Original Paper

Are More Trade Partners Necessarily More Important? — An Assessment of International Trade Networks Based on Multidimensional Network Centrality

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Abstract

In the evolving global economic landscape, international trade is indispensable to China, just as China is indispensable to the international trading system. As global trade relations become increasingly networked, traditional approaches that measure a country's status solely by trade volume or the number of trade partners face significant limitations. To capture countries' structural roles in the global trade network more comprehensively, this paper constructs a bilateral trade network of 100 countries from 2006 to 2021 using a modified gravity model and systematically evaluates its structural characteristics and community dynamics through social network analysis (SNA).

Building on this framework, we introduce five centrality measures—degree, eigenvector, closeness, betweenness, and PageRank—to conduct a multidimensional radar-chart assessment of national network positions, thereby identifying structurally pivotal countries that may have relatively few direct connections. The results reveal that: (1) countries with a large number of trade partners are not necessarily key players in the network; (2) countries with high structural centrality often serve as bridging hubs that shape network stability and transmission pathways; (3) some traditional economic powers exhibit marginalization in structural indicators; and (4) certain small or emerging economies embed themselves into the global core through transit advantages or institutional attractiveness.

This study challenges the conventional belief that "more connections imply greater influence" and underscores the importance of multidimensional centrality in identifying key participants in the international trade network. The findings provide a structural perspective and policy implications for optimizing national trade strategies and regional cooperation frameworks.

Keywords

Gravity model, social network analysis, centrality measures, trade network, radar chart

1. Introduction

1.1 Research Background and Significance

1.1.1 Research Background and Motivation

In the context of deepening globalization, the international trade network—an essential vehicle of the world economy—has become increasingly complex and dynamically evolving. Conventional wisdom generally assumes that a country's importance in the international trade system is proportional to the number of its trade partners; in other words, "the higher the degree centrality, the more important the country." However, through a systematic analysis of trade networks among 100 countries from 2006 to 2021, this study finds that while degree centrality reflects the breadth of a country's external linkages, it fails to fully capture its structural position in the global trade system. Many countries ranking high in degree centrality do not necessarily hold advantages in terms of path control, strategic connectivity, or diffusion capacity. Instead, those countries with higher scores across multiple dimensions of network centrality and stronger composite rankings in radar-chart evaluations emerge as the true pivotal nodes shaping the evolution of the trade network.

Therefore, this paper centers on the proposition that "a higher degree centrality does not necessarily imply greater importance." It seeks to transcend the single-dimensional paradigm of evaluating nodes solely by the number of connections and emphasizes the integration of multiple centrality indicators to identify countries that play critical roles as bridges, hubs, or amplifiers in the global trade network. This perspective provides not only theoretical insights for academic research but also more scientifically grounded and structurally informed support for policymaking.

Theoretical Significance: By employing social network analysis, this paper constructs a multidimensional radar chart of network centrality to systematically identify the true structural positions of key countries. It extends the conceptual framework of international trade research by deepening the understanding of structural embeddedness and functional centrality.

Practical Significance: Accurately identifying countries with strategic connectivity positions helps China move beyond the traditional logic of major powers when formulating international cooperation strategies. It enables the optimization of trade network structures, enhances resilience against external shocks, and promotes diversification and rationalization of trade arrangements.

1.1.2 Research Objectives

This study aims to address three core questions:

● Does having more trade partners necessarily imply greater importance within the network? Does degree centrality lead to structural misjudgments of being "high in number but weak in influence"?

● Which countries truly occupy central positions in multidimensional centrality assessments, and what common characteristics or economic backgrounds do they share?

● How can a scientifically rigorous evaluation system be constructed to identify key countries in the trade network?

By employing network visualization, integrating multiple centrality measures through radar charts, and analyzing community evolution and structural patterns, this paper seeks to establish a systematic and structurally robust analytical framework to reassess "who the real key participants are in the international trade network."

1.2 Research Content

Since the initiation of reform and opening-up, China has achieved remarkable accomplishments in international trade, becoming both a major participant and a key driver of global trade. To gain a clearer understanding of China's position in the international trade network, this study raises several central questions. Using bilateral trade data of 100 countries from 2006 to 2021, we construct international trade networks based on a modified gravity model and employ social network analysis (SNA) to conduct research at three levels:

Analysis of Network Structural Evolution: Depict the development trend of the international trade network from a single-core to a multipolar structure with increasing coupling, and identify structural turning points such as the 2008 global financial crisis and the 2020 pandemic.

Community Division and Functional Zone Identification: Apply the modularity algorithm to detect "trade alliance circles" at different time points, examining the trend of regional bloc formation and the persistence of structural stickiness.

Multidimensional Comparison of Centrality Measures: Construct a radar-chart system based on five centrality indicators (degree, eigenvector, betweenness, closeness, and PageRank) to compare the structural positions of countries and to analyze the deeper economic logic behind the proposition that "a wider range of connections ≠ higher importance."

To address these issues, this study first constructs international trade networks using a modified gravity model with bilateral trade data from 2006 to 2021. Next, the structural evolution and community dynamics of the trade network are examined through SNA to explore the changing positions of countries and their community affiliations. Finally, the study provides an economic interpretation of the findings.

2. Literature Review

In the context of a highly interconnected global economy, international trade networks have become an important tool for uncovering the economic relations and influence patterns among nations. Traditional trade research has focused on bilateral trade flows, comparative advantage, and trade structures. However, in recent years, with the advancement of complex network theory and social network analysis (SNA), scholarly attention has gradually shifted from a "volume-oriented" perspective to a "structure-oriented" one, examining the structural positions and functional roles of countries in the global trade system through a network lens.

(1) Construction and Evolution of International Trade Networks

The construction of trade relation networks between countries can be traced back to the gravity model framework proposed by Tinbergen (1962) and Pöyhönen (1963), which posits that bilateral trade

volumes are positively influenced by the size of economies and negatively affected by geographical distance. This model laid the theoretical foundation for subsequent weighted network construction. Anderson (2011) provided a systematic review of the gravity model's development in international trade and highlighted it as one of the most successful empirical tools in international economics. With the application of network methods, researchers have often relied on SNA techniques to analyze overall structures, community divisions, and node centrality in trade networks. Serrano et al. (2007) found that the global trade network exhibits a "core–periphery" structure, where a small number of countries dominate global trade flows. Fagiolo et al. (2010), using an undirected weighted network model, revealed the strong small-world properties and clustering evolution of trade networks. More recently, some scholars have incorporated geographic and institutional factors to analyze community evolution and structural stability (e.g., Liu, 2021).

(2) Centrality Measures and the Identification of Key Countries

Centrality analysis has become one of the most crucial methods in trade network research, with common measures including degree, betweenness, eigenvector, closeness, and PageRank centrality. However, much of the existing literature remains limited to analyzing these measures in isolation, lacking an integrated evaluative framework. For example, some studies equate high degree centrality with strong trade influence, overlooking the functional differences of countries within the network. Yet countries with relatively low degrees but high PageRank or betweenness centrality may, in fact, serve as pivotal transmission nodes in the global trade system.

(3) Research Gap and Contribution of This Study

While existing research has established a solid foundation in constructing trade networks, analyzing community structures, and applying centrality measures, several gaps remain:

●   Many studies rely on a "single-indicator" approach, which fails to capture the overall network position of countries;

●   The distinction between "number of connections" and "structural importance" is often neglected, leading to possible misidentification of network core countries;

●   There is a lack of integrative frameworks and visualization tools for multidimensional centrality assessment.

To address these limitations, this paper introduces a novel five-dimensional radar-chart approach to centrality analysis, systematically integrating multiple structural indicators to identify key participants in the international trade network from a multidimensional perspective. This method avoids the biases inherent in single-indicator analyses and provides a more nuanced view of network dynamics. Comparative analysis further reveals that some seemingly peripheral small countries play disproportionately significant roles in path control and bridging functions, thereby challenging the conventional wisdom that "the more trade partners, the greater the importance."

3. Data Sources and Network Construction

3.1 Data Sources and Processing

To ensure the robustness of the analysis and the representativeness of the results, this study selected as many countries as possible with a reasonable time span, while maintaining consistency and completeness of the dataset. Ultimately, 100 countries (with GDP exceeding USD 930 million) were chosen as the research sample, covering the period from 2006 to 2021.

In applying the gravity model, we employed several economic variables, including net exports of goods and services, GDP per capita, GDP, population, and geographical distance. Net exports of goods and services were calculated as the difference between exports and imports. Data on GDP per capita, GDP, population, and trade flows were obtained from the **World Bank Database** [Source: https://data.worldbank.org.cn/], while geographical distance (measured as the distance between capital cities) was taken from the **CEPII GeoDist dataset** [Source: http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp].

For missing values, we adopted the following strategy: countries with few missing entries were filled with the previous year's data; for countries with more missing data, additional information was collected from official online sources whenever possible. When gaps remained, average values were used to complete the dataset.

3.2 Construction of the International Trade Network

The determination of trade relationships is a key element in trade analysis. In this study, we adopt the gravity model to identify bilateral trade relationships. Following the seminal works of Tinbergen (1962) and Poyhonen (1963), we apply the gravity model to the construction of the world trade network. To further enhance robustness, we employ the revised gravity model proposed by Xueqiang Ji et al. (2023), among others. The modified gravity model used in this paper is expressed as:

$$y_{ij} = k_{ij} \frac{\sqrt[3]{P_i N_i G_i} \sqrt[3]{P_j N_j G_j}}{\left(\frac{D_{ij}}{gc_i - gc_j}\right)^2}, \quad k_{ij} = \frac{N_i}{N_i + N_j}, \tag{1}$$

where y_{ij} represents the trade linkage strength between country i and country j; G_i and G_j denote the GDP of country i and country j, respectively; N_i and N_j indicate the net exports of the respective countries; P_i and P_j represent the total populations; and k_{ij} measures the relative contribution of country i in the bilateral trade relationship. To simultaneously account for economic disparities and geographical distance, this paper incorporates the ratio of geographical distance D_{ij} to the difference in per capita GDP $(gc_i - gc_j)$ between countries i and country j. Here, gc_i and gc_j denote the per capita GDP of country i and country j, respectively.

First, based on equation (1), we calculate the gravity-derived trade intensity between countries and store the results in the adjacency matrix $G = [g_{ij}] (i = 1,2 \cdots n, j = 1,2 \cdots n)$, where the row-wise mean value of GGG is adopted as the threshold. If g_{ij} exceeds the threshold, we set $g_{ij} = 1$; otherwise, we set $g_{ij} = 0$.

Second, using the adjacency matrix G, we construct the international trade network $G(V, E)$, where V

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denotes the set of nodes representing the 100 selected countries (or regions), and E denotes the set of edges representing the presence of trade relationships. If $g_{ij} = 1$, a link is established between country i and country j; if $g_{ij} = 0$, no link is formed.

Finally, based on this framework, we employ Gephi software to visualize the international trade network of **100 countries** during 2006–2021. Taking 2018 as an illustrative example, **Figure 1** presents the network graph of international trade. In the figure, nodes represent countries, and edges denote the presence of trade relationships. The size of each node reflects its degree centrality (the larger the node, the greater the number of trade partners it connects to), while the color of the node indicates its community membership. The spatial distribution of nodes is arranged using the **Force Atlas 2** algorithm in **Gephi**, allowing for clearer representation and ranking of the structural positions of countries in the trade network. **It is worth noting that the 100 countries represented in the figure are labeled using ISO-3 codes. For instance, GBR denotes the United Kingdom, while CHN represents China.**
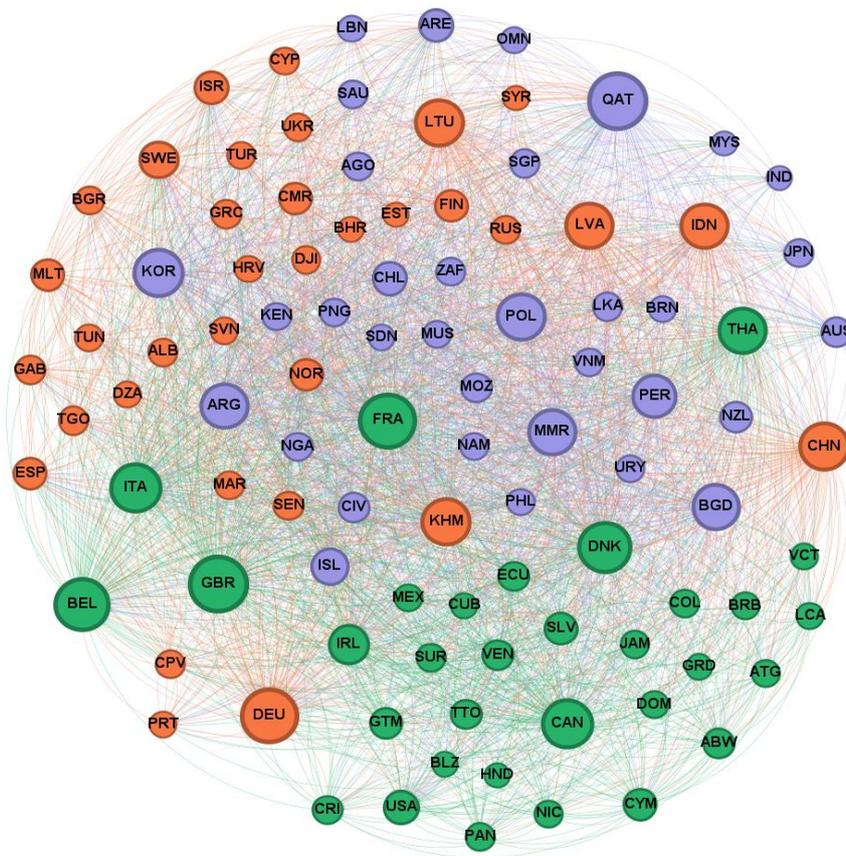

Figure 1. Visualization of the International Trade Network of 100 Countries in 2018

4. Structural Characteristics of the International Trade Network

Building upon the constructed international trade network, this chapter systematically analyzes the global trade system from both macro-level structural features and micro-level community structures. First, we examine the overall structural evolution of the trade network across different years by employing

statistical indicators such as network density, average degree, average path length, clustering coefficient, and network diameter. Second, community detection algorithms are applied to identify and trace the formation and evolution of major trade blocs (communities). Finally, by integrating the dynamic changes in network indicators with the evolution of community structures, we provide an in-depth interpretation of the global trade restructuring and the underlying structural transformation trends.

