STRUCTURAL CHARACTERISTICS OF THE OECD INTERNATIONAL TRADE NETWORK AND THEIR ASSOCIATION WITH ECONOMIC DEVELOPMENT

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Abstract

Trade interactions between states, through the exchange of resources and goods and their concomitant social interactions, contribute to enhancing the productive process, spreading technology, and promoting social, institutional, and diplomatic engagements, serving as a long-standing pillar of economic, regional, and cultural development. In this context, this paper examines the economic interdependence created by international trade in the modern global economy, exploring the emerging economic and spatial structures of global trade flows using complex network analysis. This paper focuses on trade interactions and spatial connections among 42 OECD countries, analyzing the structural mechanisms through which each country participates in international trade across different levels of transaction intensity, each representing different scales of economies. Assuming a positive correlation between the intensity of trade exchanges and national economic development, and that the degree of integration into global trade networks contributes to the strengthening of economies of scale, this study calculates network topology and centrality measures, conducting analysis at three levels of network structure: microscopic (local, node-level), mesoscopic (community-level), and macroscopic (global, network-wide). Each level provides distinct perspectives and insights into how interactions among countries shape the global economic landscape. The findings highlight important aspects of strategic cooperation and potential risks in international trade, emphasizing that international trade and economic interdependence, while supporting global development and prosperity, can also act as a source of economic vulnerability during global financial crises.

Keywords: Economic Interdependence; International Trade; Economies of Scale; Interaction Networks; Global Economy; Complex Network Analysis.
JEL Classification: F14, O19, R12, R15

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1. Introduction

International trade has long been one of the key mechanisms shaping the global economic and geopolitical landscape (Tiebout, 1956, Krugman, 1994, Capello, 2015; Polyzos, 2019), as the modern globalized economy (Tsiotas and Ducruet, 2021; Tsiotas and Tselios, 2022) is characterized by increasingly dense connections between states and markets through complex flows (Tsiotas and Polyzos, 2018; Tsiotas, 2022; Tsiotas and Tselios, 2024) of resources, goods, services, and technological knowledge. While these connections enhance productivity and development potential (Polyzos, 2019, 2023), they also make national economies more vulnerable (Tsiotas and Katsaiti, 2025) to external shocks, as developments in one country can directly or indirectly affect the stability of the international economic system (Rodrigue et al., 2013).

Understanding and mapping global trade connections requires appropriate modeling tools (Tsiotas and Tselios, 2024) capable of capturing the structural characteristics and functional dynamics of modern markets. Complex network analysis (Barthelemy, 2011; Tsiotas and Polyzos, 2018; Tsiotas, 2019) provides a robust theoretical and analytical framework for studying international trade relations, allowing transactions to be represented as a network of nodes (countries) and edges (bilateral flows), incorporating concepts such as centrality, connectivity, and the distribution of economic strength (Newman, 2010). This approach is grounded in the fundamental economic principle that international trade is a driver of economic growth (Capello, 2015; Krugman and Wells, 2024), as well as in the theory of comparative advantage formulated by Ricardo (Ruffin, 2002; Polyzos, 2019) and North's export-base theory (1955), both highlighting the importance of outward orientation for exploiting productive capacities and expanding markets. Furthermore, Adam Smith's contributions to understanding specialization (Lee, 2011; Polyzos, 2019; Uzsayilir and Baycan, 2024) and the division of labor remain crucial (McNulty, 1973; Polyzos, 2019; Ruxho et al., 2023, Ruxho, 2024; Tsiotas and Kallioras, 2025), especially in the context of modern technological innovation and the economies of scale arising from participation in the global production system (Polyzos, 2019, 202).

Central to the theoretical foundation of this paper is the concept of economies of scale (Capello, 2015; Polyzos, 2016; Krugman and Wells, 2024), which refers to the advantages that arise in production from managing large volumes of resources and inputs, as increasing output reduces average costs and enhances competitiveness. In terms of international trade (Krugman, 1994), access to larger markets (Davis and Weinstein, 2003; Capello, 2015; Polyzos, 2019, 2023), the use of diversified resources (Wan et al., 2011; Polyzos, 2022), and the integration of technologically advanced processes (Romer, 1990, 1994) strengthen production optimization capabilities (Polyzos, 2019), creating conditions for spatial concentration of production and related economies of scale, in line with New Economic Geography (Krugman, 1991).

