} is the share of domestic value-added in sector k of country i's exports and DVA_{wk} is the share of total value-added of sector k in world exports.

The asymmetry of the intervals between disadvantages and advantages is one of the limitations of the Balassa Index as it indicates a different way of measuring each and makes it difficult to compare indices over time. A normalization method, therefore, can be applied to the original Balassa RCA (BRCA) index with a range between $-1 \geq 0 \geq 1$ in which the comparative advantage neutral position becomes 0 with -1 indicating a complete comparative disadvantage and 1 indicating a complete comparative advantage. The Balassa (1965) RCA can be normalized as follows,

$$NRCA_{ik}^{DVA} = \frac{(BRCA_{ik}^{DVA} - 1)}{(BRCA_{ik}^{DVA} + 1)}$$

Given the increased fragmentation of production due to the expansion of global value chains, traditional measures for revealed comparative advantage are inadequate for deriving a country's specialization in the trade of intermediates. Traditional RCA indexes use gross export data for individual commodities or industries without accounting for the trade flows in intermediate inputs that are used in producing such commodities. Following the existing literature regarding measuring comparative advantages in GVCs, this thesis employs the normalized Balassa index with domestic value-added shares in place of gross exports in order to determine countries' comparative advantages across all 45 OECD sectors.

5. Empirical Analysis

5. 1. Revealed comparative advantages and specialization structures 2000-2020

In order to capture the contributions of each sector on domestic output, revealed comparative advantages for the United Kingdom were calculated using Domestic Value-Added shares of Gross Exports (DVA) rather than the Gross Export shares typically used in measuring comparative advantages in global trade. The 45 sectors from the OECD ICIO data were grouped into four distinct sector groupings based on R&D intensity (Bontadini, 2021; Galindo-Rueda & Verger, 2016): knowledge-intensive business services (KIBS), low-tech manufacturing (LTMF), high-tech manufacturing (HTMF), and natural resources (NR)[4].

The Balassa (1965) Index is used to calculate the domestic value-added shares of the United Kingdom relative to the world shares in the same variable. Additionally, the same calculations were conducted on a small group of other countries, including those similar to the United Kingdom (e.g. USA, Germany, Ireland) and developing economies with predicted inverse specializations (e.g. China and India). The resulting values for each country were then normalized to a -1 > 0 > +1 boundary to facilitate a generalized scale for better comparison.

The normalized RCA values for China, Germany, United Kingdom, India, Ireland, and the United States in each sector group between 2000-2020 are presented in **Figure 4**. The United Kingdom's sole advantage is in KIBS activity, and its overall specialization structure is nearly identical to the United States. Furthermore, the US and the UK's specializations mirror China's. China exhibits strong advantages in natural resource and low-tech manufacturing sectors, with a notable decline in the strength of advantages for the former.

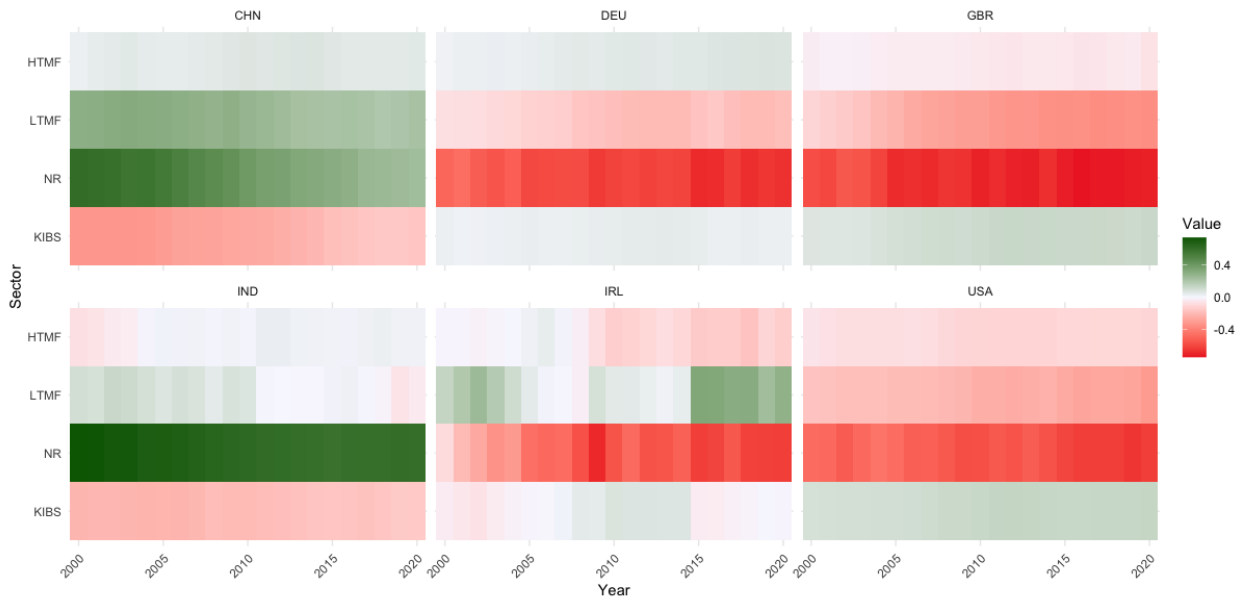
Germany's advantages appear strongest in HTMF activity, with a slight advantage in KIBS as well. Although German HTMF specialization has increased over time, the relative strength of the advantage is low. Nonetheless, it is the strongest HTMF advantage among the countries in **Figure 4**.

The most surprising result is the strength of advantages in developing versus developed economies. While most of the developed countries indicate a positive index in their respective specializations, the relative values of these advantages are much lower than those of the developing

[4] The complete table with the associated sectors for each sector group are provided in **Table 2** in **Appendix A**.

economies like China and India. Ireland's advantages appear to be the most erratic among the countries listed. A slight increase in advantage in KIBS value-added contributions from 2007-2014 eventually declined in 2015. Conversely, increase in LTMF value-added contributions in 2015 resulted in a significant gain in comparative advantage.

Figure 4: Normalized RCA indices for Domestic Value-Added (DVA) shares in aggregated sector groupings for China (CHN), Germany (DEU), the United Kingdom (GBR), India (IND), Ireland (IRL), and the United States (USA) between 2000-2020.



Source: Author's own calculations based on value-added decompositions from Bellotti et al. (2021)

By disaggregating the sectors into the original 45 distinct industries, the source of advantages for each country become clear. Germany's specialization structures appear to be more diverse than the United Kingdom, with advantages in mid-range sectors of machinery and motor vehicles (sectors 19 and 20, respectively) associated with high-tech manufacturing activity.

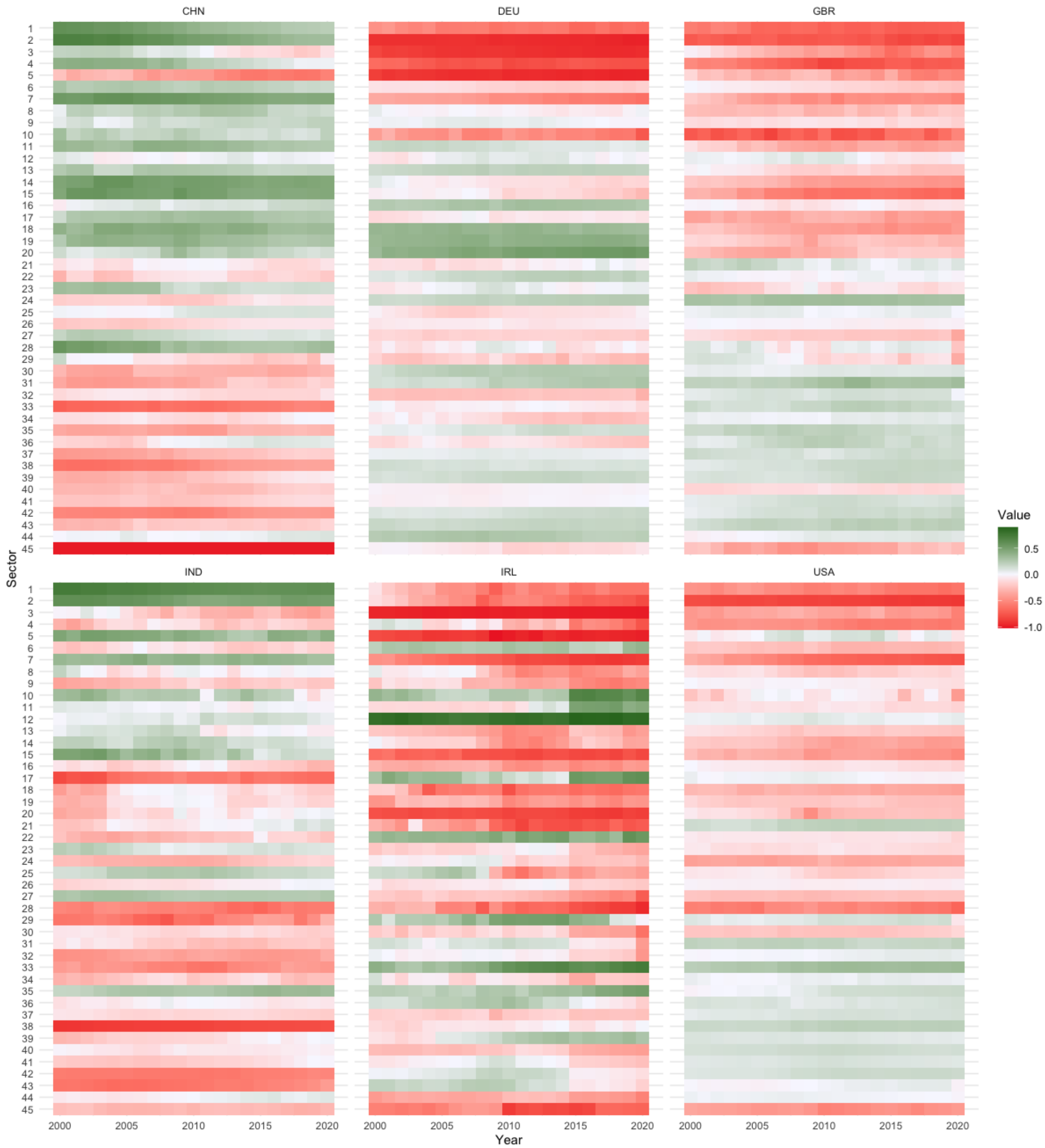
India's largest comparative advantages are in natural resource sectors of agriculture, hunting, and forestry (sector 1) and fishing and aquaculture (sector 2). India has also developed a strong comparative advantage in IT and communication services (sector 35), which has increased from 0.18 in 2000 to 0.33 in 2020.

China's comparative advantages are strongest in textiles, leather and footwear (sector 7), non-metallic mineral products (sector 14), and basic metals (sector 15), although its advantage in sector 7 has declined over time. Similarly, previously strong comparative advantages in value-added contributions in natural resource sectors have declined significantly, from 0.60 to 0.22 in agriculture and 0.70 to 0.32 in fishing and aquaculture between 2000 and 2020, respectively.

Among the developed countries in **Figure 5**, Germany and Ireland have the strongest advantages. Germany's strongest sector is motor vehicles (sector 20) which has continued to increase over time, from 0.34 to 0.52 across the time series. Ireland's strongest value-added advantage is in pharmaceutical products (sector 12), with a normalized RCA index of 0.85 in 2020. It has also developed a strong advantage in publishing activities (sector 33), increasing from 0.41 in 2000 to 0.74 in 2020.

As with the aggregated sector groups, the structure of Ireland's comparative advantages between 2000 and 2020 are the most erratic among the countries in **Figure 5**. Notably, there is a sharp increase in the RCA indices of some sectors in 2015, including mining and quarrying (sector 10), chemical products (sector 11), and computer, electronic, and optical equipment (sector 17). Ireland's advantage in IT and communication services has steadily increased from 0.41 in 2000 to 0.74 in 2020, but it appears to have lost a slight advantage in financial and insurance activities (sector 36) across the time series. Excluding Ireland, the structure of comparative advantages across the time series has remained relatively stable.

Figure 5: Normalized RCA Indices for DVA shares in individual sectors for China (CHN), Germany (DEU), the United Kingdom (GBR), India (IND), Ireland (IRL), and the United States (USA) between 2000-2020.