The network structural indicators and their definitions used in this study draw upon the seminal contributions in the field of social network analysis. Freeman (1979) first systematically introduced the concepts of degree centrality, betweenness centrality, and closeness centrality, laying the theoretical foundation for subsequent research on network structures. Watts and Strogatz (1998) proposed the "small-world network" model, which revealed the widespread coexistence of short path lengths and high clustering in real-world complex networks. Newman (2003, 2010) provided comprehensive theoretical and empirical insights into the quantification of network statistics and the identification of community structures. Barabási and Albert (1999) introduced the "scale-free network" model, highlighting the impact of heterogeneous degree distributions on network stability and efficiency. Collectively, these studies offer a mature measurement framework and evolutionary perspective for analyzing international trade networks, enabling us to characterize the topological features, evolutionary trajectories, and potential regularities of the global trade system from multiple dimensions.

4.1 Overall Structural Characteristics of the International Trade Network

Based on the trade network constructed for the period 2006–2021, we computed the network's overall structural statistics. The results are presented in **Table 1**.

Table 1. Descriptive Statistics of the International Trade Network

Year	2006	2007	2008	2009	2010	2011	2012	2013
Nodes	100	100	100	100	100	100	100	100
Edges	2603	2829	3018	3058	2709	2748	2740	2836
Graph Density	0.263	0.286	0.305	0.309	0.274	0.278	0.277	0.286
Average Degree	26.03	28.29	30.18	30.58	27.09	27.48	27.4	28.36
Network Diameter	3	3	3	3	3	3	3	3
Average Path Length	1.745	1.728	1.712	1.7	1.762	1.759	1.737	1.752
Average Clustering Coefficient	0.551	0.586	0.581	0.578	0.523	0.518	0.539	0.541

Continued:

Year	2014	2015	2016	2017	2018	2019	2020	2021
Nodes	100	100	100	100	100	100	100	100
Edges	2866	2784	3023	2933	3040	2807	2513	3088
Graph Density	0.289	0.281	0.305	0.296	0.307	0.284	0.254	0.312

Average Degree	28.66	27.84	30.23	29.33	30.4	28.07	25.13	30.88
Network Diameter	3	3	3	3	3	3	3	3
Average Path Length	1.73	1.757	1.736	1.76	1.715	1.783	1.795	1.742
Average Clustering Coefficient	0.523	0.532	0.542	0.511	0.528	0.54	0.518	0.554

Based on the indicators reported in **Table 1**, several characteristics of the trade network can be identified:

(1)Network Scale and Connectivity: Observing the changes in the number of edges, international trade links exhibit pronounced fluctuations. From 2006 to 2008, the number of edges rapidly increased from 2,603 to 3,018, reflecting the accelerated expansion of global trade prior to the financial crisis. In 2009, the network reached the first peak within the observation period (3,058 edges), followed by a sharp decline of 11.4% in 2010 to 2,709 edges, directly illustrating the impact of the global financial crisis on trade connectivity. Notably, in 2020 the number of edges fell to a cyclical low of 2,513, a 10.5% reduction compared to 2019, highlighting the unique effect of the COVID-19 pandemic on the global trade system. By 2021, edges rebounded to a historical high of 3,088, demonstrating the strong recovery capacity of the global trade network. The graph density ranged from 0.254 to 0.312, indicating that the probability of a trade link between any randomly selected pair of countries remained between 25% and 31%. The density peaks observed in 2008–2009 (0.305–0.309) and in 2018 and 2021 (0.307 and 0.312) suggest that the global trade network undergoes a tightening cycle roughly every decade. Of particular interest, the sharp drop in density to 0.254 in 2020 represents the lowest value within the observation period, corroborating the specific influence of non-economic shocks on network topology.

(2)Evolution of Network Connectivity Strength: The average degree indicates that each economy maintained between 25 and 31 trading partners on average. From 2006 to 2009, the average degree rose continuously from 26.03 to 30.58. After a significant decline in 2010, it stabilized for several years and ultimately reached a peak of 30.88 in 2021, signaling a post-pandemic expansion in the breadth of trade connections, possibly reflecting a structural upgrade in the global trade system.

(3)Persistent Small-World Characteristics: The network diameter remained constant at 3, and the average path length fluctuated within the narrow range of 1.7–1.8. This indicates that any two countries could, on average, establish trade relations through no more than two intermediate nodes. The robust "small-world" property persisted even under the extreme conditions of 2020, when the average path length increased by only 0.012, demonstrating the inherent efficiency advantage of the international trade network.

(4)Dynamic Clustering Effects: The average clustering coefficient varied between 0.511 and 0.586, indicating a significant tendency toward triadic closure among trading partners. After reaching a peak of 0.586 in 2007, the coefficient generally declined but rebounded to 0.554 in 2021. This "high clustering–short path" structure confirms that the trade network exhibits both local clustering and global efficiency. It is worth noting that the coefficient remained below 0.55 from 2014 to 2020, possibly reflecting a loosening of cluster structures during the restructuring of global value chains.

In summary, a joint analysis of the overall structural indicators identifies three critical turning periods in the trade network:

① **2009–2010**, when all indicators simultaneously declined, reflecting the lagged impact of the financial crisis;

② **2014–2016**, when a divergence between density and clustering coefficient trends possibly indicated deep adjustments in the global production network;

③ **2020–2021**, marked by a V-shaped reversal in indicators, revealing both the resilience limits and recovery momentum of the trade network under pandemic-induced shocks. These structural inflection points provide key temporal anchors for understanding the evolution of the global trade system.

4.2 Evolution of Communities in the International Trade Network

The division of communities within a network can reflect clustering phenomena among its nodes. In this study, we employed the Modularity algorithm implemented in Gephi to detect communities, analyzing the underlying causes of the observed community structures and visualizing the network's structural evolution. Network visualizations and comparative analyses were conducted for the years 2006, 2008, 2017, 2018, 2019, 2020, and 2021; due to space constraints, this paper presents only the visualizations for 2006, 2008, and 2017–2019.

4.2.1 Overall Evolution of Trade Network Communities

Using the Modularity algorithm, we systematically analyzed the evolution of communities in the international trade network, focusing on key years between 2006 and 2021. The results of the community detection are summarized in **Table 2**.

Table 2. Evolution of Communities in the International Trade Network for Key Years

Year	Modularity	Number of Communities	Largest Community Size	Smallest Community Size
2006	0.087	4	31	22
2007	0.074	4	31	16
2008	0.068	3	39	27
2009	0.063	3	47	25
2010	0.084	3	45	25
2011	0.082	3	39	28
2012	0.082	3	38	30
2013	0.088	3	37	27
2014	0.080	3	39	22
2015	0.083	3	38	26
2016	0.076	3	35	32
2017	0.083	3	36	30
2018	0.074	3	38	31

2019	0.078	3	42	28
2020	0.098	3	36	29
2021	0.065	3	41	29

The community structure of the international trade network reflects the clustering characteristics of the global trade system, where countries form relatively independent subgroups based on the intensity of trade connections. The results in **Table 2** reveal several dynamic trends in international trade cooperation:

(1) Overall Structural Characteristics

From the data presented in Table 2, the international trade network exhibited a relatively stable community structure between 2006 and 2021. The number of communities remained largely within the range of three to four, indicating that relatively fixed trade blocs or clusters exist among countries in the global trade system. This relative stability in community division reflects the institutional stickiness and path dependence inherent in international trade relations, suggesting that countries have formed enduring trade networks based on geographical, institutional, or historical ties.

(2) Modularity Variation and Its Economic Significance

Modularity is an index that measures the extent to which a network can be divided into subgroups (communities) with dense intra-community connections and sparse inter-community links. A higher modularity value indicates clearer and more cohesive community structures. Table 2 reveals that:

●   The highest modularity values occurred in 2013 (0.088) and 2020 (0.098), indicating the most pronounced internal differentiation of the trade network in these years and the formation of more clearly defined trade blocs. This trend aligns with the rise of global protectionism in the late 2010s (e.g., US-China trade tensions) and the initiation of regional trade agreements (e.g., the RCEP negotiations), reflecting a strengthening of regionalization within the international trade system.

●   The lowest modularity values were observed in 2008 (0.068) and 2021 (0.065), closely associated with the global financial crisis and the COVID-19 pandemic, respectively. In these years, the community structure of the international trade network became blurred, indicating that crisis shocks weakened inter-country trade links, reshuffled network connections, and blurred existing community boundaries.

(3) Analysis of Largest and Smallest Communities

In 2008, the largest community comprised 39 countries, representing 39% of the total, suggesting that, under the financial crisis, certain countries clustered together for survival, forming a larger trade bloc. This temporary concentration reflects strengthened cooperative mechanisms during crises and indicates a certain degree of centralization in trade relations rather than fragmentation. In contrast, after 2010, the sizes of the largest and smallest communities converged within a narrower range (largest community: 36–47 countries; smallest community: 22–32 countries), suggesting that while the global trade system experienced shocks, it stabilized post-crisis into relatively consistent regional clusters.

(4) Impact of Financial Crises and the Pandemic

The 2008 global financial crisis directly disrupted international capital flows and goods trade, sharply

reducing global trade volumes, weakening inter-country network connections, blurring community boundaries, and lowering modularity. Similarly, in 2021, the COVID-19 pandemic triggered supply chain interruptions and transportation constraints worldwide, inducing network perturbations similar to those observed during the financial crisis, resulting in community reshuffling and decreased modularity.

In summary, the international trade network exhibits the following long-term evolutionary patterns:

(1) Economic integration and regionalization coexist, with the global trade network increasingly gravitating toward stable patterns of regional clusters.

(2) Global crises—such as financial crises and pandemics—exert significant disruptive effects on the structure of international trade, blurring existing community boundaries and reshuffling trade linkages.

(3) Core countries (e.g., the United States, China, Germany) may reinforce their central positions in the trade network during periods of crisis by maintaining stronger connections, whereas peripheral countries often experience shifts in community affiliation and network status.

Based on these findings, the following policy implications can be drawn:

(1) **Strengthen regional cooperation mechanisms.** Given the pronounced trend toward regional clustering, efforts should be directed toward advancing regional free trade agreements—such as RCEP and ASEAN+ initiatives—to enhance intra-regional resilience against external shocks.

(2) **Enhance supply chain resilience.** To mitigate the disruptions caused by global crises, a diversified and highly flexible international supply chain system should be developed to reduce dependence on any single market.

(3) **Promote diversification of trade networks.** Enterprises should be encouraged to explore emerging markets and expand multilateral trade relations, thereby reducing excessive reliance on traditional major markets and improving the overall resilience of international trade.

4.2.2 Evolution of Network Communities in 2006

Figure 2 presents the overall structure of the international trade network and the results of community detection in 2006. Each node represents a country, while directed edges indicate the existence of trade relations between countries. The node size is proportional to degree centrality, the color denotes community membership, and the spatial layout is automatically generated using the Force Atlas 2 algorithm in Gephi, which facilitates the identification of structural "clustering" phenomena. Based on this figure, several key economic implications can be extracted:

(1) Community structures reveal regional economic cooperation networks. In 2006, the global trade network was divided into four major communities, displaying a pronounced regionalization pattern:

● **Purple community (e.g., France, Italy, Spain, the United Kingdom):** Primarily composed of European countries, this group reflects frequent intra-European trade interactions, forming a strong regional bloc and underscoring the high degree of integration and synergy within the EU single market.

- **Green community (e.g., Germany, Belgium, Canada, Mexico, and several Latin American countries):** This grouping embodies transatlantic cooperation, with Germany as one of the core nodes. Its high connectivity indicates significant influence on transatlantic trade flows.

- **Orange community (e.g., the United Arab Emirates, Qatar, Myanmar, Papua New Guinea, India):** Comprising a mix of Asian, Middle Eastern, and African countries, this community—though geographically dispersed—reflects a "commodity-driven" trade network shaped by shared resource-based economic structures and trade patterns.

- **Blue community (centered around Norway):** The smallest but highly cohesive cluster, largely composed of Nordic and Caribbean countries, suggesting the formation of a stable small-scale trade circle underpinned by resource trade or institutional cooperation.

(2) Core nodes highlight global trade hubs. Larger nodes indicate higher degree centrality, signifying more extensive trade partnerships and designating these countries as "hub states" in the global trade network. For example, the United States (USA) and Germany (DEU) remained pivotal, functioning as the "main engines" of world trade. Belgium (BEL) and Norway (NOR), despite their medium-sized economies, occupied important hub positions owing to locational advantages and institutional openness. By contrast, France (FRA) and Italy (ITA), though traditional powers, appeared more dispersed, suggesting early signs of marginalization in the 2006 global trade network.

(3) Community distribution reflects the "geographic segmentation" of global trade. Although globalization was advancing, the communities still displayed a degree of geographic segregation. European countries clustered tightly within the same community, underscoring the close ties of the EU internal market and customs union. American countries were grouped within the green community but maintained close links with European core nodes, highlighting the continued centrality of the transatlantic economic corridor in 2006. Asian and Middle Eastern countries were clustered into another community, demonstrating reliance on regional networks centered on energy, resources, or labor-intensive trade.