Assuming first, that there is a positive relationship between trade intensity and national (Ruxho, 2022; Chen et al., 2022; Ladias et al., 2023) economic development (Kaldor, 1964; Mo, 2010; Polyzos, 2019), second, that strong participation in trade networks (Saslavsky and Shepherd, 2014) contributes to achieving economies of scale, enhancing operational efficiency and national competitiveness (Polyzos, 2023), and third, that a country's centrality in the trade network (Smith and White, 1992; Fagiolo et al., 2010; Tsiotas and Tselios, 2024) provides a strategic advantage in the global allocation of resources (Mahutga, 2006; Polyzos, 2022), this paper empirically investigates trade and spatial connections among 42 OECD member countries, with 2021 as the reference year. The analysis is based on modeling a directed and weighted graph (Tsiotas and Polyzos, 2018), where countries are represented as nodes and trade flows as edges (Tsiotas and Ducruet, 2021; Tsiotas and Tselios, 2024), weighted according to transaction volume.

The global trade network (GTN) is analyzed at three spatial levels: microscopic (node-level), mesoscopic (community-level), and macroscopic (network-wide), to capture the multi-level structure of complex trade interactions. The ultimate goal of this paper is to provide a deeper understanding of the relationship between a country's position in the global trade network and its macroeconomic performance. Using network science tools (Newman, 2010; Barthelemy, 2011), this paper offers a detailed and realistic quantitative representation of globalization, combining the static perspective of macroeconomic equilibrium theories (Krugman and Wells, 2024) with the evolutionary perspective on trade volume variability (Tsiotas and Tselios, 2024) due to spatial and temporal heterogeneity.

This study contributes to the interdisciplinary connection between economic theory and spatial analysis through network science (Barabasi, 2013; Tsiotas and Polyzos, 2018; Tsiotas, 2019), providing empirical insights that can inform the design of more effective and adaptable development policies based on modeling. Examining the structure and functioning of global trade networks highlights critical aspects of economic interdependence, grounded in export-base theories (North, 1955; Tiebout, 1956) and subsequent theoretical developments (Polyzos, 2019, 2023), positioning networks as a valuable tool for understanding transformations in the global economy and for shaping strategies to enhance economic resilience.

2. Methods and Data

The computational approach followed in this paper is based on complex network analysis (Fortunato, 2010; Newman, 2010; Barthelemy, 2011; Tsiotas and Polyzos, 2018). The data used are multilayered and refer to international trade flows among 42 OECD member countries, primarily from the year 2021, except for Russia, for which 2020 data were used due to availability constraints. The full set of available trade flows was modeled as a weighted graph (GTN), geo-referenced for visualization purposes using the geographic coordinates of the capitals of the countries, obtained from Google Maps. In the weighted connectivity matrix of the GTN, with dimensions 42×42, each cell represents a directed trade flow from country i to country j, with the numerical value of the weight corresponding to the value of the trade transaction between the connected nodes.

The analysis of the GTN is carried out at three distinct levels: microscopic (Krugman and Wells, 2024), namely at the node-level; mesoscopic, referring to community-level (Fortunato, 2010); and macroscopic (Ladias and Stamatiou, 2006; Ladias et al., 2011; Krugman and Wells, 2024), corresponding to network-wide scale. At the microscopic level, the focus is on basic topological characteristics of the network using standard measures of network topology (Barthelemy, 2011; Newman, 2010; Tsiotas and Polyzos, 2018), such as node degree, closeness, clustering coefficient, and centrality indicators (Koschutzki et al., 2005) that assess the relative importance of each country within the overall trade network. At the mesoscopic level, the Louvain community detection algorithm (Blondel et al., 2008) is applied to reveal clusters of countries with strong trade cohesion. From an economic perspective (Krugman and Wells, 2024), this method enables the identification of regional trade “hubs” within the GTN that act as intermediaries in global commerce.

At the macroscopic level, topological properties of the entire network are calculated (Fortunato, 2010; Barthelemy, 2011; Newman, 2010; Tsiotas and Polyzos, 2018), including average degree, average path length, network density, mean clustering coefficient, and modularity. Methodologically, to highlight the most significant trade relations within the network, a successive selection procedure (filtering) of edges based on trade volume was followed. In addition to the full network, four subnetworks were constructed, including the top 50%, 25%, 10%, and 5% of trade flows by transaction value. This successive selection approach allows for isolating critical trade corridors and central nodes with key intermediary roles, enabling subsequent analysis of the contribution of different levels of economies of scale within the network.

In the final stage of this paper, the relationship between each country’s Gross Domestic Product (GDP) and its position in the trade network, based on topological characteristics, is examined. This relationship is studied quantitatively, through correlation analysis, and qualitatively, by observing patterns or deviations in network structure. This part of the analysis aims to uncover how the level of economic growth (as captured by GDP) relates to the degree of integration of each country within the international trade network.

3. Results and Discussion

3.1. Measures of Network Topology

The results of the analysis of the Global Trade Network (GTN) are presented in Table 1. Initially, it is observed that as the proportion of trade connections is reduced (from 100% to 5%), the network becomes less compact, sparser, and less cohesive. This is reflected in an increase in the average path length (from 1.065 at 100% of connections to 2.160 at 5% of connections) and in the network diameter (from 2 at 100% of connections to 4 at 5% of connections), while both the density and the clustering coefficient decreas.