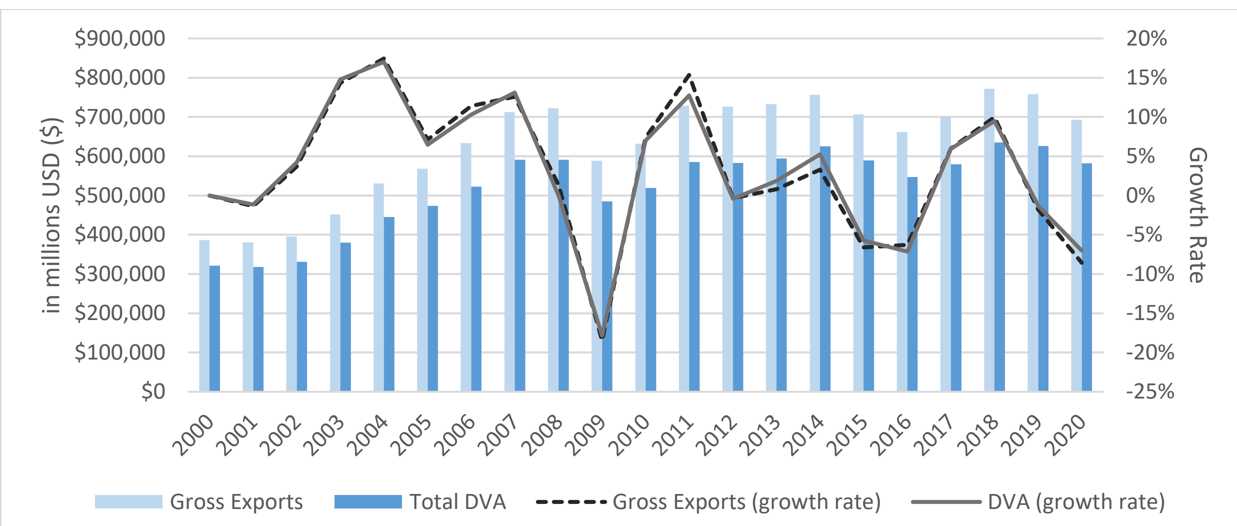


Source: Author's own calculations based on value-added decompositions from Bellotti et al. (2021)

5. 2. United Kingdom Export Performance Before and After Referendum

In the period between 2000 and 2020, UK gross exports fluctuated in the range between $386 billion and $772 billion. **Figure 6** shows the yearly changes in gross exports and DVA shares and the respective growth rates of each indicator between 2000 and 2020. The sharp decline in UK exports between 2008 and 2009 can largely be attributed to the global economic downturn of the financial crisis in 2008. Similarly, the large growth rate between 2009 and 2010 can be attributed to the recovery period following the crisis. There is a slight deviation in the growth rates of gross exports and domestic value added between 2010 and 2012. Domestic value-added shares appeared to be experiencing slower growth than exports. Up until this point, the growth rates of the two indicators were nearly identical, suggesting the United Kingdom was not influenced by the global trends toward increasing production fragmentation (Ijtsma et al., 2018). However, the slight deviation in growth rates between 2010 and 2012 can suggest a slight increase in participation in global value chains. Between 2012 and 2015, the relationship between the growth rates of gross exports and domestic value-added shares was inverted, with DVA shares growing at a higher rate than exports.

Figure 6: Total UK Gross exports and domestic value-added overlayed with growth rates of each indicator, 2000-2020.

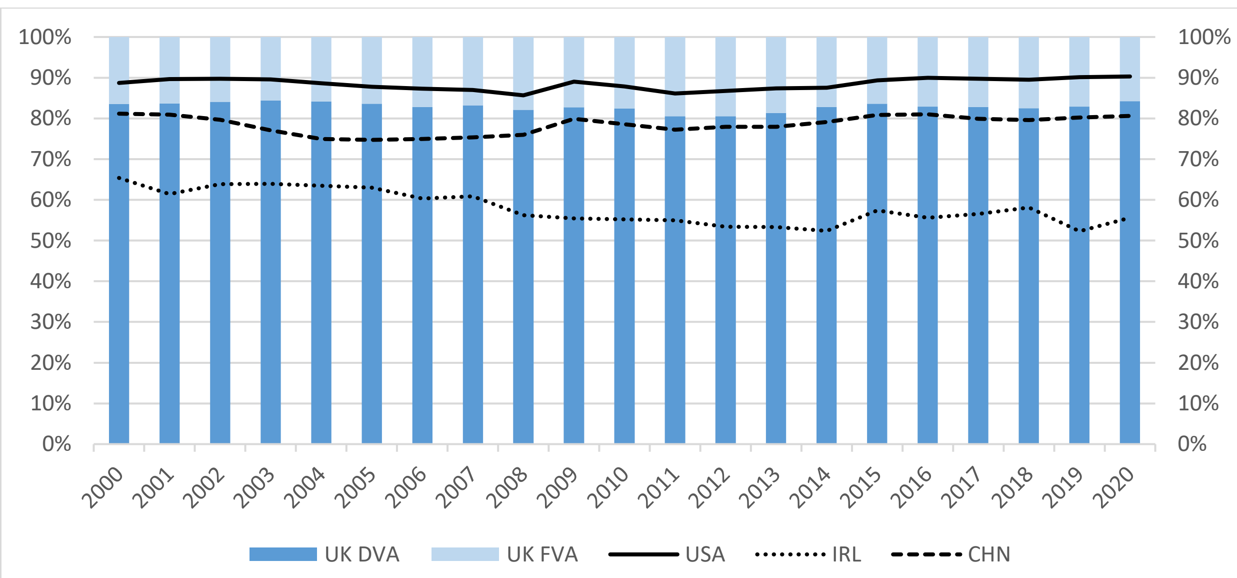


Source: Author's own calculations based on decomposed OECD ICIO data from Bellotti et al. (2021)

Gross exports steadily increased between 2010 and 2014 with a considerable decline between 2014 and 2016. Gross exports began to increase again after 2016 before another drop in 2019. This second drop in exports could be indicative of the reaction delay of supply chain reshuffling in response to the referendum in 2016. With the UK's exit from the European Union imminent, and worsening confidence in EU-UK trade agreement negotiations, firms may have begun removing operations from the United Kingdom to maintain EU supply lines and access to the single market.

The United Kingdom has historically exhibited large shares of domestic value-added in gross exports, as evidenced by **Figure 7** below. The data shows DVA shares consistently exceeded 80% of gross exports between 2000 and 2020. The United Kingdom's share of DVA in total value-added exports is in the same range as China and the United States. By comparison, Ireland's share of DVA in its exports is much more balanced with its FVA shares, declining from 65% in 2000 to 56% in 2020.

Figure 7: Domestic value-added shares as a percentage of total value-added of exports for the United Kingdom, the United States, Ireland, and China from 2000-2020



Source: Author's own calculations based on OECD ICIO decompositions from Bellotti et al. (2021)

While China also exhibits large shares of DVA in its gross exports, the United States' large shares of DVA are more similar to the United Kingdom's given the similarities in specialization and value-added output. Like the UK, the US has historically maintained a strong comparative advantage in high value-added service activities (Jensen, 2016). The United States also shares the same trade balance structure as the United Kingdom, with a trade deficit in goods offset by a large surplus in services (The White House, 2024). The differences in size and relative distance to other markets for the US and the UK, however, makes the latter's large DVA shares somewhat surprising. European markets are smaller and closer in distance to other markets. It is therefore, expected that the foreign value-added shares of gross exports would be higher. Ireland's DVA and FVA shares are more reflective of its location given these factors. Similarly, ASEAN countries that specialize in low- and high-tech manufacturing are also expected to exhibit larger shares of FVA in their exports given their size and relative locations. China, on the other hand, has been able to absorb previously imported production processes to domestic value chains, requiring less imported inputs (Lianling & Cuihong, 2017; Ma et al., 2015).

Although gross exports are insufficient in measuring trade performance in the era of global value chains, comparing the sectoral changes in gross exports with those in domestic and foreign value-added shares reveals an emerging trend among service-oriented sectors. Overall declines in UK exports among raw material and manufacturing sectors are offset by the significant increases in service-oriented exports from 2000 to 2020. This corresponds to the overall trend of a "financialization" of UK exports with a "manufacturization" of imports (Giammetti, 2020), further reinforcing the UK's advantages in high value-added service activities and its importance as a provider of these services in EU-UK value chains.

5. 3. Global GVC Network from 2000-2020

The following section presents the changes in the global value network between 2000 and 2020. Pairings of less than 10 million USD ($) were disregarded from the edge lists for each network in order to limit the volume of edges and make processing the network visualization less memory intensive. **Figure 8** shows the global network in 2000 and 2020, with node sizes scaled according to betweenness centrality. [5]

Across the 20-year period from 2000-2020, the United States and Germany remained the most dominant nodes in the network in terms of betweenness centrality. Italy's low-tech

[5] Network indicators for nine countries (including the ROW aggregate) in the global network from 2000 and 2020 are provided in **Table 5** included in **Appendix B**.

manufacturing sectors held a significant position in the network early in the period, but its position decreased over time. The most notable change between the networks in 2000 and 2020 is the rise of China, in low-tech manufacturing sectors, and then in its subsequent emergence in high-tech manufacturing.

While the increase in China's betweenness centrality is significant, other Asia & Pacific countries, namely ASEAN countries, also increased their presence in value chains in both low- and high-tech manufacturing. China's knowledge-intensive business services experienced the largest increase from its position in 2000. In absolute terms, however, the United States's KIBS sectors remained the most significant hub in the network in 2020 for value-added flows, although this was a 46 % decline from its original position in 2000.

Most countries experienced increases in in- and out-degree centrality between 2000 and 2020 indicating that the network as a whole has expanded to include more forward and backward linkages. India had the largest increase in average in- and out-degree centrality largely due to the increases in HTMF and KIBS activity, although all sector groupings experienced gains of more than 100% across both in- and out-degree centrality. Corresponding with the large increase in betweenness centrality, China's KIBS sectors had the largest relative increase in out-degree centrality with 350% from its position in 2000.

The increase in GVC participation across the time series is also evident in the changes in eigenvector centrality between 2000 and 2020. For example, countries like Saudi Arabia (SAU) and Vietnam (VNM) whose betweenness and out-degree centrality in KIBS sectors were low relative to the other KIBS nodes in the network, increased in eigenvector centrality quite significantly. The increase in the relative connectivity of these nodes versus their low rate of both forward contributions and presence on a significant share of paths in the network indicates that while they may not be contributing large shares of value-added, they are participating in more activities along the value chains of significant markets in the network.

Figure 8: Global value network of aggregated sector groupings in 2000 (a) and 2020 (b) scaled based on betweenness centrality.