(4) Network structures embody the dual influence of institutions and geography. Even countries with relatively small economic scales—such as Ireland, Norway, and Belgium—exhibited high centrality, suggesting that institutional advantages, open markets, and geographic connectivity play an equally important role in shaping network positions. Furthermore, geographic proximity remained a critical basis for community formation, with regional trade agreements and infrastructure connectivity further reinforcing this trend.

From the results of community detection in 2006, four major communities were identified, ranging in size from 22 to 31 countries. Figure 3 illustrates the community structure and the distribution of core nodes, revealing the prominent regionalization and multi-polar characteristics of global trade. The communities were organized around Europe, the Americas, Asia–Middle East, and the Nordic–small country clusters, reflecting the interplay of EU internal markets, cross-regional cooperation among high-income countries, and trade agglomeration among resource-based economies. The United States, Germany, and Belgium maintained their positions as global trade hubs due to their high connectivity,

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while smaller countries such as Norway and Ireland also emerged as key players by leveraging institutional and locational advantages. Overall, the global trade network in 2006 displayed an evolutionary pattern characterized by the coexistence of regional agglomeration and structural diversity, driven jointly by geographic proximity and institutional arrangements.
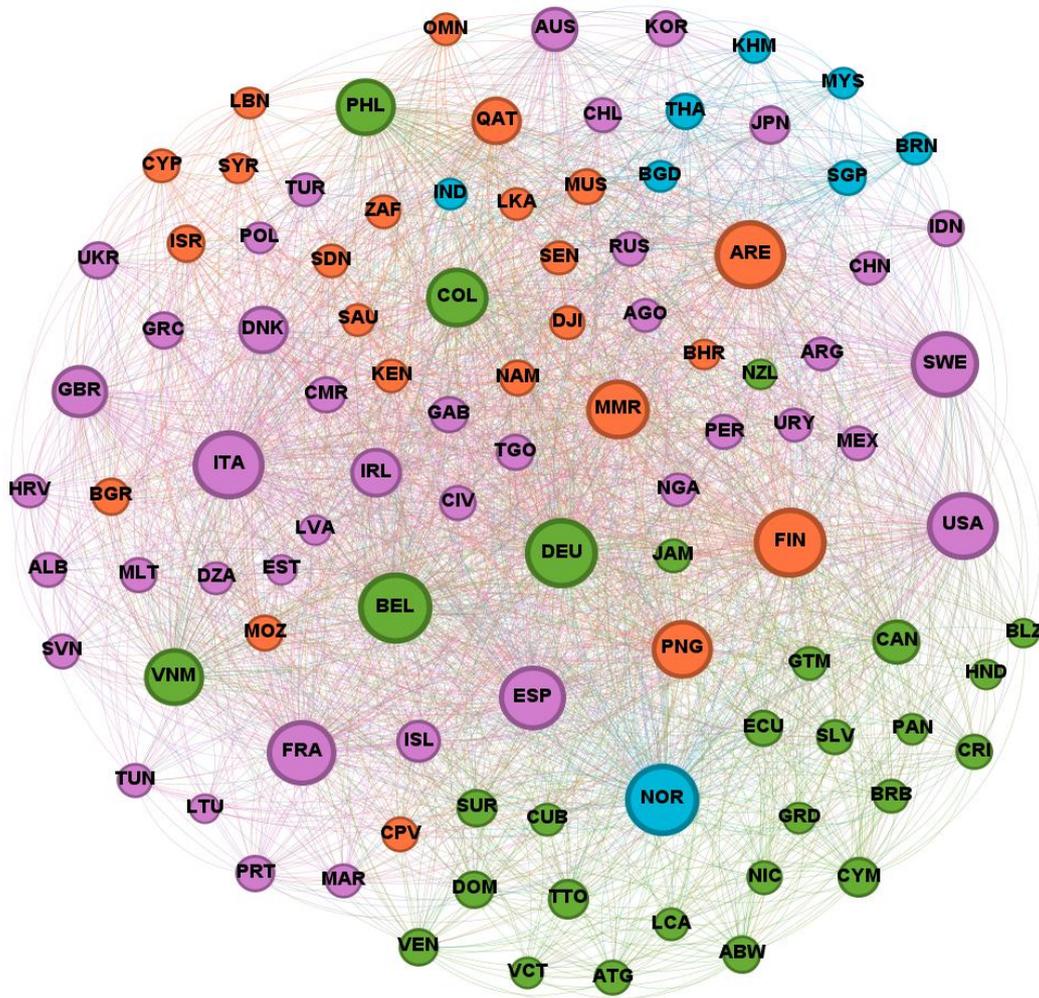

Figure 2. Visualization of Community Structures in the International Trade Network, 2006

4.2.3 Evolution of Network Communities in 2008

Figure 3 illustrates the community structure of the international trade network in 2008. Compared with 2006, the network exhibited tighter connectivity and a more pronounced multi-polar configuration. Although the four major communities still existed, their boundaries became increasingly blurred, reflecting a deeper level of global trade integration.

The **American-dominated community**, centered on the United States, demonstrated strong outward extensibility, reaching into Latin America and East Asia. This underscores the sustained leadership role of the United States in shaping regional economic dynamics. In contrast, **European countries** remained

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stably clustered within the highly integrated purple community, highlighting the collaborative advantage of intra-EU trade.

A significant number of **emerging economies** were concentrated in the green community, with noticeably higher centrality scores. This indicates their rising prominence in the global trade network and the strengthening of their structural positions. Meanwhile, smaller states such as **Norway and Ireland** retained high levels of connectivity due to institutional advantages and locational benefits, further confirming the crucial role of non-economic factors in shaping structural embeddedness.

Overall, the 2008 global trade network—despite the onset of the financial crisis—continued to display strong structural resilience and dynamic diversity in its evolutionary trajectory.
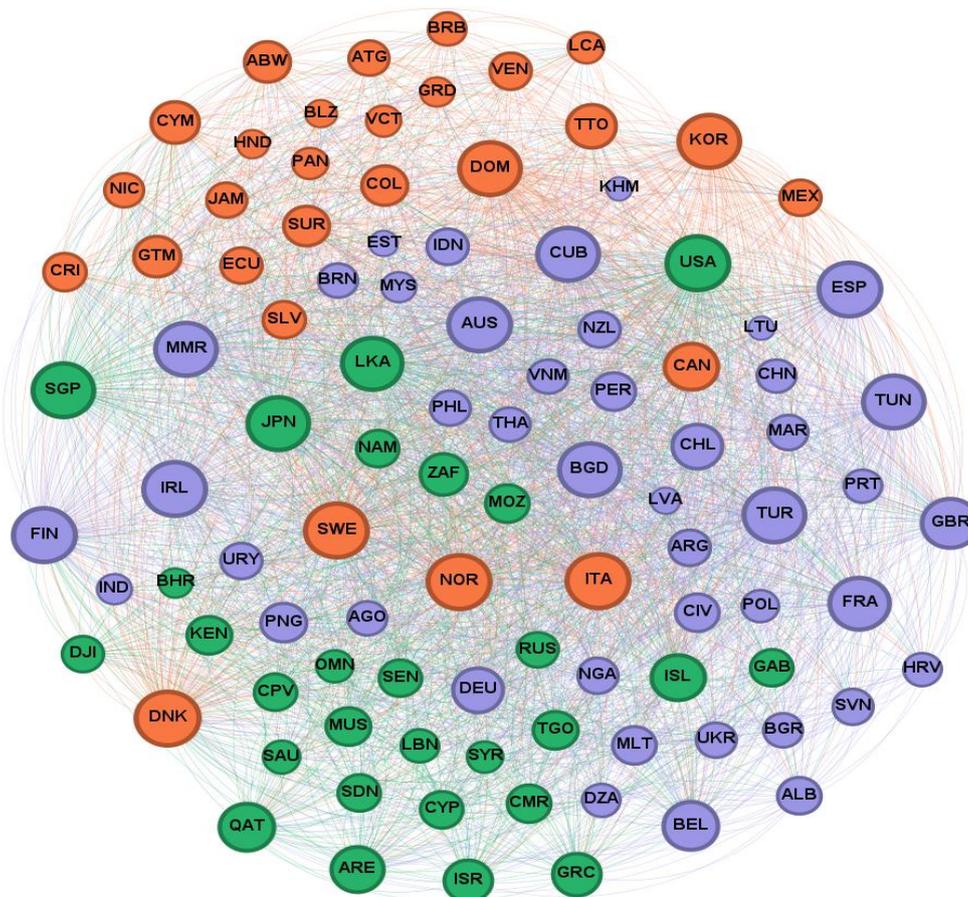

Figure 3. Visualization of Community Structures in the International Trade Network, 2008

4.2.4 Evolution of Network Communities in 2017

As shown in **Figure 4**, the international trade network in 2017 exhibited a more pronounced trend toward **multipolarity and flattening**, indicating a gradual shift of the global trade structure from dominance by traditional powers toward multi-centered coordination.

Asian and Oceanian countries were highly concentrated within the green community, suggesting that a "Pan-Asian trade circle" had emerged as a new structural hub. European countries continued to maintain stable intra-community linkages; however, compared with earlier periods, their network centrality began to show signs of marginalization. The American community, by contrast, contracted noticeably, with traditional core countries such as the United States showing diminished control over global trade pathways.

At the same time, the overall network density increased, as more peripheral countries became embedded within the global trade network. This reflects a growing inclusiveness and diversification of international trade structures, underscoring the progressive expansion of global trade participation beyond established powers.
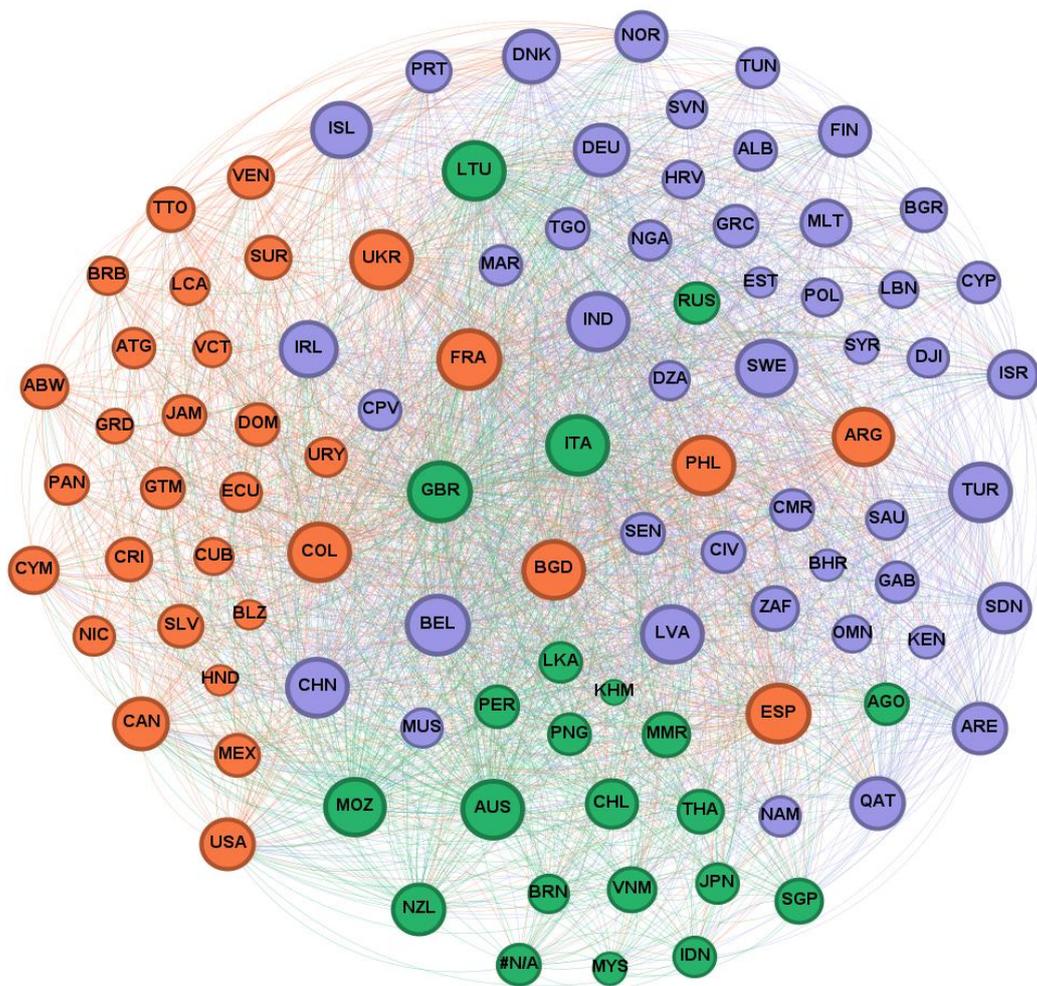

Figure 4. Visualization of Community Structures in the International Trade Network, 2017

4.2.5 Evolution of Network Communities in 2018

Figure 5 illustrates that in 2018 the global trade network continued to exhibit a highly coupled and multi-centered structure, with stronger inter-community linkages and a deeper degree of network integration.

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The **green community**, which brought together multiple structural core countries such as China, Germany, the United Kingdom, Belgium, and Canada, highlights the strengthening dominance of Eurasian countries in global trade.

The **purple community**, primarily composed of Central and Eastern European as well as African countries, maintained stable internal connections, yet its structural marginalization within the overall network became more pronounced. By contrast, the **orange community** comprised several smaller or resource-based economies. While these countries maintained extensive external linkages, their internal cohesion remained relatively weak.