Table 1: Measures of GTN’s network topology across different levels of link filtering

	Price				
Measure	Layer 100%	Layer 50%	Layer 25%	Layer 10%	Layer 5%
Nodes	**42**	**42**	40	34	26
Edges	**1610**	805	402	161	80
Connected Components	1	1	1	1	1
Max Degree	**82**	78	65	42	27

Min Degree	**60**	1	2	1	1
Average Degree	**38.333**	19.167	10.05	4.735	3.077
Average Weighted Degree	**291,014 bil.$**	284,433 bil.$	273,529 bil.$	260,991 bil.$	**272,336 bil.$**
Network Diameter	2	3	3	**4**	**4**
Graph Density	**0.935**	0.467	0.233	0.143	0.123
Modularity	0.273	0.259	0.267	**0.293**	0.254
Clustering Coefficient	0.117	0.131	**0.151**	0.145	0.082
Average Path Length	1.065	1.523	1.786	2.117	**2.160**

(Own elaboration)

From an interpretative perspective, the changes shown in Table 1 suggest the existence of a core of critical, strategically significant trade connections that confer relative resilience to the GTN (even in the 5% connections network), as the major economies maintain stable and strong trade ties among themselves. However, this also makes the network more vulnerable if any of these strategically important connections are disrupted. In terms of modularity, the highest value (0.293) in the GTN occurs at the 10% connections level, indicating that the network exhibits the greatest tendency to divide into distinct communities at this level. Nevertheless, modularity values remain moderate (in absolute terms), reflecting the overall cohesion of global trade connections, which do not easily allow the formation of regional markets. A holistic reading of the results in Table 1, which presents the fundamental topological characteristics of the GTN at different trade scales, leads to the conclusion that, through the successive removal of GTN connections, a highly interdependent core of the strongest economies emerges, representing the regulators of the global economy.

Next, in Figure 1a, the analysis of the weighted degree (the total sum of incoming and outgoing trade flows) highlights the central position of the United States (with total trade value exceeding $3.8 trillion) and China (closely following) as key nodes in the global trade network, with Germany next as the main European hub, registering trade activity exceeding $2.7 trillion both within the European Union and with external markets. The geographical distribution of the weighted degree also illustrates the strong interconnection of the EU, both among its member states (indicating a dimension of economic cohesion) and with Asia (Japan, South Korea) and Latin America (Brazil, Argentina), underlining the importance of geographical position as a pillar of trade and economic development.

Regarding the direction of trade flows, Figure 1b presents the results for the weighted in-degree of the GTN, focusing on countries that absorb the largest volumes of goods from other economies. As shown, the United States emerges as the largest global importer, followed by China and Germany, reflecting the participation profile described in the unweighted case of Figure 1a. The geographical distribution in Figure 1b indicates that import activity is concentrated primarily in developed economies, with Europe showing a particularly strong import profile both within and beyond the continent.

Concerning export flows, Figure 1c demonstrates that China records the highest export activity (with exports exceeding $1.67 trillion), confirming its role as a global production and export hub. The geographical dispersion of China's export connections spans all continents, with notable emphasis on Europe, North America, and Asia. Conversely, the United States also occupies a leading position, as does Germany, which exhibits strong export activity both within Europe and internationally. The spatial distribution in Figure 3 illustrates the uneven allocation of trade activity globally, highlighting the concentration of the largest transaction volumes among a small group of countries (as indicated by the US–China–EU trade triangle) and, secondarily, the presence of regional clusters such as intra-European interconnections.

Overall, the results of the analyses in Figures 1, 2, and 3 confirm the existence of a core of highly active trading countries (the US, China, Germany) and a periphery of less interconnected economies, emphasizing the center-periphery model (Ottaviano and Thisse, 2004) and geographic proximity (Polyzos, 2019, 2023) as key determinants of development dynamics based on trade advantage.