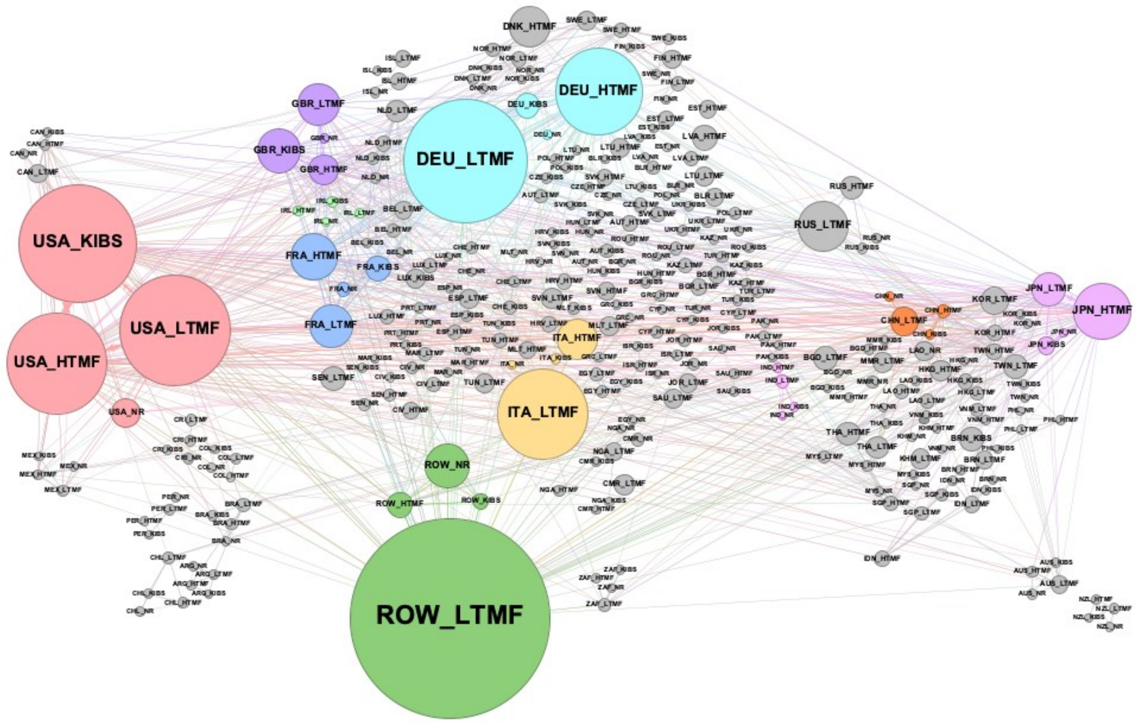


Figure 8a: Global Value-Added Network in 2000

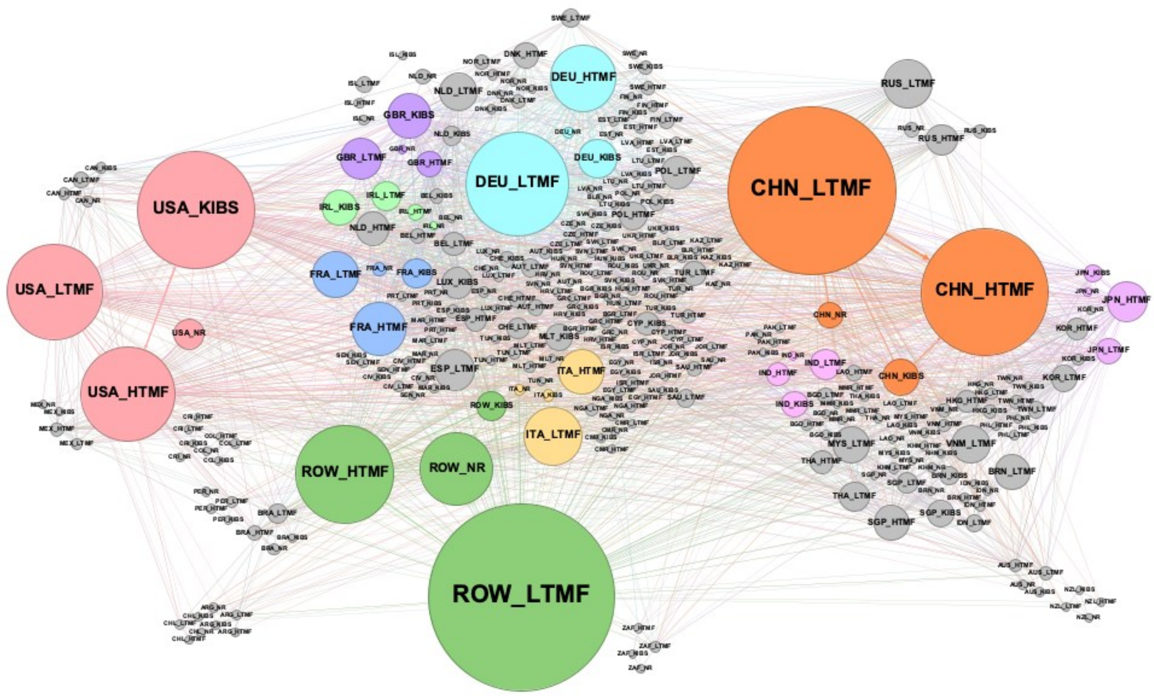
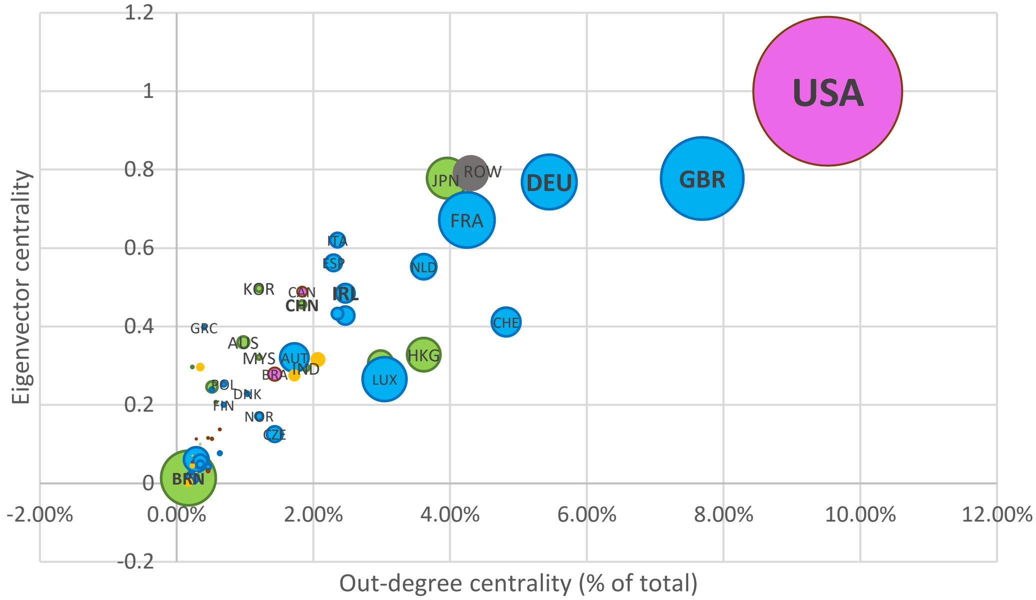


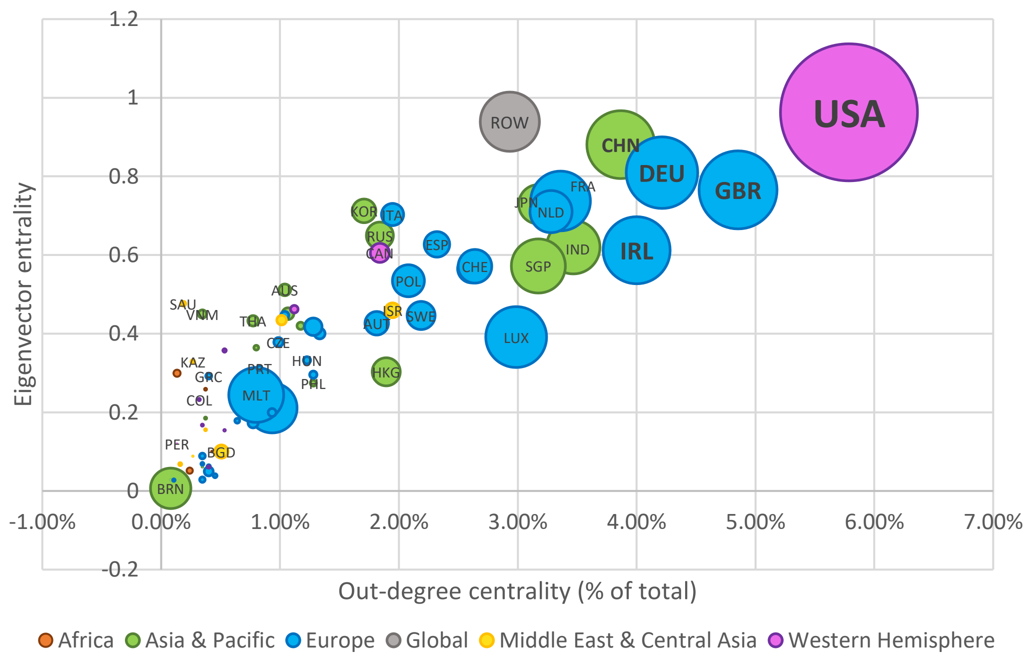
Figure 8b: Global Value-Added Network in 2020

Source: Author's own rendering.

Figure 9: Distribution of KIBS sectors in the global network based on out-degree, eigenvector, and betweenness centrality in 2000 (a) and 2020 (b).



(a)



(b)

Note: Countries are grouped based on the IMF economic region classifications. Vertices are scaled based on betweenness centrality. Although the maximum possible eigenvector centrality value is 1, the y-axis maxes out at 1.2 in order to allow for sufficient space in the chart area to incorporate all vertices at their scaled size.

Source: Author's own composition.

The distribution of the countries' KIBS sectors in the global network in 2000 and 2020 in terms of betweenness, eigenvector, and out-degree centrality are shown in **Figure 9**. Rather than presenting out-degree centrality in absolute terms, each country's out-degree centrality is presented as a percentage of the total number of KIBS out-degrees in the network. This is useful for a number of reasons. Namely, it provides a better indication of the dispersion of forward linkages in the network across the time series. For example, the US had the highest share of out-degrees among KIBS nodes in the network in 2000 at just under 10%, but its share declined to just under 6% in 2020. Overall, the distribution of out-degrees among KIBS nodes in 2020 were less concentrated around larger nodes like the United States, indicating a more balanced contribution of value-added among countries relative to 2000.

The stability of the United States and the United Kingdom's KIBS sectors in the global network is also visible. Although both markets experienced slight declines in all indicators, their positions relative to the rest of the KIBS nodes in the network remained effectively unchanged. Countries in the Asia & Pacific and Europe regions are among those with the largest relative increases in all three indicators, particularly China, Singapore, and India and the Netherlands and Ireland, respectively.

5. 4. EU-UK GVC Network from 2000-2020

The EU-UK value-added network in 2000 and 2020 is shown in **Figure 10**.[6] The nodes in the network are scaled based on betweenness centrality.

The most significant change between the EU-UK network in 2000 and 2020 is the increase in Ireland's activity in the network and the rate at which it appeared on the value chains of other nodes in the network, particularly in its KIBS sectors. Ireland's out-degree centrality in KIBS increased 200% from 2000 to 2020, relative to the 32% increase in the same indicator for the UK. Irish KIBS also experienced considerable increases in closeness and eigenvector centrality with 46% and 23% increases, respectively. This is compared to the UK's respective increases of 20%

[6] Visible edge weights have been reduced to a minimum of 500 million USD in order to provide a more concise visualization of the network. However, this is purely for visualization and does not affect the statistical analysis or centrality calculations based on the original edge list with the minimum edge weight of 10 million USD.A full breakdown of the network indicators for standout economies in the EU-UK network is provided in **Table 6** in **Appendix B**.

and 3% in the same indicators. The most significant change, however, was betweenness centrality in which Irish KIBS increased a massive 708%, while the UK decreased 38%.

A loss in significance in terms of betweenness centrality is not unique to the United Kingdom, however. Germany's high-tech manufacturing, the largest hub for betweenness centrality in the 2000 network, declined 63% in 2020. A similar result occurred with Italian low-tech manufacturing that declined 62% in 2020. These decreases in betweenness centrality are contrasted against the increases in the same indicator for countries like Poland, the Netherlands, or Ireland.

Figure 10: EU-UK network of value-added flows in 2000 (a) and 2020 (b) scaled by betweenness centrality.