Overall, the 2018 global trade network displayed a configuration increasingly centered on Eurasia, characterized by enhanced multilateral interconnectivity and co-leadership shared between traditional powers and emerging economies. This trend underscores the growing complexity and diversity of the global trade architecture, with institutional arrangements and geopolitical attributes exerting an ever-stronger influence on countries' positions within the network.
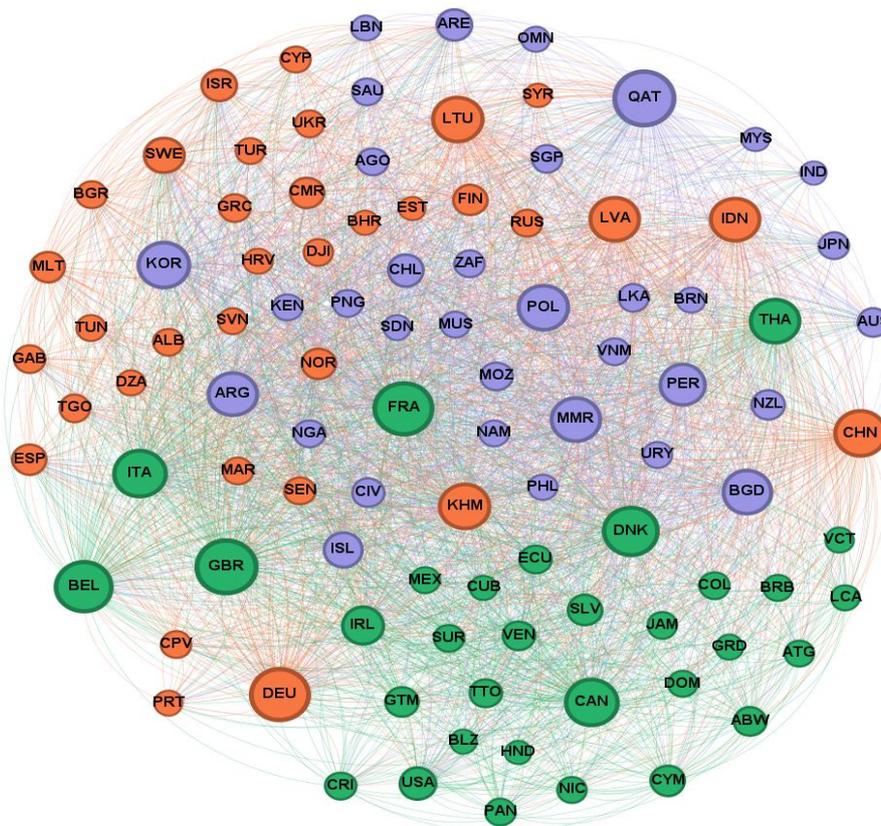

Figure 5. Visualization of community Structures in the International Trade Network, 2018

4.2.6 Evolution of Network Communities in 2019

Based on the community division of the international trade network in 2019 (**Figure 6**), the economic significance can be analyzed from the perspectives of community structure, distribution of core nodes, and network coupling.

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Figure 6 indicates that the 2019 international trade network retained a **multipolar structure** while exhibiting stronger overall coupling and closer inter-node linkages. The **purple community**, the largest in scale, encompassed countries from Central Europe, East Asia, and parts of Africa, suggesting a more pronounced trend of cross-regional trade integration. The **green community**, centered on major countries in Europe, North America, and Latin America (e.g., the United States, Belgium, Spain, Argentina), demonstrated strong internal cohesion and significant network dominance. The **blue community**, composed of geographically peripheral states such as New Zealand, Chile, and Uruguay, reflected the emergence of new forms of regional cooperation among geographically distant but economically complementary partners.

Of particular note, several countries that were previously positioned at the margins of the network (e.g., the Philippines, Bangladesh, Uganda) experienced a marked rise in their embeddedness within the trade structure. This highlights the growing inclusiveness of the global trading system.

Overall, the 2019 global trade network displayed a **multi-dimensional pattern of coordination**, characterized by tightly coupled regional clusters, high-frequency interactions across communities, and upward structural mobility of peripheral countries. These dynamics reflect a process of deep adjustment and evolutionary upgrading within the global trade network under the broader context of globalization.
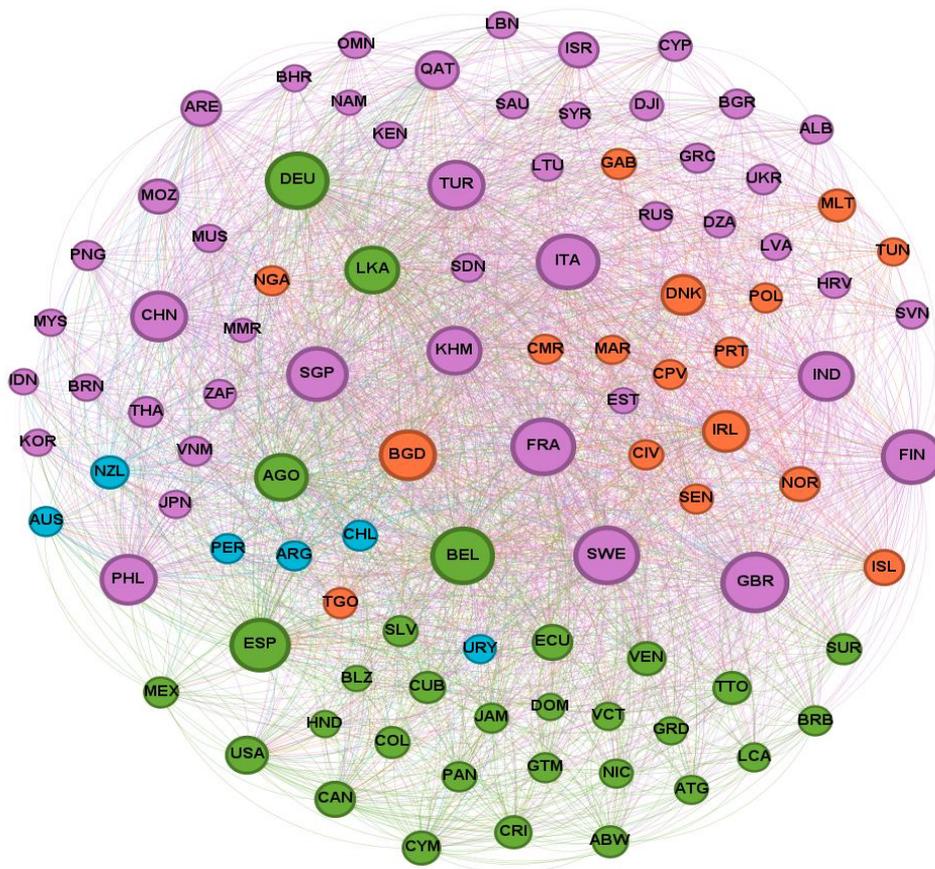

Figure 6. Community Evolution of the Trade Network among 100 Countries, 2019

4.2.7 Evolution of Network Communities in 2020

Drawing on the community structure of the international trade network in 2020 (**Figure 7**), the analysis can be contextualized against the backdrop of the global economic landscape shaped by the COVID-19 pandemic.

Figure 7 demonstrates that, despite the severe disruptions of the pandemic, the international trade network maintained a relatively high level of connectivity and structural stability. The **purple community**, encompassing Europe along with parts of Asia and Africa, preserved a strong cross-regional clustering pattern. The **green community** further expanded, incorporating economies such as the United Kingdom, Germany, Mexico, India, and Colombia, thereby forming a structural core centered around countries exhibiting strong trade resilience.

By contrast, the **orange community** contracted in scale, with core countries such as Ireland and Belgium experiencing a relative decline in network centrality. This indicates a trend of marginalization for some small and medium-sized economies amid the disruptions of global supply chains. The **blue community**, composed of South American countries including Argentina, Chile, and Peru, reflected strengthened regional cooperation within Latin America.

Overall, under pandemic-induced shocks, the global trade network displayed a new configuration characterized by **stability of core clusters, enhanced self-organization of smaller communities, and reintegration of peripheral countries**. This not only highlights the considerable resilience of the global trade system but also underscores the rising importance of regional cooperation networks in an environment of global uncertainty.
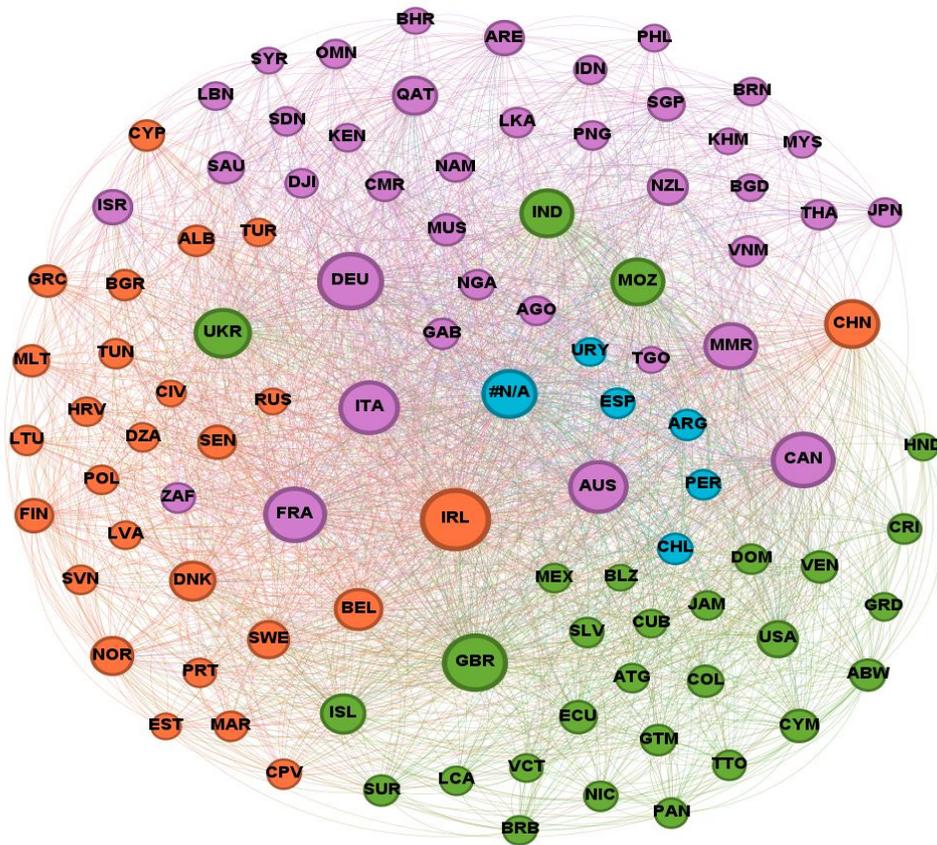
Figure 7. Community Evolution of the Trade Network among 100 Countries, 2020

4.2.8 Evolution of Network Communities in 2021

Based on the community division of the international trade network in 2021 (**Figure 8**), and taking into account node size, color, spatial distribution, and the global economic recovery following the pandemic, the structural dynamics of the network can be analyzed in greater depth.

Figure 8 reveals that the 2021 global trade network exhibited clear signs of **recovery and restructuring** after the pandemic shock. The **green community** experienced strong expansion, encompassing core economies such as the United Kingdom, Denmark, Japan, India, South Africa, and Colombia. These countries displayed significantly enhanced centrality, reflecting their growing influence within the global trade network. The **purple community**, mainly composed of the United States, Canada, Mexico, and Caribbean states, maintained tight internal linkages and structural stability, indicating a higher level of regional integration across North America and Central America.

The **orange community** remained dominated by continental European countries, supported by core nodes such as France, Germany, Italy, and Australia. However, disparities in centrality within this group widened, with certain countries showing signs of marginalization. Meanwhile, Asian economies were widely distributed across different communities, with China, South Korea, and Singapore demonstrating

cross-community embeddedness between the green and orange clusters. This underscores their bridging role in sustaining connectivity within the multilateral trading system.

Overall, the 2021 global trade network was characterized by **greater regional stability, strengthened multipolar linkages, and increased cross-community embedding**. These features reflect both the resilience of the global trade system and the trend toward **recentralization** under the reconfiguration of the world economy in the post-pandemic era.

Figure 8. Community Evolution of the Trade Network among 100 Countries, 2021

4.3 Summary of This Chapter

A comprehensive review of the evolution of the international trade network from 2006 to 2021 reveals a dynamic transformation of the global trade structure from **core concentration** toward **multi-polar coordination**.

In the early stage (2006), the trade network was relatively centralized, with Europe and North America as the dominant hubs, reflecting pronounced regionalization. By 2008, under the impact of the global financial crisis, network density increased and community boundaries became blurred, signaling the initial emergence of diversified trade pathways. Around 2017, Asian countries began to rise, with intra-Pan-Asian linkages strengthening and East Asia emerging as a new structural center.

Between 2018 and 2019, peripheral countries became more deeply embedded in the network, enhancing inclusiveness and producing a configuration characterized by both **decentralization** and **cross-regional embedding**. In 2020, despite the severe disruptions of the COVID-19 pandemic, the global trade network

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did not experience systemic fragmentation; rather, it demonstrated strong structural resilience, with the self-organizing features of several regional sub-communities becoming more prominent.

By 2021, with the onset of global economic recovery, the trade structure moved toward re-integration, featuring the coexistence of multiple core centers, strengthened cross-community linkages, and the simultaneous development of network resilience, connectivity, and regional leadership.

Overall, the international trade network has been evolving away from the traditional dominance of major powers toward a more complex configuration characterized by **structural diversity, multiple pathways, and cross-regional interconnections**.