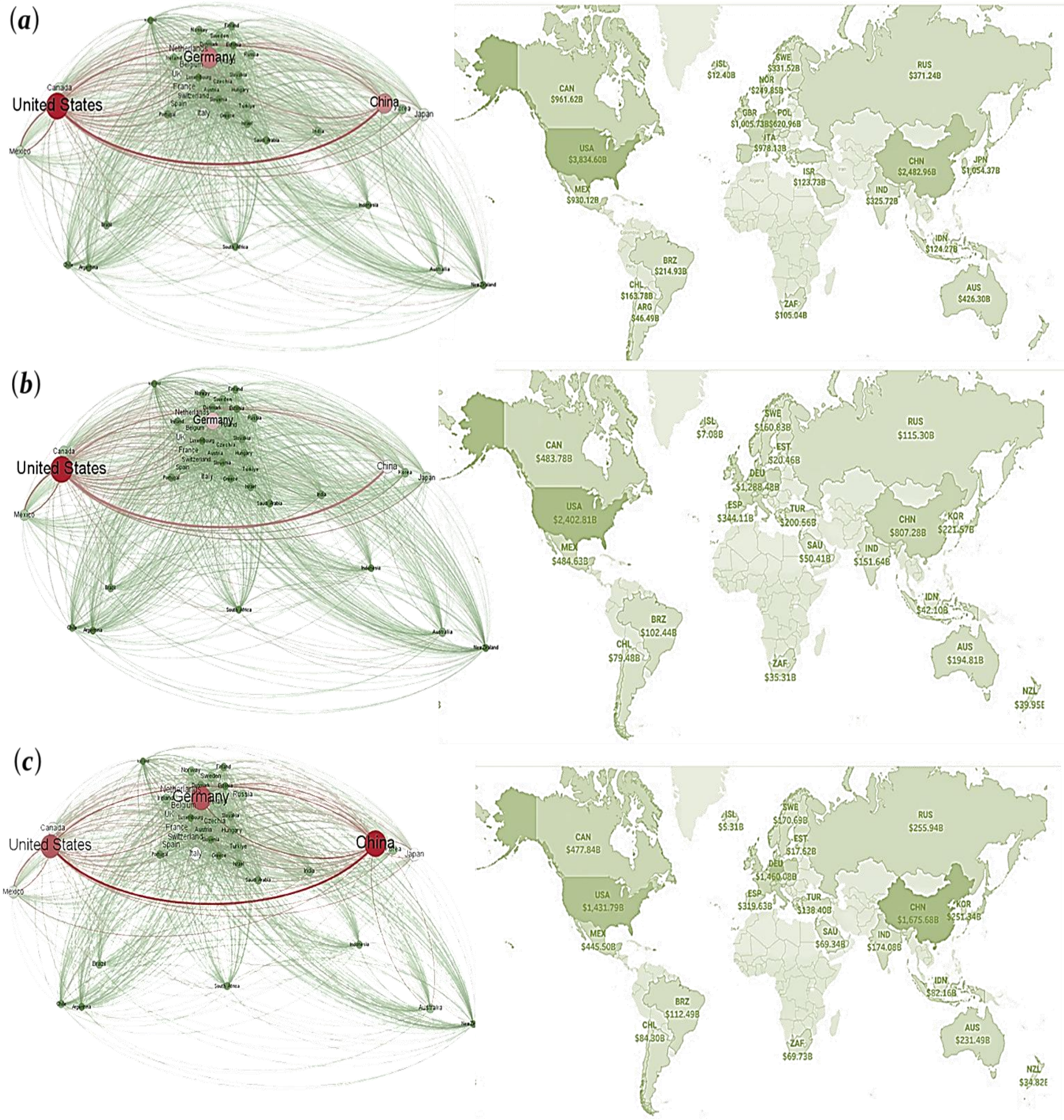

Figure 1. Spatial distribution of (a) the Weighted Degree, (b) the Weighted In-Degree, and (c) the Weighted Out-Degree in the 100% trade network (Source: own elaboration, based on OECD data, 2021).

Subsequently, the results of betweenness centrality calculations are presented in Figure 2. Betweenness centrality measures the extent to which a node (country) lies on the shortest paths between other countries, indicating the strategic importance of countries in facilitating international flows. The topology of the full network (Figure 2a) exhibits high connection density and cohesion, with the United States, China, Germany, and the United Kingdom occupying central positions.

In the 50% network (Figure 2b), geographical communities emerge, with Germany and the Netherlands functioning as central hubs within Europe, while the US, China, and Japan maintain less dense but significant connections. In the 25% network (Figure 2c), bridging functions are apparent, with Germany, the United States, and China distinguished as key intermediaries in global trade flows. In the 10% network (Figure 2d), the intermediary role of central nodes (Germany, the US, and China) becomes even more pronounced, with European flows increasingly internalized, in contrast to the more globalized connections of the US and China. Finally, in the 5% network, trade flows are concentrated among the main GTN hubs, highlighting the pivotal role of Germany and the United States.

Overall, the betweenness centrality analysis demonstrates the unequal distribution of influence among countries in global trade and underscores the central role and strategic positioning of core countries as intermediary nodes bridging regional trade networks.