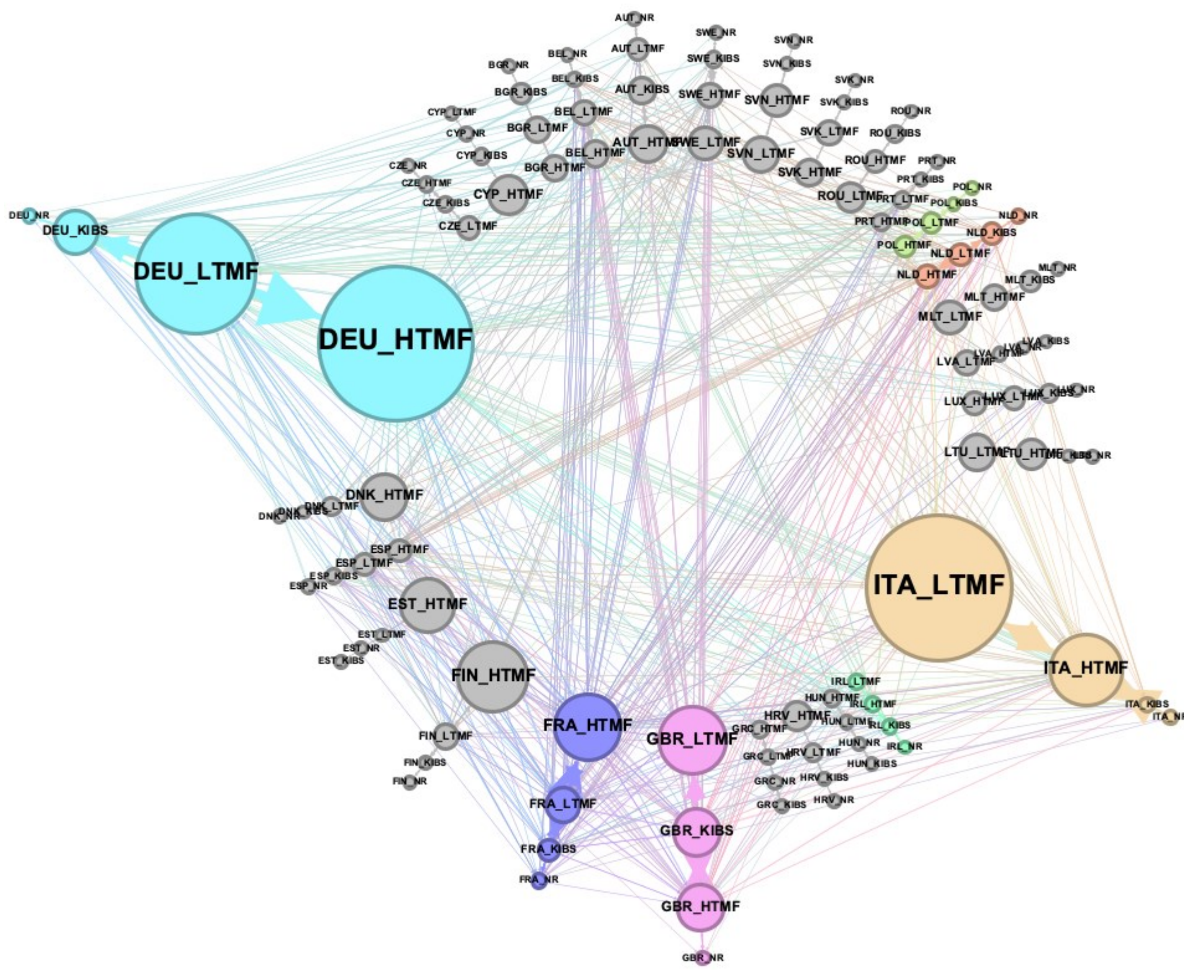


Figure 10a: EU-UK Value-Added Network in 2000

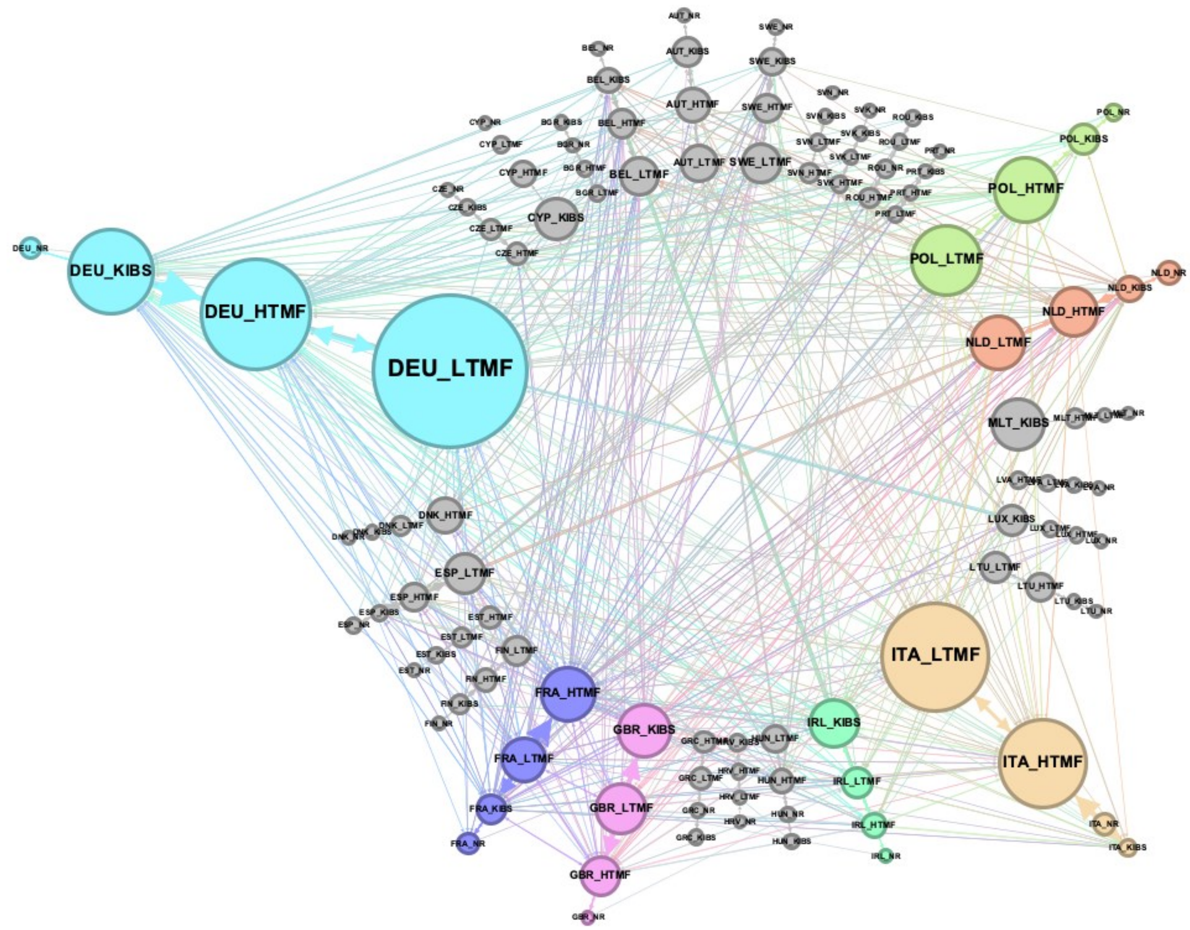
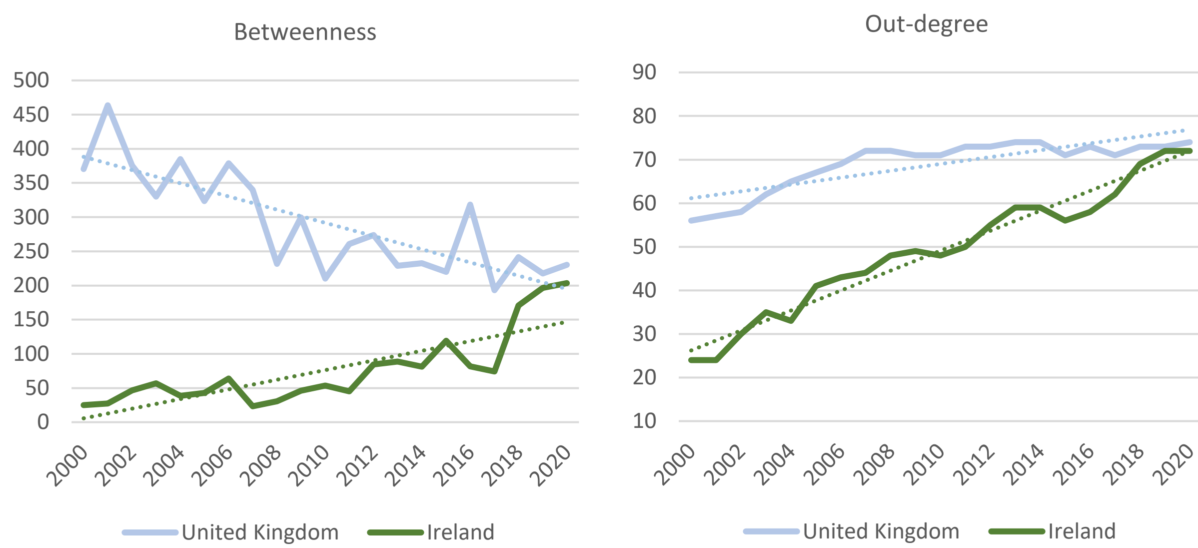


Figure 10b: EU-UK Value-Added Network in 2020

Source: Author's own rendering.

Figure 11 shows the change in centrality in terms of both betweenness and out-degree for the KIBS sectors in the UK and Ireland yearly from 2000 to 2020. Ireland's steady increase in relevancy over time as a hub for value-added flows is visible, with a sharp increase beginning in 2017. The UK's betweenness centrality fluctuates more erratically over the same period. Nonetheless, the overall trend for the UK's betweenness centrality in KIBS activity is decreasing. Ireland's out-degree centrality has also increased at a steeper rate than the United Kingdom, with another sharp increase beginning around 2016. Due to these significant changes in the post-referendum period, the two markets appear to be converging to near equivalency in both indicators.

Figure 11: Betweenness and out-degree centrality of United Kingdom and Ireland KIBS sectors in the EU-UK value-added network from 2000-2020



Source: Author's own composition.

Given the weight of edges in terms of the value of trade flows, weighted out-degree is also an important indicator for assessing the structure of the value-added contributions in the network. The UK's KIBS maintained a strong position in the network relative to the value-added contributions of other sectors across the time series. KIBS sectors in France and Germany as well as Germany's HTMF sectors were the only other nodes with larger weighted out-degree centralities than the UK's KIBS. Comparatively, while Ireland's weighted out-degree centrality increased from 2000 to 2020, it was 37% less than the UK's weighted out-degree value. The difference in the value of weighted out-degrees between Ireland and the United Kingdom, however, has decreased from a 42% difference in 2000. The EU-UK value-added network scaled by weighted out-degree centrality is shown in **Figure 12** provided in **Appendix C**.

5. 5. Time Series Expansion using FIGARO data

Since there has not been newly published data beyond 2020, the global and EU-UK networks are unable to be analyzed in a time series that incorporates the United Kingdom's exit and subsequent implementation of the TCA using OECD ICIO data. This affects the analysis for a number of reasons. Most importantly, the United Kingdom's exit from the European Union was finalized in 2020 and the TCA went into effect on January 1, 2021. This means that further adjustments to the value-added networks after the United Kingdom's exit from the European Union cannot be assessed using the OECD ICIO data.

In order to combat this limitation, the following section will utilize input-output data published by EUROstat's FIGARO database. FIGARO data is published yearly with a time series of T-2 years from the published year (Remond-Tiedrez & Rueda-Cantuche, 2019), meaning input-output data for European Union countries, the United Kingdom, as well as eighteen other countries (including an ROW aggregate) is available from 2010 to 2022.

Using the FIGARO data, the EU-UK network in 2010 and 2022 is shown in **Figure 12**. Node size is scaled once again based on betweenness centrality. The most significant change between these two years is the increase in Ireland's betweenness centrality in all sector groups, but especially in KIBS. All other country sector groups remained relatively stable in the same indicator. There is also a slight decrease in the United Kingdom's centrality in KIBS, corresponding to the rise of Ireland. Here we can see both the direct and indirect effects of Brexit on the UK and Ireland's position in the network when accounting for the flow of value-added activity.

In 2010, the United Kingdom had the largest betweenness centrality among KIBS nodes with a score of 650. The UK's KIBS was also the second-most relatively connected node in the network with an eigenvector score of 0.966. Germany was the second-largest KIBS hub with a betweenness and eigenvector centralities of 395.7 and 0.919, respectively. Ireland's KIBS sectors were the country's second-most significant hub behind LTMF but trailed behind UK KIBS with respective betweenness and eigenvector centralities of 56.418 and 0.603.

The UK's KIBS sectors had relatively balanced in- and out-degrees in 2010, with in-degrees being slightly higher at 68 compared to 61, respectively. In 2016, however, the difference widened slightly. Out-degrees increased from 56 to 64 and the combined degree of UK KIBS decreased from 128 to 120. This indicates less activity overall, while the rate of contribution from these sectors increased in the referendum year.

In 2022, Ireland's KIBS sectors had the highest betweenness centrality of 253.37 (a 146% increase from its position in 2016). The United Kingdom was still a significant KIBS hub in 2022 with a betweenness centrality of 244.32, but this was a 46% decrease from its dominant position in 2016. German KIBS similarly declined in betweenness centrality by 23% to its position in

2022. While there were countries who experienced significant increases in betweenness centrality across the time series, the absolute values for their KIBS sectors in 2022 are significantly lower than the dominant KIBS nodes in the network.

Figure 12: EU-UK network of value-added flows in 2010 (a) and 2022 (b) scaled based on betweenness centrality.