5. Network Centrality Analysis

Social network analysis primarily focuses on intuitive statistical indicators of networks, such as in-degree and out-degree, network density, and various centrality measures (including degree centrality, betweenness centrality, eigenvector centrality, closeness centrality, and PageRank centrality). However, the rankings of countries differ across these five centrality measures, making it difficult to comprehensively capture each country's overall structural position.

To more accurately characterize the structural role of countries in the international trade network from 2006 to 2020, this study adopts five mainstream centrality indicators—**degree centrality**, **eigenvector centrality**, **closeness centrality**, **betweenness centrality**, and **PageRank centrality**. The top ten countries in each measure are first identified, after which a multi-dimensional radar chart is constructed to enable both visual comparison and integrated evaluation of trade influence across countries. The final step involves interpreting the results in terms of their economic significance. To ensure systematic and rigorous analysis, the radar chart construction and indicator integration proceed as follows:

Step 1. Country selection. Collect the top ten countries for each centrality measure from 2006 to 2021 and tabulate the results. Since some countries appear repeatedly across multiple indicators, the union of all countries that ever ranked in the top ten is taken as the candidate set for the radar chart.

Step 2. Completion of centrality data. For candidate countries that do not appear in the top ten for a given centrality measure, their actual scores are supplemented using the full centrality dataset precomputed in Gephi. This ensures that each country has complete data across all five measures.

Step 3. Standardization and score calculation. To eliminate differences in scale across centrality measures, all five indicators are normalized to the [0,1] range using Min–Max standardization. The standardized scores of each country across the five indicators are then averaged arithmetically to yield a **composite centrality score**.

Step 4. Selection and ranking of top countries. Countries are ranked according to their composite scores, and the top ten are selected for visualization.

Step 5. Radar chart visualization. Using Python, a radar chart is generated in which each dimension corresponds to one centrality indicator. Each polyline represents a country's performance across the five

measures. Colors and markers distinguish between countries, while the enclosed area reflects the country's overall position in multi-dimensional centrality.

Step 6. Visualization results and interpretation. The radar chart reveals that a country's position in the international trade network is not determined by a single measure, but rather by the joint contribution of multiple dimensions. Differences in performance across the five centrality measures are then interpreted in terms of their economic significance.

5.1 Concept of Node Centrality in Networks

Centrality measures are fundamental tools for assessing the importance and role of nodes within a network structure. They are widely applied in the analysis of social, economic, and international trade networks. The five centrality indicators adopted in this study—**degree centrality**, **betweenness centrality**, **closeness centrality**, **eigenvector centrality**, and **PageRank centrality**—are rooted in the development of complex network theory. The following briefly reviews the classical literature and theoretical foundations of these measures:

● **Freeman (1978, 1979)** systematically defined degree centrality, closeness centrality, and betweenness centrality, highlighting their role in uncovering social power structures. These works represent foundational contributions to the study of centrality.

● **Bonacich (1987)** introduced the concept of eigenvector centrality, arguing that the importance of a node depends not only on the number of its connections but also on the significance of the nodes it connects to, thereby embedding an "influence propagation" mechanism.

● **Kleinberg (1999)** developed the HITS algorithm, which defined "hub" and "authority" nodes. This model was a milestone in search engine ranking and can be regarded as an extension of eigenvector centrality.

● **Brin and Page (1998)** proposed PageRank centrality, initially designed for Google's search ranking. Essentially, it measures the probability of a node being visited under a random walk model, and it has since been widely applied in the analysis of weighted and directed networks.

● **Newman (2003, 2010)**, through multiple surveys and textbooks, provided a unified framework and rigorous mathematical definitions for various centrality measures, greatly advancing their application in economic networks and complex systems.

These seminal studies not only established the theoretical foundation of centrality but also provide the conceptual underpinnings for this paper's identification of key countries in the international trade network and the construction of multi-dimensional radar charts.
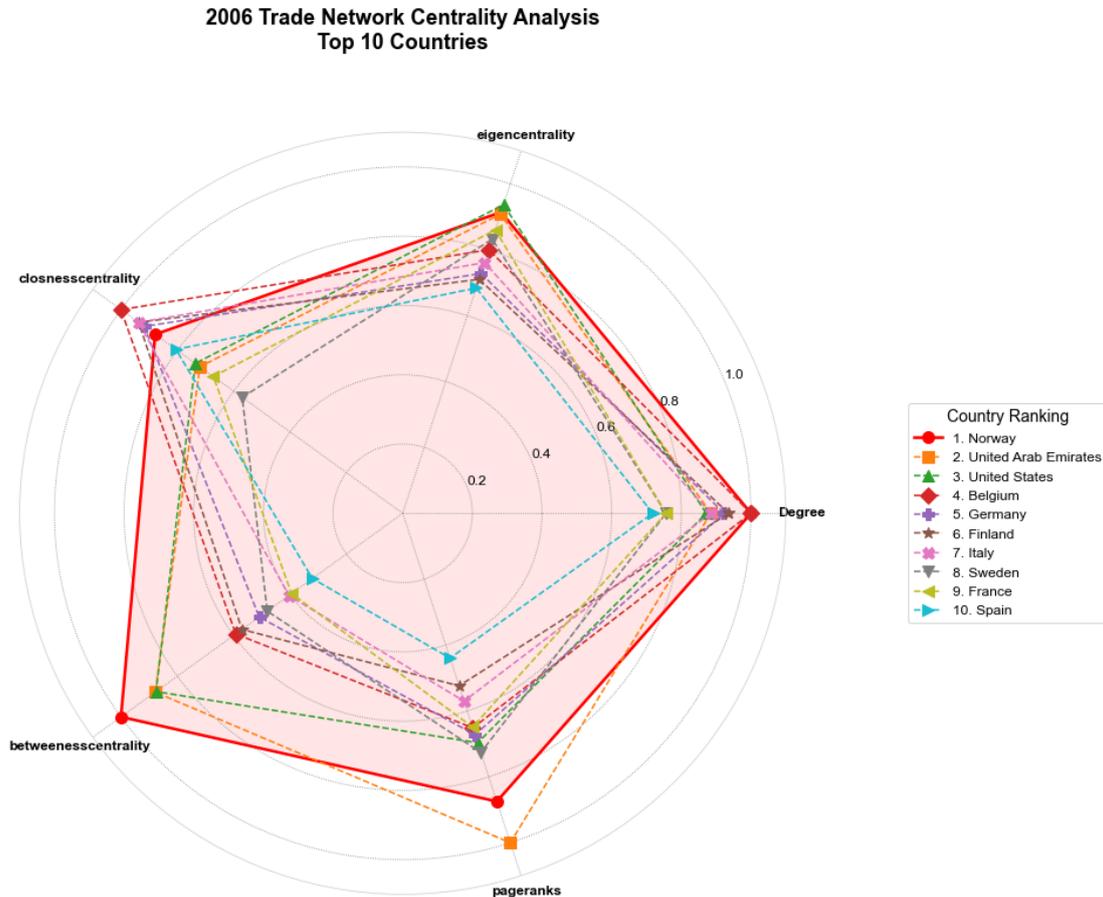
5.2 Analysis of Node Centrality

5.2.1 Centrality Rankings in 2006

This subsection first identifies the top ten countries in terms of centrality measures within the 2006 international trade network (see **Table 3**). Following the analytical procedure outlined in **Steps 1–6**, a radar chart (**Figure 9**) is then constructed to explore, from a multi-dimensional perspective, the economic implications of differences in network positions for countries' trade influence.

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Table 3. Top Ten Countries by Centrality Indicators in the 2006 International Trade Network

Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	Belgium (1.565656566)	United Kingdom(1)	Belgium (0.970588)	Norway (857.331069)	United Arab Emirates (0.034395)
2	Norway (1.565656566)	Qatar (0.965308)	Papua New Guinea (0.970588)	United Arab Emirates (760.48939)	Qatar (0.032319)
3	Finland (1.515151515)	United States (0.958997)	Myanmar (0.951923)	United States (758.392115)	Norway (0.03078)
4	Germany (1.505050505)	Norway (0.944435)	Colombia (0.951923)	Belgium (532.902179)	United Kingdom (0.026646)
5	United Arab Emirates (1.474747475)	United Arab Emirates (0.940394)	Finland (0.942857)	Finland (515.268306)	Sweden (0.026492)
6	Italy (1.474747475)	Ireland (0.936734)	Italy (0.942857)	Germany (466.650747)	Ireland (0.025808)
7	United States (1.464646465)	France (0.909391)	Vietnam (0.942857)	Sweden (443.765649)	United States (0.025643)
8	Sweden (1.373737374)	Sweden (0.891459)	Germany (0.933962)	Italy (382.678922)	Germany (0.024937)
9	France (1.373737374)	Denmark (0.873787)	Norway (0.916667)	France (375.229866)	Belgium (0.024338)
10	Spain (1.343434343)	Belgium (0.870553)	Philippines (0.916667)	Spain (316.256774)	France (0.024263)

2006 Trade Network Centrality Analysis
Top 10 Countries

Figure 9. Radar Chart of the Top Ten Countries in 2006 by Composite Centrality Score

As illustrated in **Figure 9**, the performance of different countries across the five centrality measures varies considerably, reflecting their distinct positions within the international trade network.

(1) **Norway** demonstrates balanced performance across all five indicators, with a particularly outstanding lead in betweenness centrality. This highlights its role as a "path intermediary" and "bridge" in the 2006 trade network, underscoring its critical function in transshipment and connectivity.

(2) The **United Arab Emirates** ranks highly in both PageRank centrality and betweenness centrality, indicating not only strong connectivity but also its role as a highly relied-upon export node. This reflects the strategic position of the Middle Eastern trade hub within the global network.

(3) The **United States**, though slightly outperformed by Norway and the UAE on certain measures, shows consistently strong scores across all five indicators. This stability reflects its dominant position in the global economy and its broad influence in multilateral trade.

(4) **Belgium, Germany, and Finland** perform prominently in degree and closeness centrality, suggesting extensive trade linkages and high market accessibility. This underscores the close integration among core EU economies.

(5) **France, Sweden, Italy, and Spain**, while not leading in any single indicator, still appear among the top ten, indicating their continued activity in global trade and maintaining meaningful connectivity and regional influence.

In summary, the radar chart reveals that a country's position in the international trade network is shaped by **multi-dimensional structural characteristics**, rather than solely by economic size. Norway, for instance, despite its relatively modest economic scale, occupies a pivotal role as a "path intermediary." This finding underscores the importance of moving beyond traditional size-based metrics in identifying key countries, by emphasizing their **connectivity attributes and functional roles**. The use of multi-dimensional centrality measures allows for a more comprehensive evaluation of network positions—ranging from breadth of trade ties and market accessibility to path control capacity—which is especially critical in the context of regional integration.

5.2.2 Centrality Rankings in 2008

This subsection first identifies the top ten countries in terms of centrality measures within the 2008 international trade network (see **Table 4**). Following the six-step analytical procedure, a radar chart (**Figure 10**) is constructed to explore the economic significance of differences in network positions for countries' trade influence, while also enabling comparison with the 2006 results.

Table 4. Top Ten Countries by Centrality Indicators in the 2008 International Trade Network

Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	Norway (1.595959596)	United Kingdom(1)	Turkey (0.99)	United States (718.961073)	Turkey (0.032802)
2	Sweden (1.59595959)	United States (0.960127)	Tunisia (0.99)	Norway (657.180139)	Qatar (0.032473)
3	Ireland (1.59595959)	Ireland (0.947221)	Myanmar (0.99)	Ireland (538.947369)	United Arab Emirates (0.026863)
4	United States (1.55555555)	Qatar (0.945246)	Norway (0.980198)	Sweden (538.659042)	Sweden (0.025688)
5	Finland (1.53535353)	France (0.941405)	Sri Lanka (0.980198)	Denmark (511.119523)	Ireland (0.025436)
6	Denmark (1.53535353)	Sweden (0.917114)	Dominican Republic (0.970588)	Finland (443.97403)	Norway (0.024692)
7	Italy (1.46464646)	Germany (0.886218)	Bangladesh (0.961165)	Turkey (342.499555)	United Kingdom