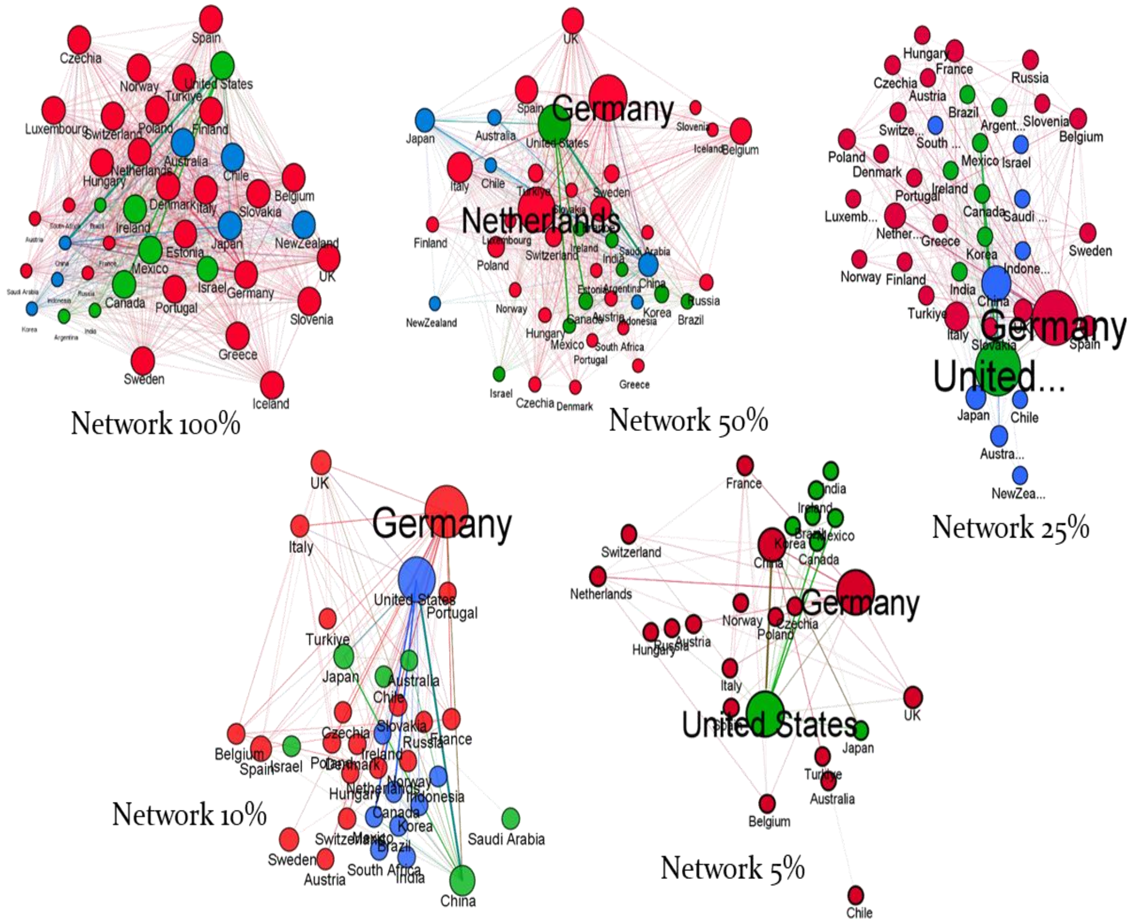

Figure 2. Distribution of betweenness centrality in the GTN across five distinct levels of analysis (from left to right): (a) 100%, (b) 50%, (c) 25%, (d) 10%, and (e) 5%, respectively. Color differentiation corresponds to grouping according to connection affinity (Source: own elaboration, Gephi).

3.2. Community detection analysis

Community detection in the GTN was performed at all levels of trade intensity (100%, 50%, 25%, 10%, 5%) using the Louvain algorithm (Blondel et al., 2008), which is based on the optimization of modularity, producing dense intra-community connections and sparse inter-community links. This approach groups countries that exhibit stronger trade relationships among themselves compared to the rest of the network. The results of the analysis are presented in Figure 3. In the case of the full network (100% of connections), three main communities are observed. The first spans a broad continental arc, including primarily European countries, Russia, and several Middle Eastern states; the second consists of countries from the Americas; and the third is formed in the Asia-Pacific region.