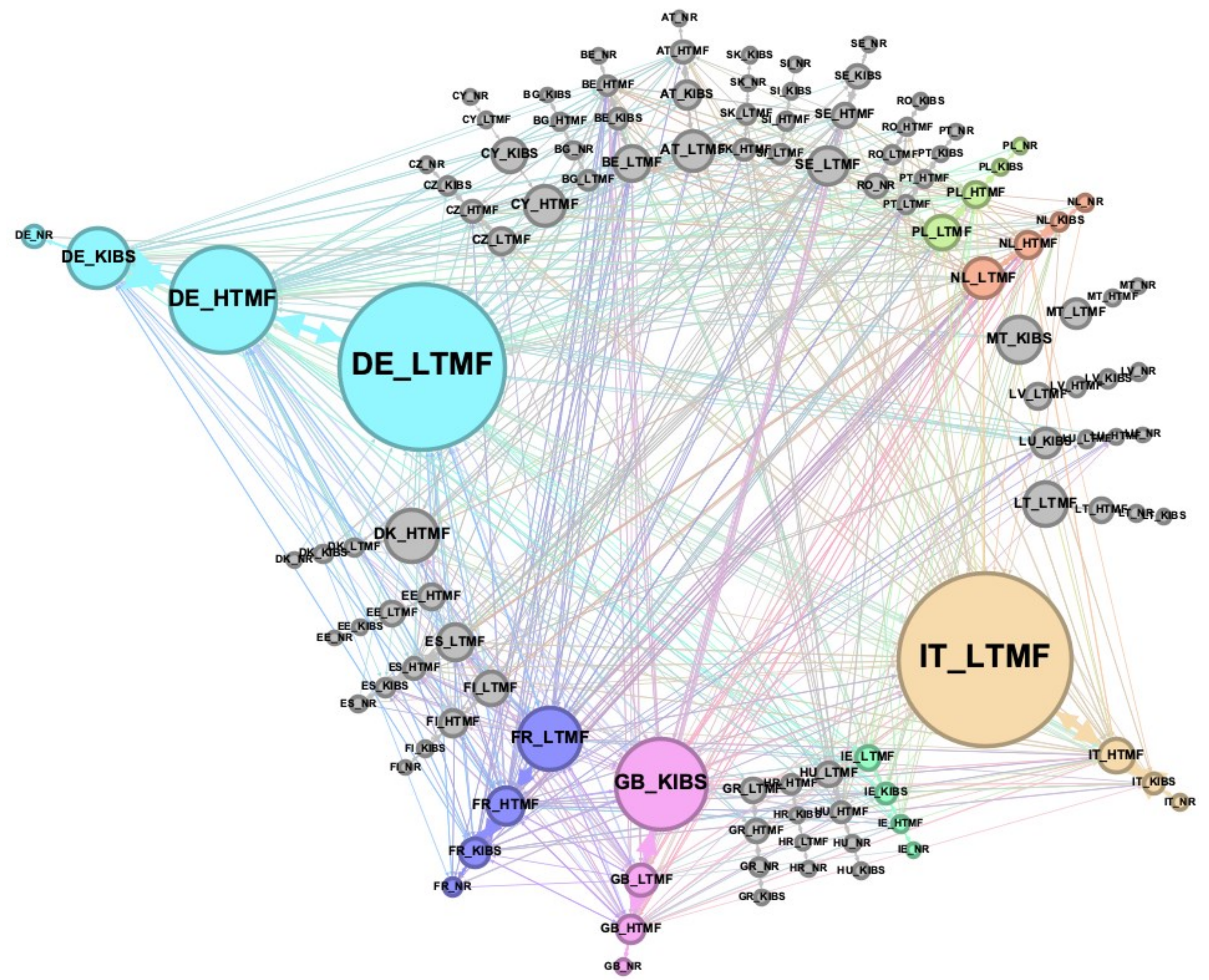


Figure 12a: EU-UK FIGARO Network in 2010

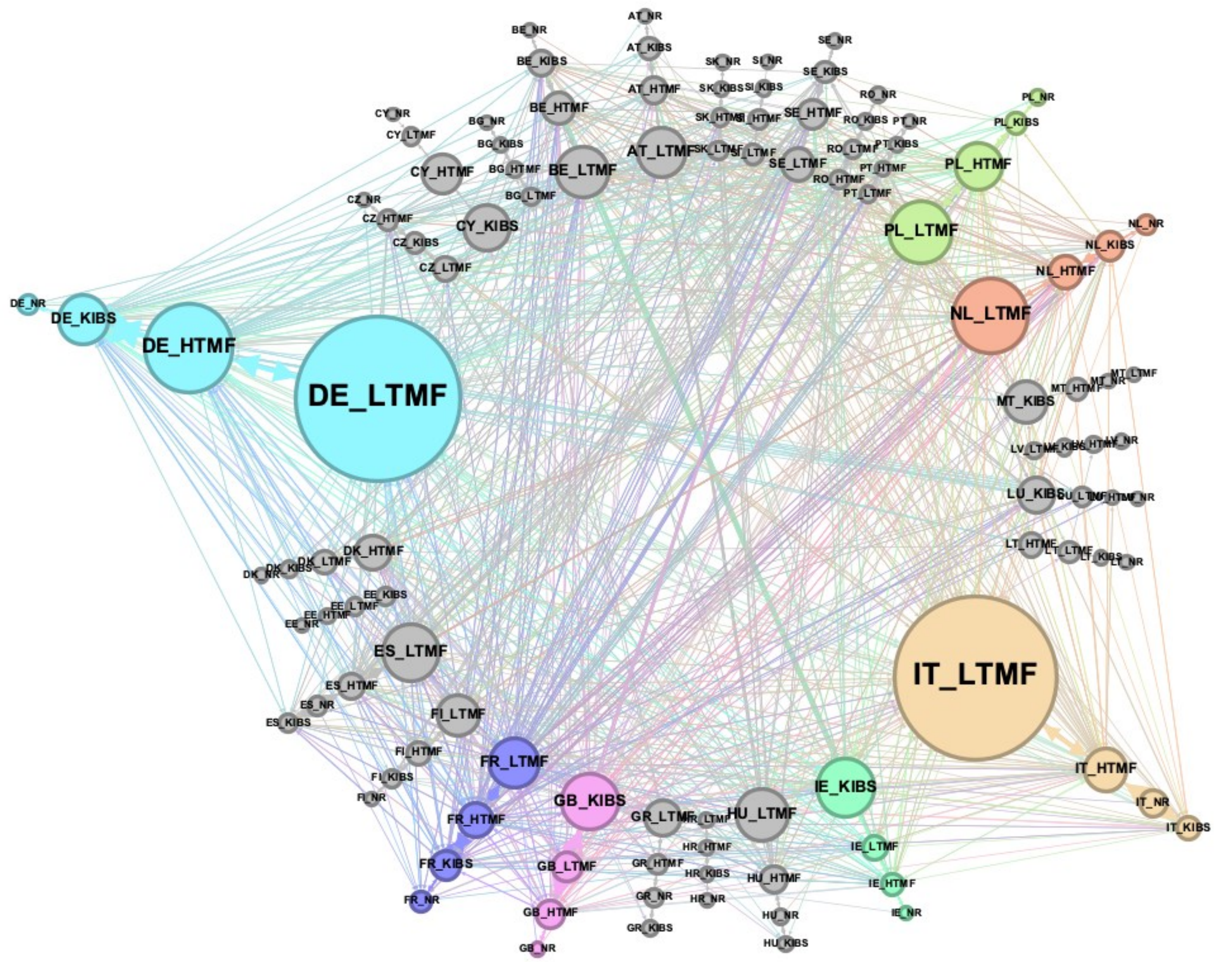
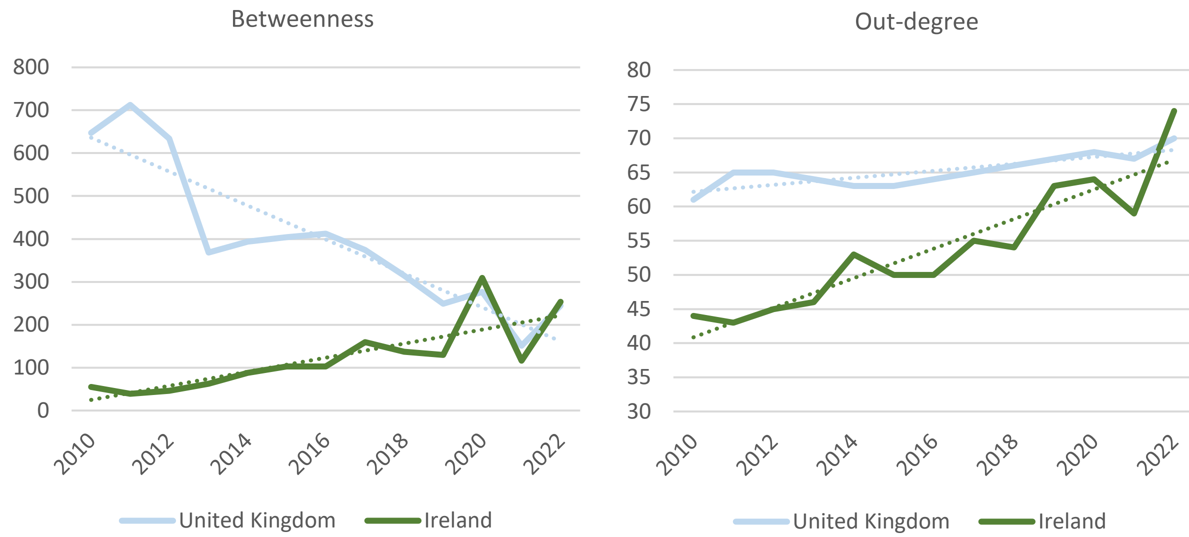


Figure 12b: EU-UK FIGARO Network in 2022

Source: Author's own rendering.

The differences in absolute values aside, when viewing the trends in KIBS activity for the UK and Ireland, significant similarities with the results from the OECD data emerge. **Figure 13** shows the yearly changes in betweenness and out-degree centrality for the United Kingdom and Ireland's KIBS sectors. Comparing these results to **Figure 11** from the previous section, we can see the similarities in the downward and upward trends in betweenness centrality for the United Kingdom and Ireland, respectively. The UK's KIBS sectors experienced an overall decline in betweenness centrality across the time series, while changes in out-degree centrality for the two markets also show a similar trend to the results from the OECD data. The United Kingdom experienced a much flatter increase in out-degree centrality relative to Ireland. Betweenness centrality increased significantly for Ireland's KIBS sectors after 2019 before experiencing a substantial decline in 2021. A similar dip in Ireland's out-degree centrality in 2021 was followed by a large recovery in 2022. As of 2022, Irish KIBS have more out-degree connectivity than the UK.

Figure 11: Changes in betweenness and out-degree centrality for UK and Ireland KIBS activity from 2010-2022 (FIGARO).



Source: Author's own composition.

6. Discussion of Results

The results of the analysis overwhelmingly show the degree to which the expansion of global value chains has affected the positionality of countries in value-added networks, particularly those in developed economies. In the global network, countries like Germany, Italy, and the United States previously held dominant positions in their specialized sectors, with fewer countries competing for those activities. As global production dispersed over time, the position of these countries relative to the rest of the network shrank. Other economies began to compete with or even surpass their positions in the network. China is the greatest example of this, with its influence in the network largely attributed to its accession to the World Trade Organization (WTO) in 2001 (Amador & Cabral, 2016). ASEAN countries also experienced large increases in centrality among low- and high-tech manufacturing sectors. With the rise of China and ASEAN countries in these activities, the influence of corresponding sectors in countries like Germany, Italy, and the United States understandably decreased.

The proliferation of GVCs also affected the structure of the EU-UK network relative to the increased participation in value-added activities, particularly in the positions of new member states in Central and Eastern European countries (Gurgul & Lach, 2016; Hagemejer & Ghodsi, 2017). The change in the flow of value chains through Ireland's KIBS sectors across the time series can be attributed to the large share of multi-national corporations (MNCs) that operate in Ireland, taking advantage of its low corporate tax incentives. Furthermore, Ireland is an attractive destination for foreign direct investment (FDI) from businesses seeking "frictionless access to the EU's single market (Du & Shepotylo, 2022)." The United Kingdom, however, was able to maintain a relative level of stability as a hub for KIBS activity in the EU-UK network. Although the UK's KIBS decreased from its position in 2000 in terms of betweenness centrality, the overall decline was minimal relative to other sectors in the network. Italy or Japan's LTMF sectors, for example, were more directly affected by the emergence of China and ASEAN countries participation in these activities.

The relative changes in centrality contrast the stability of specialization structures for most countries. The stability in RCA for countries like the United States and the United Kingdom can largely be attributed to their consistently dominant position in GVCs. In the UK's case, it was able to gain comparative advantage in services through its membership in the EU (Mulabdic et al., 2017) and maintain those advantages through its continued participation in GVCs (Peneder &

Streicher, 2018). If the UK were to have specializations in low- or high-tech manufacturing sectors, the change in relative importance of these sectors may be much more attributable to the rise of China and ASEAN countries than to Brexit, as evidenced by the decline in Italy's LTMF sectors in the global networks. However, China's KIBS sectors have not increased nearly to the same degree as its LTMF and HTMF sectors since 2000. Narrowing the network down to the 27 current EU member states and the United Kingdom reveals significant shifts in the restructuring of EU value-added flows in service-related sectors as a result of Brexit.

The relative stability of the UK's value-added service contributions and its corresponding position in the global and EU-UK networks must also be compared against the rise of Ireland in the same group. The respective rates of change among UK and Irish KIBS is a strong indication of Brexit's indirect impact on the EU-UK value-added network. Since 2016, more and more value-added flows have begun to pass through Ireland, especially through its KIBS services. The growth of Ireland's KIBS sectors as a significant hub for value-added activity in the network is important within the context of Brexit's impact on EU-UK value chains. However, accounting for Ireland's forward contributions in services reveals it is not yet competitive with other dominant markets in the EU like France, Germany, or especially the UK. Therefore, an additional level of analysis must be undertaken to test the similarity in value-added contribution of the United Kingdom and Ireland in the EU market.

6. 1. Robustness check using Value-Added Similarity Index (VASI)

The following section utilizes an adaptation of the Export Similarity Index (ESI) developed by Finger and Kreinin (1979). Originally created to test the similarity in exports of two countries in a third market, the boundary of the index is 0:100, with 0 indicating complete dissimilarity between each country's exports and 100 inversely indicating complete similarity.[7] Countries with similar exports would face increased competitiveness in their respective exports, but dissimilarity indicates a complementary relationship in the exports to the third market (Finger & Kreinin, 1979; Wang & Liu, 2015). Adapting the index to use value-added shares instead of gross exports in each sector group provides the resulting index for the UK and Ireland's value-added contributions in the EU market, shown in **Table 1**.

[7] The calculation method for the ESI is provided in **Appendix D**.