					(0.023952)
8	Spain	Denmark	Finland	Italy	United States
	(1.41414141)	(0.878987)	(0.951923)	(328.04755)	(0.023942)
9	Turkey	Norway	Singapore	Spain	Denmark
	(1.29292929)	(0.871401)	(0.951923)	(307.34778)	(0.022504)
10	Australia	Belgium	Cuba	Dominican	Germany
	(1.26262626)	(0.841492)	(0.951923)	Republic	(0.022291)
				(230.136777)	
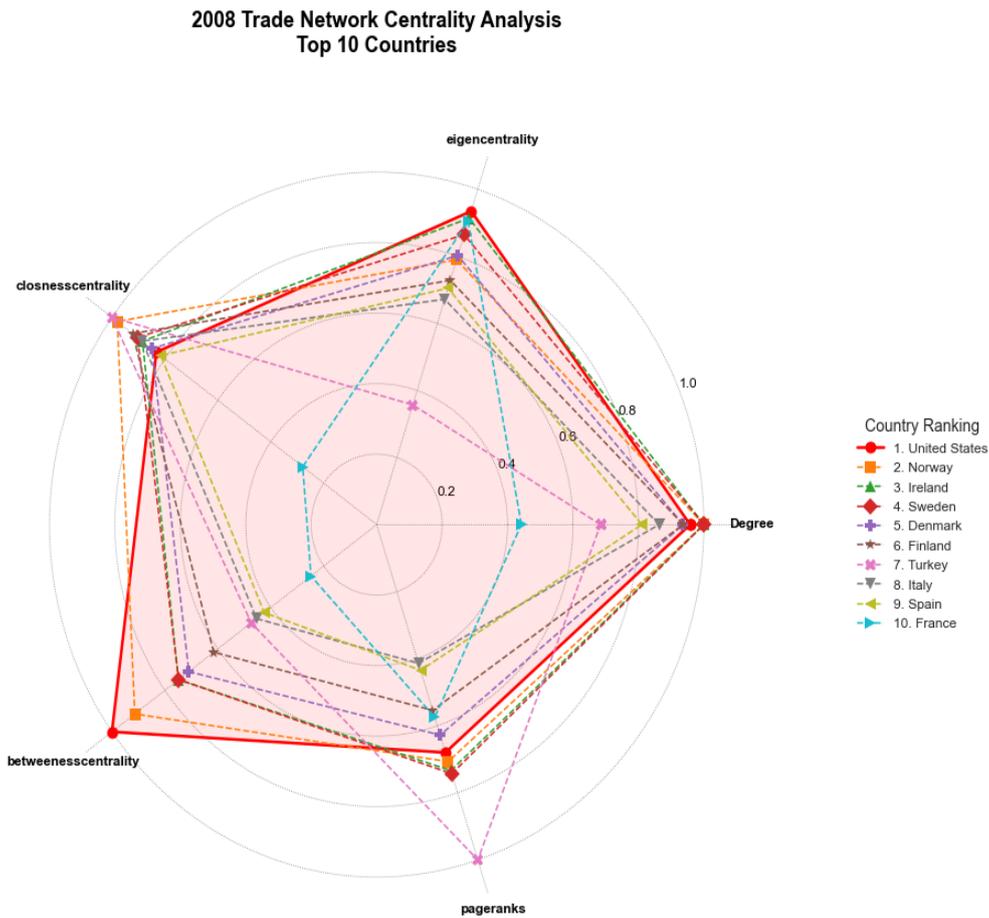
Figure 10. Radar Chart of the Top Ten Countries in 2008 by Composite Centrality Score

To continue the multi-dimensional analysis of countries' positions within the trade network, Figure 10 presents the radar chart for the ten highest-scoring countries in 2008, based on the five centrality measures. The chart highlights the relative positions and functional roles of key states in the global trade network, and allows for direct comparison with the 2006 results. Several notable patterns emerge:

The United States returned to the core position. In 2008, the U.S. performed strongly across all five indicators, particularly in degree centrality, eigenvector centrality, and betweenness centrality. This reflects not only its extensive network of trade partners but also its pivotal role as a "bridge" in global trade pathways, closely tied to its dominance in global finance and consumption prior to the financial crisis.

Nordic countries remained highly active. Norway, Sweden, Finland, and Denmark consistently ranked among the top performers across multiple dimensions. Norway maintained a leading role in betweenness centrality, underscoring its stable function as a transshipment hub. Sweden and Finland achieved high scores in eigenvector and closeness centrality, indicating close linkages to network core nodes and strong market accessibility. This highlights the compact and outward-oriented structure of Nordic trade.

Ireland emerged as a high-influence country. Ireland scored particularly well in degree and eigenvector centrality, nearly reaching the level of the U.S., indicating its role as a highly connected node in the trade network. This rise may be linked to its favorable tax policies and its attractiveness as a base for multinational export-oriented enterprises.

France's trade influence weakened. Although still ranked among the top ten, France's betweenness and PageRank scores declined significantly, suggesting erosion of its hub position in global trade pathways and rising dependence on external linkages. This reflects a trend toward marginalization within both the EU and the broader trade network.

Southern European countries maintained moderate positions. Italy and Spain scored at mid-levels in closeness and PageRank centrality but were notably weaker in betweenness centrality compared with Nordic and Anglo-American economies. This indicates their role as "participants" rather than "path controllers" within the network.

Turkey entered the core for the first time. Turkey appeared in the top ten in 2008, with a particularly strong performance in PageRank centrality. This suggests growing trade attractiveness for surrounding countries and a shift from serving as a "geopolitical hub" to a "structural hub." Given its unique Eurasian location, this trend carries important strategic implications.

Comparative dynamics with 2006.

Relative to 2006, three main trends are evident:

(1)**Reinforced core:** The U.S. rose significantly in 2008, shifting from a secondary core position in 2006 to a leading node across multiple dimensions, underscoring its pre-crisis dominance of global markets.

(2)**Structural stability:** Nordic countries such as Norway, Finland, and Sweden maintained consistently high centrality scores, indicating the persistence of their key roles within regional trade systems.

(3)**Peripheral shifts:** France and Spain declined in relative influence, pointing to marginalization in structural terms within the global trade network.

The radar chart underscores that countries' positions in the global trade network are inherently **multi-dimensional** and cannot be fully captured by a single indicator. For example, although France performs strongly in export volume, its weakening "path control" reduces its overall network significance.

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Conversely, Ireland and the Nordic states—despite smaller economies—achieve high centrality scores due to institutional advantages and geographic positioning. This demonstrates that **institutional arrangements and geopolitical location are critical non-economic variables** in shaping national trade influence.

5.2.3 Centrality Rankings in 2017

This section first identifies the top ten countries in terms of centrality measures within the 2017 international trade network (see **Table 5**). Following the six-step analytical procedure, a radar chart (**Figure 11**) is then constructed to explore, from a multi-dimensional perspective, the economic implications of differences in network positions for countries' trade influence.

Table 5. Top Ten Countries by Centrality Indicators in the 2017 International Trade Network

Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	United Kingdom (1.57575757)	Ireland (1)	Latvia (0.99)	United Kingdom (786.671873)	Ireland (0.030726)
2	France (1.45454545)	United Kingdom (0.98042)	Lithuania (0.99)	Belgium (590.160996)	Qatar (0.028585)
3	Belgium (1.42424242)	Germany (0.891693)	China (0.970588)	France (506.711191)	United Kingdom (0.027917)
4	Italy (1.38383838)	France (0.84614)	India (0.951923)	Italy (433.855637)	Denmark (0.026977)
5	Spain (1.37373737)	United States (0.842286)	Australia (0.942857)	Colombia (390.865878)	Germany (0.024596)
6	Turkey (1.28282828)	Denmark (0.838401)	Ukraine (0.933962)	Turkey (350.094691)	Belgium (0.022299)
7	Australia (1.28282828)	Qatar (0.826348)	Mozambique (0.933962)	Spain (324.928553)	France (0.022208)
8	China (1.26262626)	Canada (0.811847)	Spain (0.925234)	Sweden (308.671309)	United Arab Emirates (0.021686)
9	Colombia (1.21212121)	Sweden (0.745922)	Turkey (0.925234)	Iceland (269.490732)	Canada (0.021662)

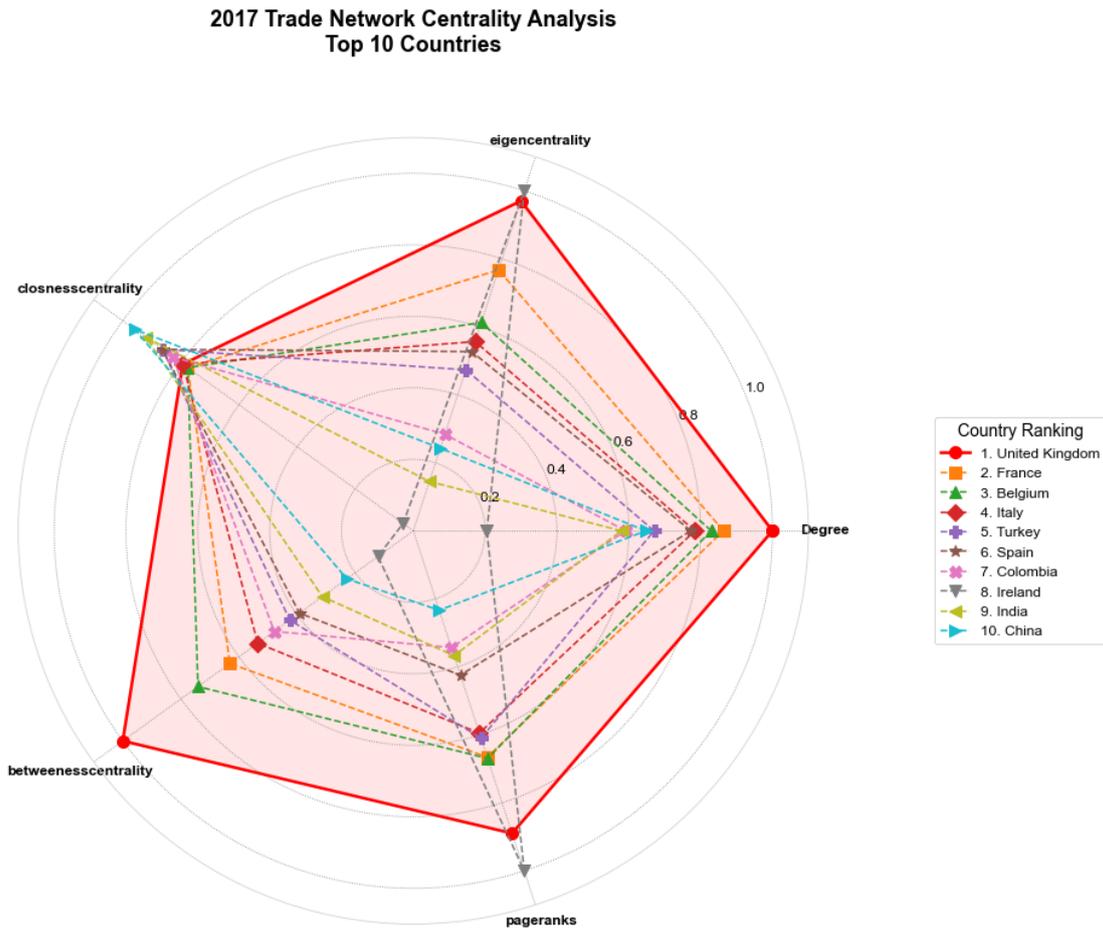| 10	Ukraine	Belgium	Colombia	India	United States
	(1.20202020)	(0.743931)	(0.908257)	(265.298264)	(0.020927)

Figure 11. Radar Chart of the Top Ten Countries in 2017 by Composite Centrality Score

Structural analysis of the radar chart for 2017 reveals several noteworthy patterns:

(1)The United Kingdom as a comprehensive leader. The UK ranked highly across all five centrality indicators, with absolute advantages in degree, betweenness, and PageRank centrality. This indicates that it was not only the most connected country but also a critical path controller and a major trade target, embodying the characteristics of a "core network hub."

(2)Belgium, France, and Italy as a Western European sub-core cluster. These countries achieved high scores in eigenvector and closeness centrality, suggesting close linkages to high-status nodes and strong trade accessibility. This reflects the dense cooperation within Western Europe.

(3)Turkey and Colombia as emerging regional bridges. Despite their relatively modest economic size globally, both countries scored well in PageRank and betweenness centrality, indicating their critical role in regional trade transmission and diffusion chains.

(4)China and India's structural roles remained underdeveloped. Although China ranked among the world's top trading powers in terms of actual trade volume, its PageRank and betweenness scores were relatively weak. This reflects a "broad outreach but limited structural embeddedness," meaning that while it maintained many trade connections, its intermediary and strategic influence within the network had yet to be fully realized. India showed a similar pattern.

(5)Persistent marginality of smaller economies. Emerging economies such as Ireland and India ranked lower in betweenness and eigenvector centrality, indicating that they had not yet established stable strategic positions within the global trade network.

In summary, the 2017 centrality radar chart highlights the **multi-dimensional nature of trade influence**. The United Kingdom exhibited the profile of a "comprehensive trade hub," combining broad connectivity with strong path control. Belgium, France, and Italy formed a high-connectivity cluster centered on Western Europe, while Turkey and Colombia, despite their smaller economies, demonstrated notable bridging capacity within their regions. By contrast, China's relatively low scores in PageRank and betweenness suggest that its strategic intermediary role within the trade network was still underdeveloped. These findings reinforce the point that a country's influence in the international trade network derives not only from economic size but also from its **connectivity and hub functions** within the global structure.

5.2.4 Centrality Rankings in 2018

This section first identifies the top ten countries in terms of centrality measures within the 2018 international trade network (see **Table 6**). Following the six-step analytical procedure, a radar chart (**Figure 12**) is then constructed to explore, from a multi-dimensional perspective, the economic implications of differences in network positions for countries' trade influence.

Table 6. Top Ten Countries by Centrality Indicators in the 2018 International Trade Network

Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	United Kingdom (1.61616161)	Ireland (1)	China (0.99)	Qatar (975.083565)	Qatar (0.032417)
2	Qatar (1.61616161)	United Kingdom (0.956382)	Lithuania (0.99)	United Kingdom (632.934075)	Ireland (0.028202)
3	France (1.53535353)	Qatar (0.924937)	Cambodia (0.99)	Canada (621.928283)	Canada (0.027731)
4	Germany (1.53535353)	United States (0.877765)	Latvia (0.99)	Denmark (614.597763)	United Kingdom (0.026489)

5	Belgium (1.45454545)	France (0.877052)	Poland (0.980198)	Germany (488.275991)	Sweden (0.023892)
6	Denmark (1.37373737)	Germany (0.864351)	Myanmar (0.951923)	France (474.760397)	Germany (0.023784)
7	Italy (1.29292929)	Sweden (0.840866)	Qatar (0.942857)	Belgium (440.810013)	Denmark (0.023729)
8	Canada (1.28282828)	Canada (0.839088)	United Kingdom (0.933962)	Italy (299.138181)	France (0.022428)
9	China (1.25252525)	Denmark (0.826495)	Thailand (0.933962)	Indonesia (208.916776)	United Arab Emirates (0.021948)
10	South Korea (1.23232323)	Belgium (0.785835)	France (0.925234)	China (165.326224)	Belgium (0.021096)

Figure 12. Radar Chart of the Top Ten Countries in 2018 by Composite Centrality Score

Structural analysis of the 2018 radar chart reveals several key findings:

(1)Qatar's structural position rose sharply. Qatar performed strongly across all five centrality measures, ranking first in betweenness, PageRank, and degree centrality. This indicates that in 2018 Qatar was not only a broadly connected country but also a crucial path controller and dependency node, reflecting the impact of its energy-exporting role and increasingly outward-oriented economic policies.