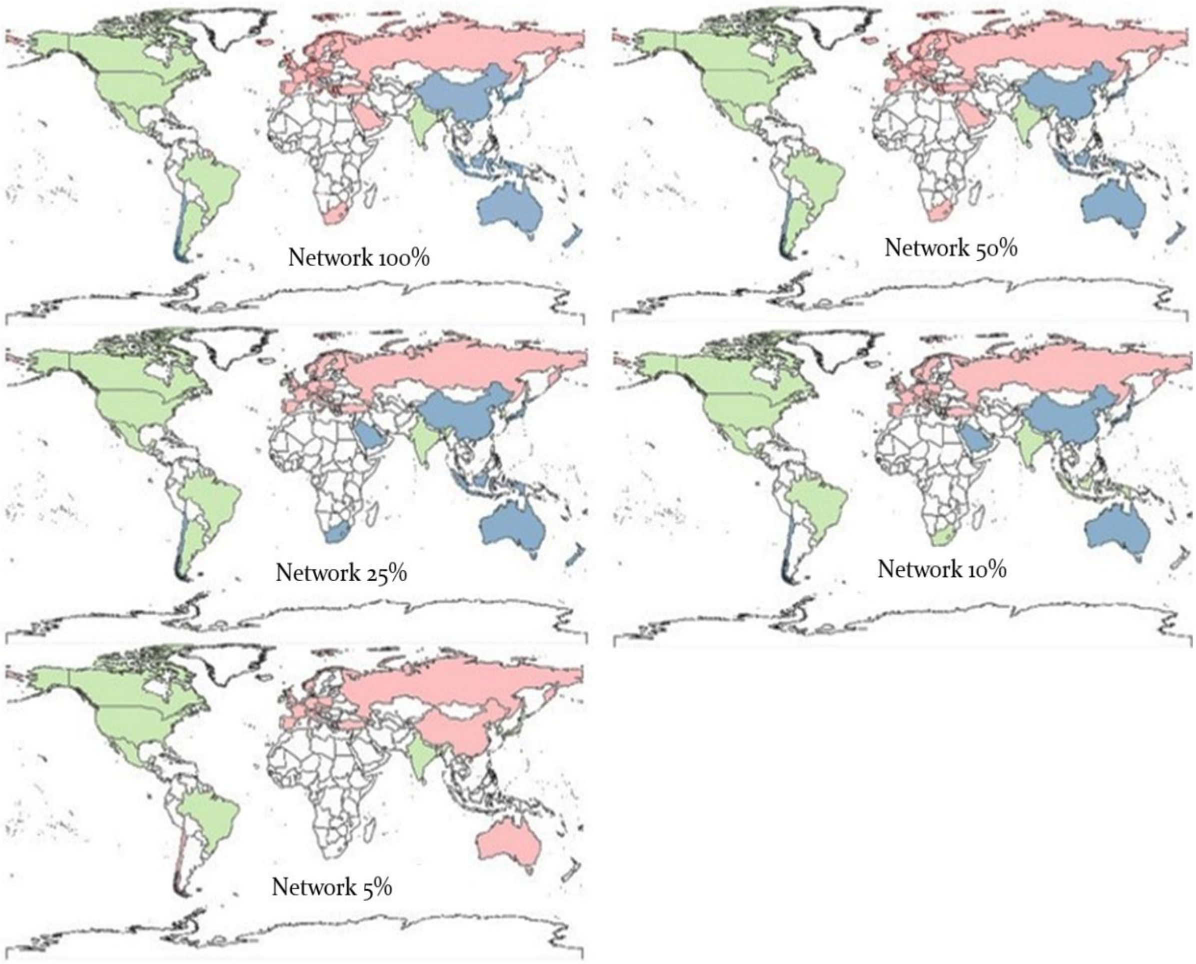

Figure 3. Spatial representation of communities in the global trade network (Source: own elaboration, based on OECD data, 2021).

Table 2: Communities in the GTN

Network	Community	Countries
100%	**Red**	Iceland, Norway, Sweden, Finland, Netherlands, Denmark, Germany, Estonia, UK, Belgium, Czechia, Poland, Russia, France, Luxembourg, Austria, Slovakia, Hungary, Portugal, Spain, Switzerland, Italy, Slovenia, Greece, Turkey, Saudi Arabia, South Africa
	Green	USA, Canada, Mexico, Brazil, Argentina, Ireland, Israel, India
	Blue	China, Korea, Japan, Australia, New Zealand, Indonesia, Chile
50%	**Red**	Iceland, Norway, Sweden, Finland, Netherlands, Denmark, Germany, Estonia, UK, Belgium, Czechia, Poland, Russia, France, Luxembourg, Austria, Slovakia, Hungary, Portugal, Spain, Switzerland, Italy, Slovenia, Greece, Turkey, Saudi Arabia, South Africa
	Green	USA, Canada, Mexico, Brazil, Argentina, Ireland, Israel, India, Korea
	Blue	China, Japan, Australia, New Zealand, Indonesia, Chile
25%	**Red**	Norway, Sweden, Finland, Netherlands, Denmark, Germany, UK, Belgium, Czechia, Poland, Russia, France, Luxembourg, Austria, Slovakia, Hungary, Portugal, Spain, Switzerland, Italy, Slovenia, Greece, Turkey
	Green	USA, Canada, Mexico, Brazil, Argentina, Ireland, India, Korea
	Blue	China, Japan, Australia, New Zealand, Indonesia, Chile, Israel, Saudi Arabia, South Africa
10%	**Red**	Norway, Sweden, Netherlands, Denmark, Germany, UK, Belgium, Czechia, Poland, Russia, France, Austria, Slovakia, Hungary, Portugal,