The similarity in value-added from KIBS activity between Ireland and the United Kingdom in the EU, peaked in 2010 at 40.8. It remained relatively stable before declining in 2015 from 40.3 to 33.2 in 2020. Overall, the UK and Ireland's value-added contributions to the EU across all sectors is high, albeit decreasing over time.

Comparatively, the similarity in value-added contributions between the United Kingdom and the United States in the EU market is much higher. This similarity is also increasing from 2010 to 2020. The UK and the US have greater similarity in KIBS contributions than with Ireland. This is expected given the strong specializations in service activities for both economies. Ireland's value-added activity in services is still growing, but the UK and the US have been well-established KIBS contributors for some time.

Table 1: Value-Added Similarity Index (VASI) of the United Kingdom value-added contributions with Ireland and the United States in the EU market.

Year	Ireland					The United States				
	NR	LTMF	HTMF	KIBS	VASI	NR	LTMF	HTMF	KIBS	VASI
2010	0.556	7.329	20.597	40.832	**69.314**	0.599	11.255	25.185	42.679	**79.717**
2011	0.730	7.611	21.453	39.766	**69.560**	0.763	12.106	25.154	42.307	**80.331**
2012	0.710	7.728	21.602	40.317	**70.357**	0.726	11.735	24.324	45.029	**81.814**
2013	0.548	7.677	20.933	38.820	**67.978**	0.570	11.303	23.867	45.994	**81.734**
2014	0.644	7.417	20.426	40.336	**68.823**	0.666	11.042	23.677	46.832	**82.216**
2015	0.618	7.021	15.133	35.466	**58.237**	0.616	9.293	23.684	48.830	**82.423**
2016	0.604	6.685	16.942	34.548	**58.779**	0.603	8.999	22.991	49.334	**81.927**
2017	0.495	6.574	16.470	35.389	**58.927**	0.506	9.384	23.715	48.994	**82.600**
2018	0.427	6.288	15.108	35.598	**57.420**	0.437	9.731	22.870	48.737	**81.775**
2019	0.582	6.215	15.021	33.561	**55.379**	0.585	9.259	22.347	50.401	**82.592**
2020	0.546	6.120	13.708	33.215	**53.589**	0.572	8.806	21.925	51.471	**82.774**

Source: Author's own calculations.

The results of the similarity index indicate that although service and other value-added flows through Ireland are increasing after Brexit, the similarity in the value-added contributions of the two markets to the EU are becoming more complementary. This is also evident in the vast difference in betweenness and weighted out-degree centrality for each market in the EU-UK network. The large increase in value-added flows moving through Ireland's KIBS sectors compared to the minimal increase in weighted contributions indicates Ireland is increasing its value-added activity in service sectors at a faster rate than its value-added output.

Furthermore, the two markets were more competitive in the EU prior to the referendum. The competitiveness of their respective sectors in value-added contributions has continued to decline. The structure of Ireland's specializations compared to the UK is the likely factor contributing to the dissimilarity of value-added contributions to the EU. The UK has maintained stable advantages in KIBS activity over time, while Ireland's specializations are still evolving. Therefore, EU importers are likely continuing to import UK value-added in its specialized sectors through its established value chains, and receiving value-added contributions from Ireland in sectors in which the UK has a disadvantage (e.g. LTMF).

6. 2. Limitations and Avenues for Future Research

While the results of this study are robust, there are naturally some limitations to the research. Firstly, the inconsistent time series availability of the data from OECD and FIGARO databases led to somewhat incongruous results in the network analysis. As the FIGARO data is not available in the same breadth of time as the OECD ICIO data, there were naturally some significant differences in the results. Notably, Ireland held a dominant position in the network for KIBS activity as early as 2020 with FIGARO data when accounting for betweenness centrality. However, Ireland trailed behind Germany, the United Kingdom, and Malta in terms of betweenness centrality in 2020 in the OECD ICIO data. The limited number of countries in the FIGARO data compared to the OECD data could be causing an overestimation of the importance of some nodes in the edge list due to absent value-added flows that are present in the OECD tables.

However, the utilization of both datasets afforded the opportunity for an increased level of robustness in the analysis through the ability to compare trends across the time series. Although the absolute values in the results differed between the two datasets, there were consistent trends among the results of the analysis for each.

Perhaps the greatest challenge in measuring the fallout of Brexit is the fact that the United Kingdom's exit from the European Union occurred amidst the height of the COVID-19 pandemic. Not only did the global economy face a recession as a result of the pandemic, but global value chains were severely affected by disruptions in the supply of goods predominantly provided by Asian manufacturers. The proliferation of GVCs has not only led to increased fragmentation of production processes, but it has also contributed to a concentration in the production of certain inputs among a relatively small group of countries. The pandemic exacerbated the issues with such concentrated production processes and led to a complete stoppage of supply chains in certain products, particularly medical PPE equipment that was vital for emergency response to outbreaks across the globe. Furthermore, the changing attitudes towards globalization and economic integration were further aggravated by the effects of the pandemic on global supply chains. More recent policy responses to this fallout have move away from the offshoring policies that defined the economic liberalization of the globalization era, with many focusing instead on re-shoring value chains back to domestic markets or those closer to home (e.g. friendshoring) (Clancy et al., 2023).

The trade impacts of the pandemic are visible in the analysis of the year-to-year changes in centrality among the global and EU-UK networks using FIGARO data. While there is some recovery in GVC activity visible in 2022, the immediate effects of Brexit and the TCA are nearly impossible to disentangle from the effects of the pandemic. Moreover, given the fact that it has been just four years since the United Kingdom left the European Union, it is still too early to assess the long-term effects of Brexit on EU-UK value-added trade. This is exacerbated by the limited time series of inter-country input-output tables.

Given these limitations, potential areas for future research emerge. The role of services in value-added trade specializations is relatively understudied. More specifically, the impact of policy shocks like Brexit on the specialization of value-added service activities offers an exciting area for additional study. Much of the current study in global trade utilizes established econometric models such as general equilibrium or gravity models to test the effects of variables like non-tariff barriers on the cross-border flow of goods. Computable general equilibrium models offer a better indication of the welfare effects of GVC trade while gravity models can provide some explanation on possible trade diversions caused by Brexit. A methodology that incorporates these models into network analysis to test the effects of these variables on positionality within the network is a potentially rich area for future research. Micro-level data on economic activity at the regional or local levels within a particular market can also be combined with the input-output data used in this study to provide some additional depth to the value-added flows in the network.

The effect of specialization in high value-added services on the resiliency to policy shocks in GVC trade networks is another area of inspiration for further research from this thesis. A potential future study could build a model network to test the effects of a similar exit scenario like Brexit on other EU member states whose specializations are in traditional manufacturing sectors. Germany is an excellent candidate, as its network position and value-added contributions to both the EU and global markets have remained relatively stable over time, even with the increased participation of China and ASEAN countries in Germany's specialized HTMF sectors.

7. Conclusion

The United Kingdom's value-added position in the network has remained relatively stable across the time series assessed in this study. Moreover, the UK has maintained its specialization in value-added service activities with little to no impact found from Brexit. The fact that services are less tradable and rely less on foreign inputs has potentially mitigated the effects of Brexit on UK value-added exports in its specialized sectors. More importantly, the nature of trade in services compared to traditional manufactured goods along with the high level of integration in GVCs prior to Brexit have contributed to the UK's increased resiliency in its specialized sectors against trade-related shocks brought on by Brexit. Had the United Kingdom possessed advantages in other value-added activities such as high- or low-tech manufacturing, the effect of Brexit on the UK's position in the EU-UK value added network may have been more immediate and severe.

There is no guarantee that the United Kingdom will be able to maintain its relative stability in service-related activities in the network, however. Other contributors of high-value added services such as France or Germany rival the UK in weighted out-degree centrality. The large shares of value-added flowing through Germany's service sectors also spells potential danger for the stability of the United Kingdom's services centrality. The City of London is arguably the most important financial center in Europe and is a significant contributor to the UK's global value-added output in financial services. As a result of Brexit, there were discussions within the EU regarding the potential for alternative financial centers such as those in Dublin or Paris to absorb some financial services typically provided by the City of London (Lavery et al., 2017). Although, the City remains a well-established financial center and is unlikely to lose its dominance in global financial services, strategies like the re-orientation of financial markets in post-Brexit Europe may also signal trouble for the UK's dominance in high value-added services in the long run.

Furthermore, the rate at which Ireland is increasing its presence in EU-UK value chains, especially in high value-added service activity, could also aggravate the United Kingdom's decline in the long run. Ireland's membership in the European Union and the fact it is the only predominantly English-speaking member in the EU makes it an attractive destination for high-skilled talent from the United Kingdom (Du & Shepotylo, 2022; Freeman et al., 2022). Changes in RCA indices in some sectors emerged as early as 2015, coinciding with the United Kingdom's general election in which the exit referendum was a key component of the Conservative Party's platform. The events surrounding these changes for Ireland could be potential factors in the shift of EU value-added flows away from the United Kingdom in response to the uncertainty regarding the future trading relationship and unpredictability of UK policy-making decisions following the general election and subsequent referendum. Despite this, Ireland's share of weighted out-degrees in the EU-UK network does not yet compete with the level of value-added output from other significant contributors of value-added services. However, Ireland's rapid growth in centrality in knowledge-intensive business services within the EU-UK network, especially after the 2016 referendum, places it in an advantageous position to become a significant hub for service activity in the future.

Geopolitical factors influencing EU-UK relations also affect the resiliency of the United Kingdom's position in global and EU-UK networks. Today's global economy is interconnected not only through trade, but also in the political ties between nations that influence trade policy. Russian aggression in Ukraine has made the need for EU-UK defense collaboration even more integral not only for Europe, but for the rest of the world as well. From a political economy perspective, defense initiatives also rely on the strength of the political and economic relationships among NATO allies. The ”progressive withdrawal” of the United States from NATO involvement has triggered a push for a more comprehensive strengthening of the EU's defense collaborations (*The Future of EU-UK Cooperation on Security and Defence - European Movement*, 2023). The stability of the UK's trade relationship with the European Union following Brexit highlights the importance of maintaining strong ties to leverage the UK's capabilities in EU defense collaborations.

Although it has been almost four years since the United Kingdom left the European Union, it is still too soon to tell what the long run impacts of Brexit will be on the UK's trade performance and overall economic outlook. The latest general election ousted the Conservative Party responsible for Brexit after 14 years in majority. With a new Labor government now in office and greater confidence in rational policymaking somewhat restored, the United Kingdom and European Union appear to be moving towards mending the political and economic relationship that was severely affected by Brexit.

Overall, the impact of Brexit on the UK's position in value-added trade networks relative to its specialized sectors was minimal. The United Kingdom has been able to maintain its position as a provider of high value-added services after Brexit, even with the additional costs associated with EU-UK trade. The UK's stable position in service-based activities can be attributed both to the high-level of integration in GVCs prior to Brexit and the nature of trade in services (e.g. low tradability and fewer foreign inputs). Its integration in GVCs allowed the United Kingdom to maintain its comparative advantages in service-based sectors over time. The lower reliance on foreign inputs in the value-added output of services, as well as the tendency for the value-added to be indirectly embodied in the value of other inputs and goods, also contributed to the resiliency of the UK's service sectors post-Brexit. Speculation about Ireland potentially overtaking the UK's position in high value-added services is not greatly supported by the data. The dissimilarity of the UK and Ireland's value-added contributions to the EU indicates they are more complementary than competitive in the EU market. Nonetheless, the increasing flow of EU value chains through Ireland, especially in knowledge-intensive business services (KIBS), places Ireland in an advantageous position to absorb some of the UK's service flows to the EU in the future. As more time passes, the effects of Brexit on EU-UK value-added trade will become more apparent. Future research into this topic will therefore only be richer given the ability to observe more data across an even wider time series.