(2)The United Kingdom maintained high stability. Following its performance in 2017, the UK continued to rank near the top in multiple indicators, especially closeness and PageRank centrality, reaffirming its stable position as a global trade hub.

(3)Germany and France formed the continental European core. Both countries achieved high scores in eigenvector and closeness centrality, underscoring their close ties with high-centrality states and their strong accessibility. This reinforces their hub roles in intra-EU and extra-EU trade.

(4)Middle powers such as Canada and Denmark served as secondary hubs. These countries scored at medium-to-high levels across most indicators, reflecting stable connectivity and influence despite not being absolute cores.

(5)China remained structurally weaker in centrality. While China showed improvement in eigenvector centrality, its PageRank and betweenness scores remained moderate to low. This suggests that its broad trade ties had yet to translate fully into structural influence, with limited "path control" and dependency centrality in the network.

(6)Ireland and Italy exhibited peripheral features. Although performing reasonably in selected indicators, both ranked relatively low across the composite measures, suggesting limited overall influence on the network structure.

Overall, the 2018 radar chart indicates the **emergence of new structural hubs alongside the rebalancing of traditional cores**. Qatar rose to the center with leading positions across multiple measures, reflecting its critical role in global energy trade and transshipment pathways. The UK sustained its global hub status with strong structural stability, while Germany and France remained central connectors within Europe. By contrast, China's influence remained constrained by weaker embeddedness in path control measures, despite broad connectivity. Meanwhile, Canada and Denmark maintained steady performance as secondary hubs, whereas Ireland and Italy remained closer to the periphery. Taken together, these results highlight the dual dynamics of rising new hubs and the recalibration of established core states in the evolving global trade network.

5.2.5 Centrality Rankings in 2019

This section first identifies the top ten countries in terms of centrality measures within the 2019 international trade network (see **Table 7**). Following the six-step analytical procedure, a radar chart (**Figure 13**) is then constructed to explore, from a multi-dimensional perspective, the economic implications of differences in network positions for countries' trade influence.

Table 7. Top Ten Countries by Centrality Indicators in the 2019 International Trade Network

| Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	United Kingdom (1.57575757)	Ireland (1)	United Kingdom (1.00)	United Kingdom (127.376661)	United Kingdom (0.020563)
2	France (1.50505050)	Qatar (0.884091)	Sweden (1.00)	Sweden (127.376661)	Sweden (0.020563)
3	Sweden (1.50505050)	United Kingdom (0.859251)	Italy (1.00)	Italy (127.376661)	Italy (0.020563)
4	Belgium (1.46464646)	United States (0.842457)	Finland (1.00)	Finland (127.376661)	Finland (0.020563)
5	Germany (1.45454545)	Denmark (0.837749)	Singapore (1.00)	Singapore (127.376661)	Singapore (0.020563)
6	Italy (1.44444444)	France (0.81016)	Bangladesh (1.00)	Bangladesh (127.376661)	Bangladesh (0.020563)
7	Finland (1.37373737)	Germany (0.782281)	China (1.00)	China (127.376661)	China (0.020563)
8	Singapore (1.35353535)	Canada (0.763711)	India (1.00)	India (127.376661)	India (0.020563)
9	Spain (1.31313131)	Sweden (0.763513)	Cambodia (1.00)	Cambodia (127.376661)	Cambodia (0.020563)
10	Bangladesh (1.22222222)	Belgium (0.748418)	Philippines (0.99)	Philippines (126.822659)	Philippines (0.020384)
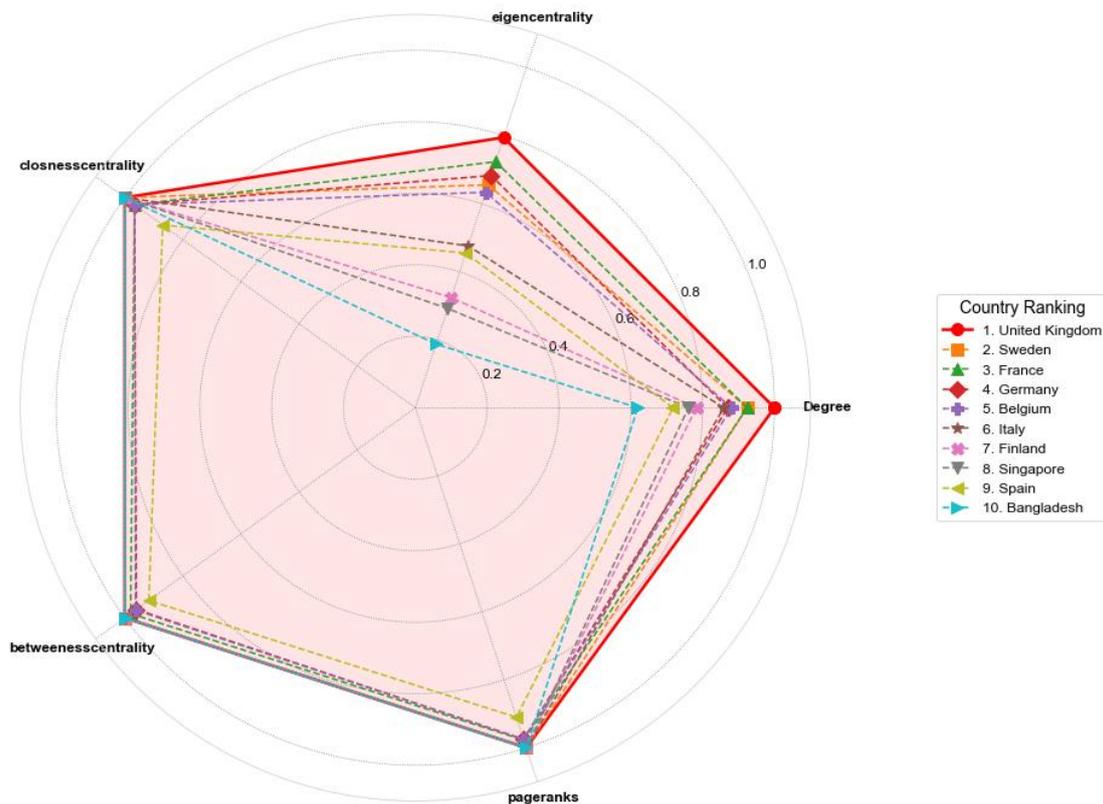
Figure 13. Radar Chart of the Top Ten Countries in 2019 by Composite Centrality Score

Structural analysis of the 2019 centrality radar chart yields several key insights:

(1)The United Kingdom remained firmly at the network core. In 2019, the UK continued to rank at the top in degree, PageRank, and betweenness centrality, highlighting its strong connectivity, path control, and dependency within the global trade network. This reinforced its status as a "multi-dimensional all-round hub state."

(2)Sweden and Germany demonstrated stability as regional cores. Sweden ranked highly across multiple indicators, combining strong connectivity with notable intermediary functions, while Germany's high scores in closeness and PageRank centrality underscored its efficiency of trade linkages and broad market influence.

(3)France, Belgium, and Italy formed the EU's traditional triad. These countries performed well in eigenvector and PageRank centrality, reflecting their dense intra-EU connections and their function as compact regional clusters critical to the stability of the European trade network.

(4)Emerging economies began embedding into the global structure. Singapore, leveraging its geographic and logistical advantages, increasingly displayed the characteristics of a regional transit node through its performance in betweenness and closeness centrality. Bangladesh entered the top ten for the

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first time, signaling that its role as a global garment exporter was being structurally recognized within the trade network.

(5)China and Japan were absent from the top ten. Despite their dominance in trade volume, neither country reached the top ten in structural centrality in 2019. This suggests that while their trade networks are broad, their strategic positioning and path control within the global structure remain underdeveloped. In summary, the 2019 radar chart shows that the United Kingdom retained a clear lead across all five centrality measures, consolidating its role as the foremost global trade hub. Sweden, Germany, and France exhibited structural stability, forming the backbone of the European regional trade system, with Sweden enhancing its bridging capacity and Germany and France demonstrating strong market reach through high PageRank scores. At the same time, the inclusion of Singapore and Bangladesh highlights how certain emerging economies are embedding themselves into the global trade network through sectoral specialization or locational advantages. By contrast, major trading powers such as China and Japan, while significant in absolute trade volumes, have yet to convert their scale advantages into equivalent structural influence. Overall, the 2019 trade network exhibited a **dual dynamic of stable core states and selective breakthroughs by peripheral economies**.

5.2.6 Centrality Rankings in 2020

This subsection first identifies the top ten countries in terms of centrality measures within the 2020 international trade network (see **Table 8**). Following the six-step analytical procedure, a radar chart (**Figure 14**) is then constructed to explore, from a multi-dimensional perspective, the economic implications of differences in network positions for countries' trade influence.

Table 8. Top Ten Countries by Centrality Indicators in the 2020 International Trade Network

Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
1	Ireland (1.75757575)	Ireland(1)	Canada (0.980198)	Ireland (1538.56734)	Ireland(0.050099)
2	Germany (1.57575757)	Germany(1)	Germany (0.980198)	Germany (711.167363)	Germany(0.37977)
3	United Kingdom (1.54545454)	Canada(1)	Ukraine (0.980198)	Canada (791.860899)	Canada(0.33182)
4	Canada (1.48484848)	Italy(1)	China (0.970588)	Italy (388.918196)	Qatar(0.32319)
5	France (1.43434343)	Ukraine(1)	United Kingdom (0.961165)	Ukraine (367.842786)	Denmark(0.025078)

6	Italy (1.37373737)	Australia(1)	Australia (0.961165)	India (329.598033)	Sweden(0.023903)
7	Australia (1.32323232)	China(1)	Ireland (0.951923)	Australia (255.953674)	United Kingdom(0.02144)
8	Ukraine (1.212121212)	South Korea (0.994594)	Myanmar (0.951923)	Norway (209.149236)	Arab(0.020737)
9	South Korea (1.16161616)	United Kingdom (0.993319)	India (0.942857)	Singapore (203.281108)	Belgium(0.020718)
10	China (1.15151515)	France (0.993319)	Mozambique (0.942857)	Belgium (154.645188)	Singapore(0.018975)
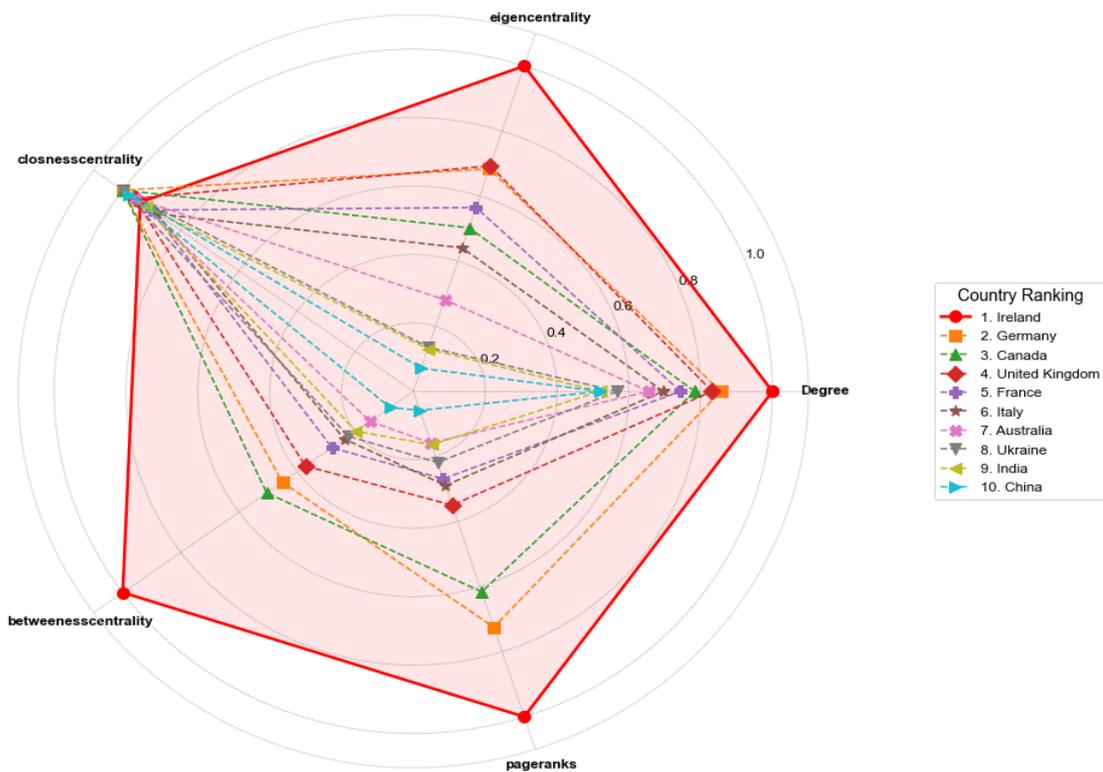
Figure 14. Radar Chart of the Top Ten Countries in 2020 by Composite Centrality Score

Structural analysis of the 2020 centrality radar chart reveals several important findings:

(1)Ireland surged as a core global hub. Ireland ranked among the top performers across all five centrality measures, with particularly strong advantages in eigenvector, PageRank, and betweenness

centrality. This underscores its multi-dimensional influence in the 2020 trade network, likely supported by its flexible tax system, highly open economy, and concentration of multinational enterprises, making it a prime example of a "small state punching above its weight."