Network	Community	Countries
		Spain, Switzerland, Italy, Turkey
	Green	USA, Canada, Mexico, Brazil, Ireland, India, Korea, South Africa, Indonesia
	Blue	China, Japan, Australia, Chile, Israel, Saudi Arabia
5%	Red	Norway, Netherlands, Germany, UK, Belgium, Czechia, Poland, Russia, France, Austria, Hungary, Spain, Switzerland, Italy, Turkey, China, Australia, Chile
	Green	USA, Canada, Mexico, Brazil, Ireland, India, Korea, Japan

(Own elaboration)

Considering the overall community structure across the other available networks (with 50%, 25%, 10%, and 5% of connections), it is noted that the composition of communities remains generally stable (Table 2). However, individual groups gain greater internal cohesion, as some countries detach from their original clusters, forming more distinct aggregations. This highlights a shift from a globalized and dense trade web toward a polycentric system organized around geographic and economic regions. The maintenance of high internal connectivity within these regional markets, even when the total volume of trade relations is reduced, underscores the strategic importance of these connections in the context of global commerce.

3.3. Empirical analysis

In the empirical analysis of this section, the bivariate Pearson correlation coefficient was calculated (Norusis, 2011; Walpole et al., 2012) to detect the existence of a linear relationship between the level of economic growth (as represented by countries' GDP) and the network topology measures computed in the previous sections. The results of the correlation coefficient calculations are presented in the scatter plots of Figures 4 and 5 and in Table 2. From Figures 4 and 5, it emerges that the United States, China, and Germany stand out as economies with both high GDP and high connectivity within the GTN. The clear linearity observed in all cases of the weighted degree (total, in-degree, and out-degree) in Figures 4 and 5 confirms the research hypothesis of this study, suggesting that the intensity of a country's trade flows is positively associated with its level of economic growth.

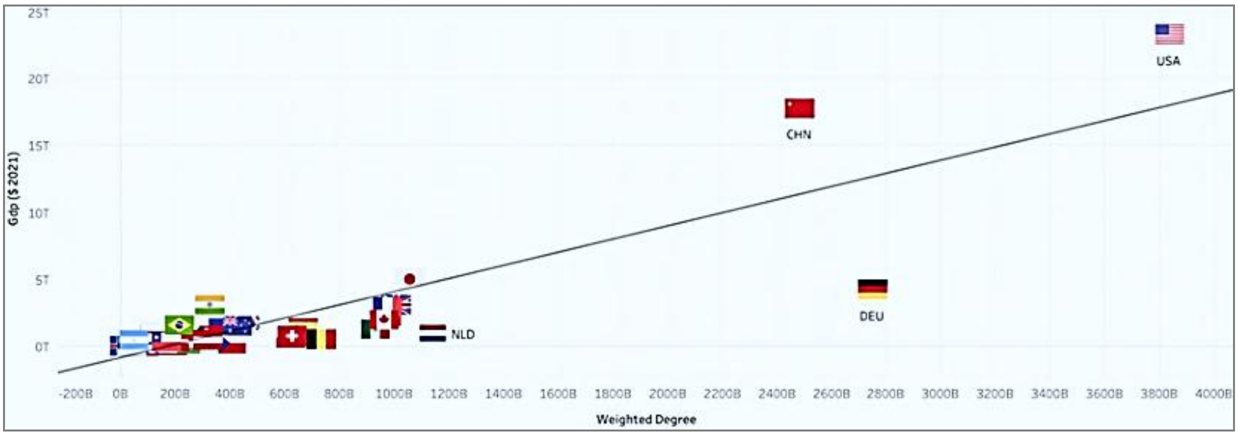

Figure 4. Scatter plot between total weighted degree and GDP for 100% of the network connections (Source: own elaboration, based on OECD data, 2021).