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Appendix A

Table 2: OECD ICIO sectors with associated aggregated sector groupings

Sector	OECD code	Industry description	ISIC rev. 4	Aggregated Sector Group
1	A01_02	Agriculture, hunting, forestry	01, 02	NR
2	A03	Fishing and aquaculture	03	NR
3	B05_06	Mining and quarrying, energy producing products	05, 06	LTMF
4	B07_08	Mining and quarrying, non-energy producing products	07, 08	LTMF
5	B09	Mining support service activities	09	LTMF
6	C10T12	Food products, beverages and tobacco	10, 11, 12	LTMF
7	C13T15	Textiles, textile products, leather and footwear	13, 14, 15	LTMF
8	C16	Wood and products of wood and cork	16	LTMF
9	C17_18	Paper products and printing	17, 18	LTMF
10	C19	Coke and refined petroleum products	19	LTMF
11	C20	Chemical and chemical products	20	LTMF
12	C21	Pharmaceuticals, medicinal chemical and botanical products	21	LTMF
13	C22	Rubber and plastics products	22	LTMF
14	C23	Other non-metallic mineral products	23	LTMF
15	C24	Basic metals	24	LTMF
16	C25	Fabricated metal products	25	LTMF
17	C26	Computer, electronic and optical equipment	26	HTMF
18	C27	Electrical equipment	27	HTMF
19	C28	Machinery and equipment, nec	28	HTMF
20	C29	Motor vehicles, trailers and semi-trailers	29	HTMF
21	C30	Other transport equipment	30	HTMF
22	C31T33	Manufacturing nec; repair and installation of machinery and equipment	31, 32, 33	HTMF
23	D	Electricity, gas, steam and air conditioning supply	35	HTMF
24	E	Water supply; sewerage, waste management and remediation activities	36, 37, 38, 39	HTMF
25	F	Construction	41, 42, 43	HTMF
26	G	Wholesale and retail trade; repair of motor vehicles	45, 46, 47	HTMF
27	H49	Land transport and transport via pipelines	49	HTMF
28	H50	Water transport	50	HTMF

29	H51	Air transport	51	HTMF
30	H52	Warehousing and support activities for transportation	52	HTMF
31	H53	Postal and courier activities	53	HTMF
32	I	Accommodation and food service activities	55, 56	KIBS
33	J58T60	Publishing, audiovisual and broadcasting activities	58, 59, 60	KIBS
34	J61	Telecommunications	61	KIBS
35	J62_63	IT and other information services	62, 63	KIBS
36	K	Financial and insurance activities	64, 65, 66	KIBS
37	L	Real estate activities	68	KIBS
38	M	Professional, scientific and technical activities	69 to 75	KIBS
39	N	Administrative and support services	77 to 82	KIBS
40	O	Public administration and defence; compulsory social security	84	KIBS
41	P	Education	85	KIBS
42	Q	Human health and social work activities	86, 87, 88	KIBS
43	R	Arts, entertainment and recreation	90, 91, 92, 93	KIBS
44	S	Other service activities	94,95, 96	KIBS
45	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	97, 98	KIBS

Source: Author's own adaptation based on OECD (2023) OECD Inter-Country Input-Output Tables, Galindo-Rueda & Verger (2016), and Bontadini (2021).

Table 3: Classification of economic activity based on R&D intensity

	Manufacturing	R&D as % of GVA[2]	Non-manufacturing	R&D as % of GVA[2]
High R&D intensity industries	303[1]: Air and spacecraft and related machinery	31.69	72: Scientific research and development	30.39
	21: Pharmaceuticals	27.98	582[1]: Software publishing	28.94
	26: Computer, electronic and optical products	24.05		
Medium-high R&D intensity industries	252[1]: Weapons and ammunition	18.87	62-63: IT and other information services	5.92
	29: Motor vehicles, trailers and semi-trailers	15.36		
	325[1]: Medical and dental instruments	9.29		
	28: Machinery and equipment n.e.c.	7.89		
	20: Chemicals and chemical products	6.52		
	27: Electrical equipment	6.22		
	30X[1]: Railroad, military vehicles and transport n.e.c. (ISIC 302, 304 and 309)	5.72		
Medium R&D intensity industries	22: Rubber and plastic products	3.58		
	301[1]: Building of ships and boats	2.99		
	32X[1]: Other manufacturing except medical and dental instruments (ISIC 32 less 325)	2.85		
	23: Other non-metallic mineral products	2.24		
	24: Basic metals	2.07		
	33: Repair and installation of machinery and equipment	1.93		
Medium-low R&D intensity industries	13: Textiles	1.73	69-75X: Professional, scientific and technical activities except scientific R&D (ISIC 69 to 75 less 72)	1.76
	15: Leather and related products	1.65	61: Telecommunications	1.45
	17: Paper and paper products	1.58	05-09: Mining and quarrying	0.80
	10-12: Food products, beverages and tobacco	1.44	581[1]: Publishing of books and periodicals	0.57
	14: Wearing apparel	1.40		
	25X[1]: Fabricated metal products except weapons and ammunition (ISIC 25 less 252)	1.19		
	19: Coke and refined petroleum products	1.17		
	31: Furniture	1.17		
	16: Wood and products of wood and cork	0.70		
	18: Printing and reproduction of recorded media	0.67		
Low R&D intensity industries			64-66: Financial and insurance activities	0.38
			35-39: Electricity, gas and water supply, waste management and remediation	0.35
			59-60: Audiovisual and broadcasting activities	0.32
			45-47: Wholesale and retail trade	0.28
			01-03: Agriculture, forestry and fishing	0.27
			41-43: Construction	0.21
			77-82: Administrative and support service activities	0.18
			90-99: Arts, entertainment, repair of household goods and other services	0.11
			49-53: Transportation and storage	0.08
			55-56: Accommodation and food service activities	0.02
			68: Real estate activities	0.01

Source: Galindo-Rueda & Verger (2016)

Table 3: Macro-level sector groupings

Sector groups	Included sectors	ISIC codes
KIBS	Computer and related activities	C72
	R&D and other business services.	C73T74
NR	Agriculture, hunting, forestry and fishing	C01T05
	Mining and quarrying.	C10T14
LTMF	Food products, beverages, and tobacco	C15T16
	Textiles, textile products, leather, and footwear	C17T19
	Wood, products of wood, and cork	C20
	Pulp, paper, and paper products	C21T22
	Coke, refined petrol products, and nuclear fuel	C23
	Rubber and plastic products	C25
	Other nonmetallic mineral products	C26
	Basic metals	C27
	Fabricated metal products	C28
	Manufacturing NEC and recycling	C36T37
HTMF	Chemicals and chemical products	C24
	Machinery and equipment	C29
	Computer, electric, and optical equipment	C30T33X
	Electrical machinery and apparatus	C31
	Motor vehicles, trailers, and semitrailers	C34
	Other transport equipment	C35

Source: Bontadini (2021)

Appendix B

Table 5: Network indicators for select economies in the global aggregated network in 2000 and 2020, with averages for each country in the primary row.

	Degree													
	Out		In		W-Out		W-In		Closeness		Betweenness		Eigencentrality	
	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020
CHN	**65**	**183.25**	**70.25**	**182.5**	**459429.915**	**2854050.934**	**470011.137**	**2924430.205**	**0.518**	**0.727**	**353.153**	**2564.296**	**0.537**	**0.883**
HTMF	83	237	76	203	615942.022	3021138.812	758178.087	5515493.881	0.534	0.812	245.189	3746.195	0.591	0.953
KIBS	32	144	53	170	210474.767	2042180.255	238179.518	1634185.879	0.478	0.652	27.942	876.111	0.456	0.881
LTMF	113	256	92	206	881024.647	5177136.791	799384.215	3799679.038	0.577	0.853	1098.958	5081.152	0.622	0.935
NR	32	96	60	151	130278.224	1175747.877	84302.728	748362.021	0.484	0.589	40.524	553.727	0.480	0.762
DEU	**114.75**	**165.75**	**113.5**	**155.25**	**401587.342**	**476080.885**	**402462.384**	**460357.099**	**0.582**	**0.698**	**3047.657**	**1473.225**	**0.754**	**0.798**
HTMF	161	229	134	170	593135.822	788875.437	721873.655	860225.360	0.641	0.795	4543.599	1820.426	0.864	0.864
KIBS	95	157	105	152	615038.646	609864.795	495599.090	450034.012	0.549	0.670	903.830	970.843	0.769	0.810
LTMF	169	227	167	210	373955.671	467646.023	374367.583	497850.410	0.654	0.789	6709.897	3017.472	0.941	0.952
NR	34	50	48	89	24219.229	37937.287	18009.208	33318.614	0.482	0.538	33.303	84.158	0.442	0.567
FRA	**96.5**	**148.75**	**96.5**	**135**	**269206.548**	**260425.123**	**273619.385**	**273202.653**	**0.557**	**0.665**	**1340.490**	**860.494**	**0.684**	**0.719**
HTMF	140	211	113	154	375724.711	393667.943	427137.366	490346.145	0.612	0.760	2202.521	1413.236	0.801	0.801
KIBS	74	125	83	135	423596.426	380247.896	377525.314	303264.056	0.529	0.627	929.030	683.876	0.672	0.738
LTMF	126	187	131	163	234663.352	219135.904	254809.430	256638.184	0.589	0.714	1960.029	1200.141	0.801	0.808
NR	46	72	59	88	42841.703	48648.749	35005.429	42562.227	0.496	0.559	270.381	144.722	0.461	0.529
GBR	**99.5**	**128.5**	**98**	**129.5**	**309557.019**	**239562.752**	**308041.677**	**233026.756**	**0.557**	**0.636**	**1291.339**	**692.560**	**0.681**	**0.690**
HTMF	122	160	116	145	489665.257	336109.100	500801.603	353058.699	0.577	0.675	1212.442	553.470	0.821	0.790
KIBS	134	181	109	144	482628.874	428032.038	500238.590	377060.015	0.598	0.707	2005.815	1148.749	0.777	0.766
LTMF	117	146	121	165	250441.392	177640.935	216680.442	181252.117	0.579	0.655	1921.526	1045.606	0.748	0.785
NR	25	27	46	64	15492.551	16468.936	14446.075	20736.193	0.476	0.508	25.572	22.413	0.378	0.418
IND	**35.5**	**121**	**43.25**	**107**	**139650.838**	**329569.096**	**143239.043**	**346018.926**	**0.485**	**0.624**	**77.474**	**425.928**	**0.351**	**0.607**
HTMF	35	143	53	132	157778.966	369587.862	185956.949	551097.492	0.488	0.650	34.750	441.063	0.446	0.735
KIBS	33	129	36	110	66696.688	243135.853	111426.162	235660.011	0.473	0.629	20.021	553.419	0.295	0.620
LTMF	58	164	60	126	221161.363	452909.310	211250.414	536508.782	0.515	0.679	247.306	693.197	0.456	0.686
NR	16	48	24	60	112966.334	252643.359	64322.646	60809.418	0.465	0.538	7.821	16.036	0.206	0.388
IRL	**41.5**	**111**	**43.5**	**97.75**	**24093.581**	**76357.486**	**25152.950**	**74384.381**	**0.482**	**0.611**	**61.884**	**437.539**	**0.380**	**0.561**
HTMF	60	125	54	111	34169.454	60083.179	39030.397	66889.794	0.509	0.627	71.380	229.226	0.463	0.653
KIBS	43	149	58	113	39121.401	154281.400	39589.714	145351.661	0.479	0.659	120.084	855.755	0.485	0.612
LTMF	51	138	48	131	18710.703	85799.855	18945.047	79933.906	0.498	0.640	55.179	654.289	0.441	0.724
NR	12	32	14	36	4372.766	5265.511	3046.643	5362.161	0.442	0.520	0.891	10.885	0.131	0.252
ITA	**82.75**	**124.75**	**94.5**	**123.75**	**270019.777**	**236682.028**	**277537.102**	**240443.905**	**0.540**	**0.634**	**1671.803**	**736.633**	**0.657**	**0.670**
HTMF	129	192	120	138	415509.398	365400.608	478527.806	417831.816	0.598	0.722	1830.761	1177.656	0.833	0.771
KIBS	41	72	75	121	337488.003	306319.812	285454.815	215206.275	0.489	0.560	77.947	105.249	0.621	0.703
LTMF	131	187	146	174	299284.758	242578.411	330708.412	305386.452	0.604	0.717	4739.633	1582.015	0.841	0.828
NR	30	48	37	62	27796.951	32429.280	15457.373	23351.075	0.470	0.536	38.871	81.611	0.332	0.380
ROW	**121.25**	**177.75**	**122**	**207.5**	**301565.734**	**782444.769**	**266751.086**	**736069.879**	**0.592**	**0.710**	**3602.615**	**2805.375**	**0.816**	**0.943**
HTMF	108	205	121	204	317753.727	925353.248	318298.363	1050683.843	0.565	0.749	908.349	2844.386	0.840	0.939
KIBS	75	109	104	190	212671.866	442830.092	258735.424	766853.252	0.530	0.604	372.091	672.433	0.791	0.939
LTMF	185	240	165	233	567233.335	1427781.438	405035.589	885021.354	0.692	0.821	11106.289	5666.989	0.943	1.000
NR	117	157	98	203	108604.010	333814.297	84934.968	241721.066	0.582	0.666	2023.731	2037.690	0.691	0.894
USA	**152.25**	**194.75**	**147.75**	**187.25**	**2007297.133**	**1706932.951**	**2043140.697**	**1728096.963**	**0.624**	**0.735**	**4704.530**	**2409.057**	**0.900**	**0.882**
HTMF	184	224	151	197	2377879.077	2511131.905	2615005.975	2863914.967	0.670	0.783	5325.295	2734.521	0.950	0.938
KIBS	166	216	168	207	3715060.667	2574095.136	3720848.460	2286546.429	0.639	0.769	6373.398	3469.262	1.000	0.963
LTMF	168	213	173	211	1750133.996	1493641.858	1694435.300	1560607.502	0.639	0.762	5945.259	2759.374	0.975	0.941
NR	91	126	99	134	186114.794	248862.903	142273.052	201318.955	0.548	0.624	1174.168	673.069	0.676	0.686

Source: Calculations generated from Gephi?