(2)Germany and the United Kingdom retained their positions as traditional core states. Germany continued to excel in closeness and PageRank centrality, reflecting its efficiency and reach in global supply chains. The UK maintained strong scores across multiple measures, demonstrating the resilience of its structural hub position despite the uncertainties following Brexit.

(3)Canada and France sustained balanced mid-to-high influence. Canada performed well in degree and betweenness centrality, confirming its stable connectivity within North American and transatlantic trade networks. France maintained stability in eigenvector centrality, reinforcing its structural role within continental Europe.

(4)Italy, Australia, and Ukraine formed a secondary support group. While none dominated across all dimensions, these countries achieved balanced scores overall, indicating their function as structural "bridges" with significant regional diffusion capacity.

(5)China and India continued to display a "volume-strong but structure-weak" profile. Despite China's position as one of the world's largest traders by volume, it ranked relatively low in PageRank and betweenness centrality—measures associated with path control and dependency. This suggests a persistent gap between its scale advantage and its structural embeddedness and control in the global trade network.

In summary, the 2020 radar chart shows Ireland's remarkable rise as a multi-dimensional structural hub, combining connectivity, path control, and influence diffusion. Germany and the UK retained their strong core roles, with Germany as an efficiency-oriented hub and the UK as a resilient intermediary center. Canada and France continued to function as stable regional bridges, while Italy, Australia, and Ukraine provided secondary structural support. By contrast, major emerging economies such as China and India remained in a transitional stage, with global trade volume leadership not yet fully matched by structural influence. Overall, the 2020 trade network reflected a **threefold pattern of stability among traditional cores, breakthrough by small states, and adjustment among major economies**.

5.2.7 Centrality Rankings in 2021

Based on the composite ranking of five centrality measures for the 2021 international trade network, the top twelve countries were: **El Salvador, France, Ukraine, Germany, Australia, India, Spain, Lithuania, China, the United Kingdom, Denmark, and Thailand**. These countries constituted the "first tier" of the global trade network in that year. All twelve exhibited identical scores across six centrality indicators, ranking first with degree centrality (99/100), eigenvector centrality (1.0), PageRank centrality (0.0184), betweenness centrality (94.39), closeness centrality (1.0), and authority (0.1545).

For the "second tier" (composite ranks 13–20,see Table 9), a radar chart was constructed to further investigate structural differences (see Figure 15). Several findings emerge:

(1)Cambodia, Ecuador, and Namibia demonstrated remarkable "structural breakthroughs." These three economies scored near maximum values across all five centrality dimensions. Cambodia, in particular, stood out in betweenness and PageRank centrality, indicating a sharp rise in its role as a conduit and highly dependent node within the global supply chain. Its advantages in labor-intensive manufacturing (e.g., textiles and apparel), export-oriented policies, and geographic logistics likely explain this structural leap.

(2)Colombia and the Philippines began to emerge as regional transit hubs. Both recorded strong scores in PageRank and betweenness centrality, reflecting growing connectivity and intermediary control within their respective regions. This trend is consistent with their integration into agricultural, resource-based, and lower-tier global value chain activities.

(3)Portugal and Sweden exhibited structural stability. Portugal, despite its peripheral status within the EU, performed well in eigenvector and closeness centrality, underscoring its steady ties with European core economies. Sweden, benefiting from long-standing openness and institutional advantages, retained a strong and balanced network position.

(4)Bangladesh and South Africa displayed a dual profile as "trade nodes and manufacturing bases." While their betweenness centrality remained relatively low, they achieved strong performance in PageRank and degree centrality, suggesting that their primary function was as export-dependent markets rather than as trade intermediaries.

(5)Ireland slipped out of the top twelve but maintained notable influence. Although its overall rank declined, Ireland continued to score well in closeness and PageRank centrality, reflecting its enduring global trade connectivity supported by corporate registrations and tax advantages.

(6)The first-tier group remained dominated by advanced Western economies. France, Germany, and the United Kingdom remained firmly within the top twelve, reflecting the enduring centrality of developed nations in the global trade structure.

Overall, the radar chart for the 13th to 20th ranked countries in 2021 revealed the rapid rise of several "structural challengers." Emerging economies such as Cambodia, Ecuador, and Namibia performed exceptionally well in key centrality measures, underscoring their growing importance as channels and export-oriented hubs within global production chains. Colombia and the Philippines consolidated their status as regional intermediaries in the Americas and Southeast Asia, while Portugal and Sweden preserved strong embeddedness through stable institutions and integration with regional networks. Bangladesh and South Africa stood out as heavily relied-upon export markets, albeit with weaker transit functions. Ireland, though no longer part of the structural core, maintained respectable scores in multiple dimensions. In sum, the 2021 trade network reflected both the continued dominance of advanced economies and the accelerated embedding and ascent of selected developing countries.

Table 9. Top Ten Countries by Centrality Indicators in the 2021 International Trade Network

| Rank	Degree Centrality	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality	PageRank Centrality
13	Cambodia (0.98989899)	Namibia (0.993106)	Namibia (0.99)	Cambodia (93.439844)	Cambodia (0.018233)
14	Ecuador (0.98989899)	Ecuador (0.992141)	Ecuador (0.99)	Colombia (92.306807)	Ecuador (0.018222)
15	Namibia (0.98989899)	Cambodia (0.988055)	Cambodia (0.99)	Ecuador (91.722187)	Namibia (0.018215)
16	Colombia (0.97979798)	Sweden (0.985408)	Sweden (0.980198)	Namibia (91.319659)	Colombia (0.01807)
17	Portugal (0.97979798)	Philippines (0.982154)	Philippines (0.980198)	Portugal (91.162347)	Portugal (0.018062)
16	Philippines (0.97979798)	Portugal (0.979472)	Portugal (0.980198)	Philippines (89.771354)	Philippines (0.018047)
17	Sweden (0.97979798)	Colombia (0.976498)	Colombia (0.980198)	Bangladesh (88.892263)	Sweden (0.018039)
18	Bangladesh (0.96969697)	South Africa (0.97349)	South Africa (0.970588)	Sweden (88.673769)	Bangladesh (0.017885)
19	South Africa (0.96969697)	Bangladesh (0.970209)	Bangladesh (0.970588)	South Africa (87.770108)	South Africa (0.017884)
20	Ireland (0.89898989)	Ireland (0.912117)	Ireland (0.908257)	Ireland (72.695849)	Ireland (0.016665)
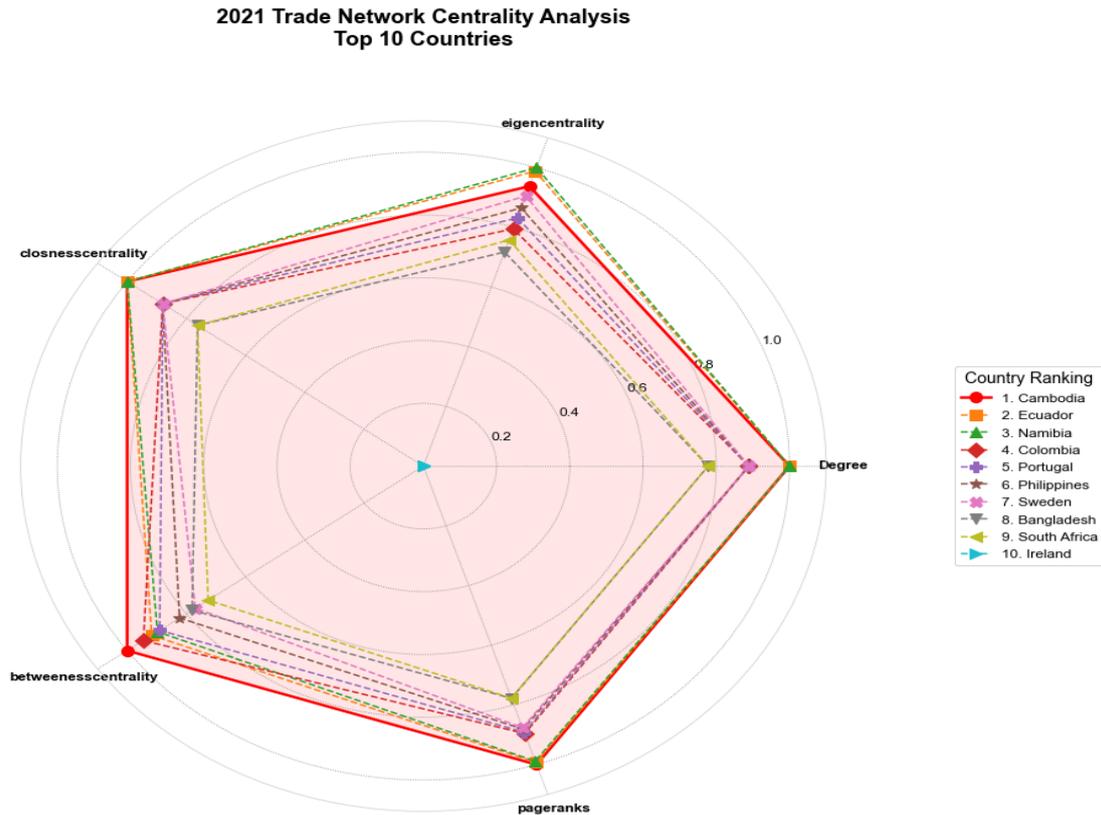
Figure 15. Radar Chart of the Top Ten Countries in 2021 by Composite Centrality Score

5.3 Summary

From 2006 to 2021, the dynamic evolution of radar charts of centrality in the international trade network reveals a clear trajectory of structural transformation and hierarchical reconfiguration.

On the one hand, **traditional developed economies such as the United Kingdom, Germany, and France consistently occupied leading positions across all five centrality measures**, demonstrating strong structural stability and path-controlling capacity. These countries typically exhibit extensive trade linkages (high degree centrality), broad spillover influence (high PageRank), and command over critical trade corridors (high betweenness centrality), thereby securing their position at the core of the global trade system.

On the other hand, a group of **smaller states and emerging economies gradually achieved "structural breakthroughs."** Countries such as Norway, Ireland, Lithuania, and Qatar rose to prominence in certain years due to their roles as regional transit hubs, institutional advantages, or integration into global value chains—an illustration of the "small state, high centrality" phenomenon. In recent years, low-income economies including Cambodia, Bangladesh, and El Salvador have also ranked highly in centrality, reflecting structural reshaping driven by the deepening of global value chains. This suggests that "small in scale but crucial in pathways" can also generate significant influence.

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At the same time, **major emerging economies such as China and India have been transitioning from "scale dominance" to "structural embeddedness."** Their scores in degree centrality and PageRank have steadily improved, yet their lagging performance in betweenness and eigenvector centrality indicates that, while they remain powerful exporters and end markets, their roles as strategic hubs within multilateral trade structures are still in development.

In sum, the structure of the international trade network between 2006 and 2021 has shifted from a **"core–periphery" model toward a multi-core, multi-channel configuration**. Centrality in global trade is gradually evolving from a concentrated pattern dominated by a few developed economies into a more **polycentric, stratified, and dynamically evolving network structure**. This transformation provides both theoretical foundations and empirical evidence for future global trade governance, regional cooperation, and the restructuring of global value chains.

6. Conclusion and Outlook

6.1 Conclusion

This paper constructed an international trade network for 101 countries from 2006 to 2021 using trade-related data, and employed traditional social network analysis (SNA) methods to examine network structure, community evolution, and changes in country positions. The analysis was followed by an interpretation of the economic implications. The key findings are as follows:

● **Degree centrality alone cannot determine a country's importance within the network.** A larger number of trade partners merely reflects higher connectivity but does not necessarily indicate greater control over trade pathways or circulation structures.

● **"Composite centrality" better reflects a country's true influence.** Radar charts integrating multiple dimensions—including degree, betweenness, and other centrality measures—reveal that smaller economies such as Norway, Qatar, and Belgium, despite their limited size, play critical intermediary and strategic roles within the trade network.

● **Some traditional powers exhibit signs of "structural marginalization."** Countries such as France and Spain, while maintaining a large number of connections, score relatively low on PageRank and betweenness centrality. This suggests that their influence is still largely dependent on traditional scale rather than structural advantage.

● **Emerging economies are increasingly embedded within global trade pathways.** Countries such as Bangladesh and the Philippines have leveraged specific value chains or policy instruments to gradually secure structural positions in the global network.

6.2 Policy Recommendations

Based on these findings, the number of trade partners may reflect the breadth of external linkages but does not determine a country's pivotal role in the global trade network. Accordingly, the following recommendations are proposed:

● **Develop a multidimensional trade assessment system.** Policymakers should incorporate structural indicators such as PageRank and betweenness centrality to identify truly critical network players, rather than relying solely on degree centrality or trade volume.

● **Strengthen connections with key nodes.** Priority should be given to deepening cooperation with countries exhibiting high betweenness and strong path control, thereby enhancing national embeddedness in the global trade network.

● **Enhance institutional hub status.** Customs and taxation systems should be optimized to attract multinational enterprises, drawing on the experiences of countries such as Ireland and Singapore to establish internationally competitive transit platforms.

● **Promote regional cooperation and community stability.** Initiatives such as RCEP and other regional frameworks should be advanced to foster cohesive trade communities and enhance resilience against external shocks.

● **Establish a trade structure early-warning mechanism.** By combining multidimensional centrality measures with community evolution trends, policymakers can dynamically monitor network changes, anticipate risks, and strengthen the forward-looking capacity of trade policy.

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