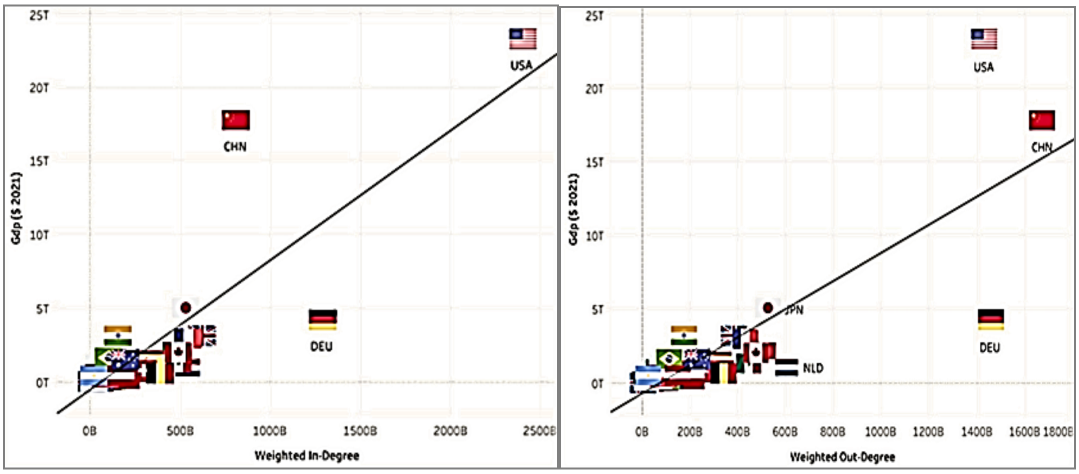

Figure 5. Scatter plot between weighted in-degree (left) and out-degree (right) and GDP (Source: own elaboration, based on OECD data, 2021).

Finally, the results in Table 2 indicate that the weighted degree (or strength) exhibits the highest positive linear correlation with GDP, even when the network connections are restricted to the top 5% of the strongest trade flows. Furthermore, closeness centrality and the clustering coefficient also show strong positive correlations, reinforcing the theoretical hypothesis that countries with high connectivity and centrality enjoy greater accessibility to markets, technologies, and economic resources, which in turn contribute to promoting their economic growth and development.

Table 3. Results of the correlation coefficient calculation between GDP and the GTN's topological measures.

y	**x**	**Link percentage**	**Correlation coefficient (r_{XY})**	**x**	**Link percentage**	**r_{XY}**
GDP	Weighted Degree	100%	0.866166266	Weighted Clustering Coefficient	100%	0.10243
		50%	0.865883941		50%	0.27331
		25%	0.868659312		25%	0.28495
		10%	0.876204885		10%	0.67225
		5%	0.885510023		5%	0.16296
	Weighted In-Degree	100%	0.842766872	Betweenness Centrality	100%	0.1248
		50%	0.842720001		50%	0.49367
		25%	0.84332556		25%	0.76276
		10%	0.844810038		10%	0.66339
		5%	0.846392935		5%	0.77706
	Weighted Out-Degree	100%	0.82943957	Closeness Centrality	100%	0.12394
		50%	0.829214086		50%	0.44318
		25%	0.830065058		25%	0.21357
		10%	0.840848381		10%	0.53236
		5%	0.84088168		5%	0.25439

(Own elaboration)

Overall, the empirical analysis supports the research hypothesis that strong participation in the global trade network constitutes a fundamental component of economic prosperity, highlighting the intensity of external trade connections as a driver of economic growth.

4. Conclusions

This study highlighted the complex nature and multifaceted structural, functional, and spatial characteristics of the international trade system interconnecting 42 OECD member countries (GTN), using complex network analysis. The results suggest that the GTN exhibits a hierarchical structure, with a few highly connected central nodes configuring a core substrate of global flows. The analysis verified the correlation between a country's (node's) functional position within the network and its trade volume, as well as its GDP, supporting the export-base hypothesis and confirming that international trade integration constitutes a critical driver of economic growth.

Furthermore, examining the GTN at different trade volume levels revealed structural trends describing the transition from functional cohesion to concentrated and polar forms, confirming the findings of a recent study by Tsiotas and Kallioras (2025) that increasing the (geographical, functional, administrative) scale of networks leads to more distinct structures, reflecting polar dynamics. Within the GTN, the United States, China, and Germany emerged as central structural pillars of the network and key shapers of trade flow criticality and system stability.

From a geographical perspective, the cartographic depiction of GTN communities revealed the formation of cohesive trade markets, generally characterized by strong internal connectivity and geographical clustering, consistent with empirical observations that community detection in spatial networks is heavily constrained by spatial proximity (Barthelemy, 2011; Tsiotas and Polyzos, 2018). However, the networks also feature strong intercontinental connections, indicating the overcoming of geographical constraints and the emergence of economies of scale with increasing geographic distance and the rise of global trade hubs, in line with theoretical approaches in economic geography (Krugman, 1991).

From a policy perspective, the results highlight the need to strengthen trade connections and multilateral cooperation within the regional markets identified by the analysis, adopting economic and regional development policies (Polyzos, 2019, 2023) that promote the diversification of trade partners (e.g., fostering interregional alliances, targeted support for low-connectivity countries), investments in connectivity infrastructure, and the advancement of interoperability.

Overall, the study demonstrated the usefulness of complex network analysis as a methodological tool for modeling and interpreting the economic-geographical space, suggesting directions for further research through dynamic and comparative approaches, integrating time series, transportation networks, technological flows, and disruption scenarios.

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