Table 6: Network indicators for select economies in the EU-UK aggregated network in 2000 and 2020, with averages for each country in the primary row.

	Degree													
	Out		In		W-Out		W-In		Closeness		Betweenness		Eigenvector	
	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020
DEU	**55.5**	**76.5**	**54**	**73.75**	**380810.756**	**808081.113**	**380193.558**	**803442.322**	**0.641**	**0.773**	**748.642**	**451.910**	**0.858**	**0.889**
HTMF	74	98	64	81	546913.365	1314386.352	682223.118	1436126.512	0.728	0.888	1507.686	552.584	0.933	0.950
KIBS	48	78	55	74	607727.551	1320212.327	480170.350	1149379.138	0.594	0.760	334.596	410.962	0.914	0.902
LTMF	77	96	67	90	344697.694	557673.520	340929.474	594094.070	0.738	0.867	1137.387	800.056	1.000	1.000
NR	23	34	30	50	23904.415	40052.252	17451.291	34169.567	0.502	0.578	14.900	44.038	0.585	0.703
FRA	**49**	**65.5**	**44**	**64**	**258293.624**	**491302.220**	**258754.694**	**505295.047**	**0.598**	**0.708**	**234.189**	**138.795**	**0.772**	**0.819**
HTMF	65	84	53	73	352760.276	663483.677	403895.291	772763.616	0.665	0.799	579.486	236.926	0.880	0.895
KIBS	37	58	44	65	417074.396	972289.440	367699.437	884831.040	0.552	0.669	95.580	92.512	0.789	0.855
LTMF	63	78	49	70	221339.485	267626.731	229805.746	308047.163	0.656	0.760	236.478	179.225	0.848	0.867
NR	31	42	30	48	42000.339	61809.034	33618.301	55538.371	0.519	0.603	25.213	46.516	0.573	0.658
GBR	**45.5**	**57.75**	**41.5**	**58.25**	**292425.564**	**471238.635**	**290181.514**	**465175.056**	**0.584**	**0.677**	**332.558**	**146.960**	**0.707**	**0.745**
HTMF	54	72	51	68	464953.334	724956.360	468449.266	723915.196	0.608	0.730	362.839	144.889	0.831	0.844
KIBS	56	74	46	64	457787.992	911763.647	477410.305	895014.870	0.618	0.740	370.414	230.110	0.799	0.825
LTMF	56	66	44	68	231823.602	229231.531	201022.298	219396.387	0.626	0.703	585.512	210.404	0.726	0.821
NR	16	19	25	33	15137.329	19003.004	13844.187	22373.770	0.484	0.536	11.468	2.437	0.472	0.491
IRL	**24.5**	**49.75**	**24.25**	**48.5**	**22471.344**	**67173.185**	**22278.663**	**62808.942**	**0.506**	**0.644**	**21.469**	**93.395**	**0.457**	**0.659**
HTMF	34	56	27	55	31206.840	59882.357	33924.936	68690.819	0.546	0.661	28.035	69.255	0.523	0.730
KIBS	24	72	30	52	37526.185	137570.212	34691.648	112204.462	0.502	0.735	25.192	203.471	0.566	0.695
LTMF	32	56	32	60	16868.060	67018.454	17569.838	65243.381	0.530	0.657	32.169	100.180	0.608	0.799
NR	8	15	8	27	4284.292	4221.717	2928.231	5097.104	0.448	0.524	0.479	0.674	0.129	0.411
ITA	**43.75**	**63.25**	**46.25**	**60**	**261503.114**	**410787.021**	**264941.687**	**415151.149**	**0.589**	**0.709**	**521.130**	**260.473**	**0.759**	**0.758**
HTMF	64	90	58	69	397561.143	650847.485	461454.750	723068.000	0.677	0.828	631.304	426.880	0.924	0.863
KIBS	26	38	38	58	336044.805	600691.576	280266.197	501287.601	0.512	0.594	22.843	27.743	0.717	0.785
LTMF	62	89	63	76	284838.540	354877.330	302857.299	408980.378	0.669	0.828	1413.077	539.869	0.898	0.886
NR	23	36	26	37	27567.967	36731.695	15188.500	27268.619	0.498	0.584	17.295	47.399	0.496	0.498

Source: Calculations generated from Gephi

Appendix C

Figure 12: EU-UK value-added network in 2000 (a) and 2020 (b) scaled by weighted out-degree

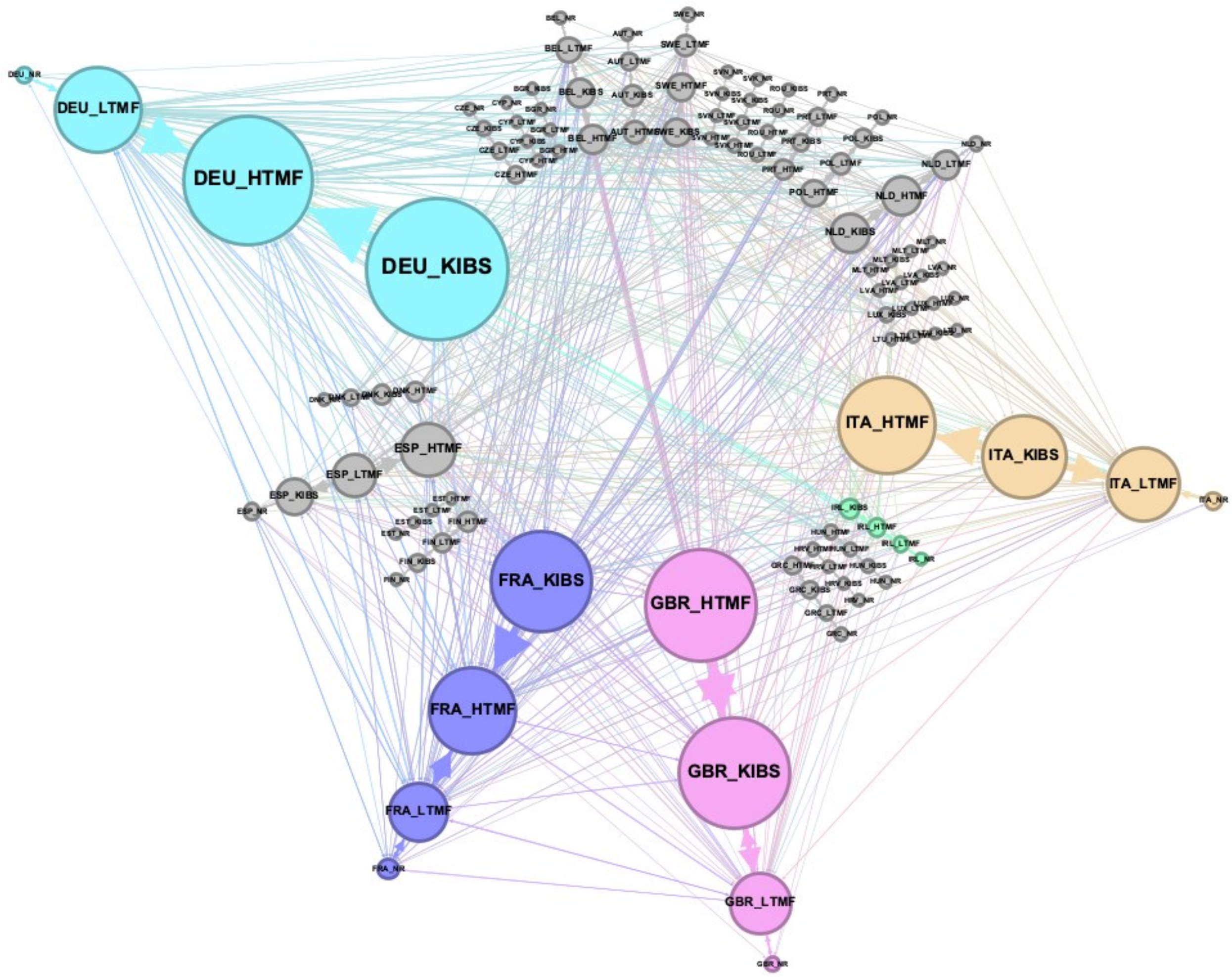

Figure 12a: EU-UK Value-Added Contributions Network in 2000

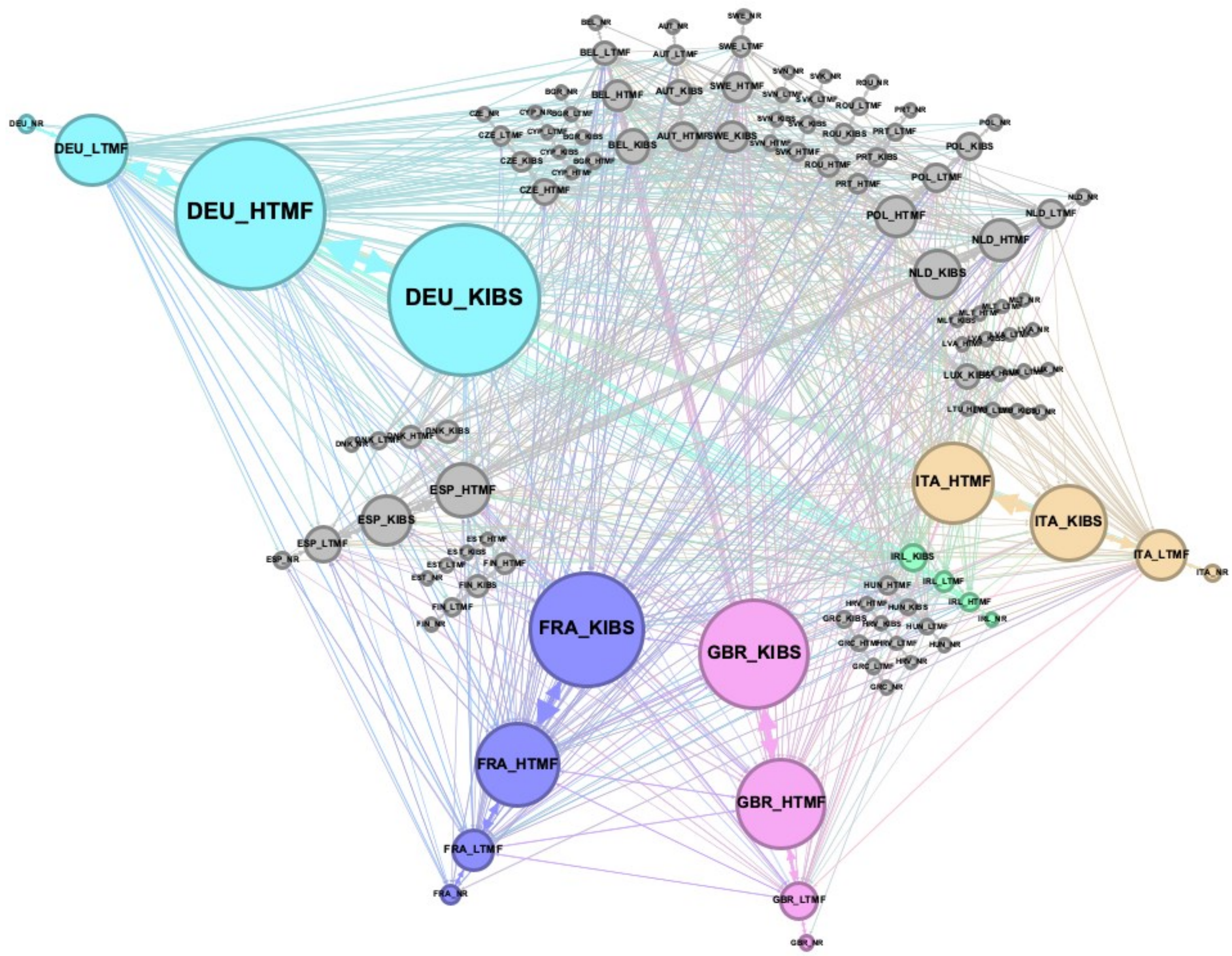

Figure 12b: EU-UK Value-Added Contributions Network in 2020

Source: Author’s own rendering.

Appendix D

The method for calculating the original Export Similarity Index is drawn from Finger and Kreinin (1979) and Wang and Liu (2015). The ESI can be calculated as follows,

$$S(ab,c) = \left\{\sum_i \text{Minimum}\,[X_i(ac), X_i(bc)]\right\} \times 100$$

in which $X_i(ac)$ is the share of exports in product or sector i from country a to country c.

In order to account for value-added flows, rather than gross exports, a similar adaptation method to the RCA indices in the methodology section 4. 3. is used to create the Value-Added Similarity Index (VASI),

$$S(ab,c) = \left\{\sum_i \text{Minimum}\,[VA_i(ac), VA_i(bc)]\right\} \times 100$$

in which $VA_i(ac)$ is the share of value-added contributions in sector group i from country a to country c. The indices in each sector group are then aggregated to get the total VASI for the value-added contributions from countries a and b to the market in country c.