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Global Marble Trade After China's World Trade Organisation Membership: A Complex Network Approach

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Abstract This study explores the evolution of the global marble trade network (GMTN) over the period 1995–2021, with a particular focus on structural changes linked to China's accession to the World Trade Organisation (WTO) in 2001. By employing complex network analysis on a long-term temporal scale, the research documents the gradual transformation of the network and the increasing centrality of China within global marble trade flows. The results show that the post-2001 period is associated with a marked increase in trade integration, during which China moved from a relatively peripheral position towards a more central role in both raw and processed marble trade. Analysis of key network metrics—including density, centrality, and modularity—reveals notable shifts in network organisation following WTO accession, highlighting China's growing structural embeddedness within global producer–consumer linkages. This research contributes to the literature by offering an empirical framework for understanding how significant institutional changes may be associated with the reorganisation of global natural resource trade networks.

Keywords Marble · Complex Network Analysis · World Trade Organisation · China · International Trade

Jel Codes L14, L72, C49

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Global Marble Trade After China's World Trade Organisation Membership: A Complex Network Approach

Natural stones, as geologically occurring materials, represent an important category of natural resources due to their durability, aesthetic appeal, and long-standing historical use. Their distinctive visual characteristics have contributed to their widespread application in artistic and architectural contexts since antiquity. The cultural and structural significance of natural stones is evident across civilisations; for instance, ancient Egyptians employed large stone blocks in the construction of pyramids, whereas the Romans extensively used marble in monumental architecture, many examples of which have survived to the present day with rich decorative features (Hanieh et al., 2014). In contemporary settings, natural stones remain widely used in the construction sector, particularly for surface cladding, flooring, and decorative elements. Sustained global demand for these materials is driven by their unique natural patterns, environmental compatibility, structural strength, and broad range of colours and textures that meet diverse aesthetic requirements.

Natural stones occur in varying forms and quantities across most countries, with differences in colour, texture, and pattern reflecting their geological origins. These variations play an important role in shaping international trade dynamics. Among natural stone types, marble is among the most commercially significant commodities. From a geological perspective, marble is a metamorphic rock formed by the recrystallisation of limestone (calcite or dolomitic) under high-temperature, high-pressure conditions. The global marble trade exhibits a complex and interconnected structure in which countries assume distinct yet sometimes overlapping roles along the supply chain. Broadly, three groups can be identified. The first consists of producer countries that extract raw marble blocks and export them to other markets, often located along the Alpine–Himalayan orogenic belt, including Italy and Türkiye. The second group comprises processing countries that import marble blocks and add value through cutting and polishing, with China as a prominent example. The third group includes consumer countries that primarily import finished marble products, with the United States serving as a primary end market. In practice, several countries simultaneously play multiple roles as producers, processors, and consumers in the global marble trade (González, 2008).

China, one of the world's oldest civilisations, historically occupied a leading position in technological innovation and commercial activity. However, between the sixteenth and eighteenth centuries, Western European powers gradually surpassed China in global economic and political influence, particularly during the Age of Exploration, as trade routes increasingly shifted towards the Atlantic and the Americas (Zhu, 2012). This process diminished the Silk Road's strategic importance and contributed to China's marginalisation within international trade networks for several centuries. A gradual reintegration began in the late 20th century, most notably following the introduction of market-oriented reforms and the "Open Door Policy" in 1978. China's accession to the WTO in 2001 marked a further stage in this process. Since then, China has experienced sustained economic growth, maintaining its expansion despite major global disruptions, such as the 2008 financial crisis and the COVID-19 pandemic. As of 2023, China ranks as the world's second-largest economy by gross domestic product, with an estimated value of approximately 17.73 trillion USD (The World Bank, n.d.), and has increasingly outperformed many European Union economies (Li & Bai, 2023). Long-term projections indicate that China might overtake the United States to become the world's largest economy by the mid-21st century (Goldman Sachs, 2022; Fitch, 2023).

Against this background, this study examines structural changes in the GMTN over the period 1995–2021, with particular attention to developments observed in the years following China's accession to the WTO. The analysis focuses on how trade relationships evolved, how interdependencies among countries were reconfigured, and what implications these changes may hold for industry stakeholders and policymakers involved in the marble trade.

This study contributes to the literature by analysing the temporal evolution of the GMTN in the post-accession period, documenting key structural patterns, and examining conditions associated with changes in bilateral trade relationships. By employing a complex network analysis framework, the research offers insights into the organisation and structural characteristics of GMTN. Accordingly, the study addresses three main research questions. First, it investigates which countries function as the primary driving forces within the GMTN. Second, it examines how China's role has evolved in terms of its centrality in imports and exports since its accession to the WTO. Finally, it explores how structural groupings and community configurations within the GMTN have changed over time.

Literature Review

As part of its accession to the WTO, China committed to several core trade principles, including non-discrimination, transparency, predictability, trade liberalisation, and fair competition (WTO, n.d.). In line with these commitments, China implemented a series of policy reforms, such as reductions in customs barriers, the adoption of more liberal trade policies, and the integration of WTO dispute settlement mechanisms into its domestic trade framework. The existing literature associates these reforms with China's expanding role in international trade and its growing attractiveness to foreign investors. In particular, increased inflows of foreign direct investment have been linked to accelerated industrial development and export capacity (Agarwal & Wu, 2004). Contemporary studies further note that China's manufacturing prominence reflects a combination of relatively low labour costs and sustained industrial investment, which has supported its extensive participation in global markets.

International trade is commonly conceptualised as a complex system shaped by economic interdependencies among countries. Within this framework, trade networks are modelled as configurations of nodes (countries) and edges (trade relationships), allowing researchers to examine structural properties such as connectivity, density, and centrality (Gan, 2004). Therefore, complex network analysis has become a widely used methodological approach for analysing global trade patterns. Previous studies applying this framework document notable changes in China's position within the global trade network over time, particularly after its WTO accession. Empirical research reports an increase in China's trade connections, especially with Asian economies and emerging markets, alongside higher levels of network embeddedness (Gan, 2004; Wang, 2003; Cui, 2022). These developments are frequently discussed in the literature regarding China's expanding trade volumes and its evolving role within global supply chains.

A growing body of research employing network-based approaches emphasises China's prominent position within international trade structures. Herman (2022) highlighted the importance of network dependencies in shaping bilateral trade flows and identified China as a key actor within these interconnections. Farooq et al. (2018) similarly described China as one of the most central nodes in global trade networks, noting its significance in both import and export activities. Sajedianfard et al. (2021) examined trade density and connectivity measures and reported that China occupies a structurally influential position within the international trade network. Xu and Cheng (2016) analysed China's bilateral relationships in service trade

and identified strong correlations that reinforce mutual exchange patterns. In a related institutional context, Trucmel et al. (2022) investigated China's engagement with the WTO dispute settlement mechanism, underscoring its increasing involvement in global trade governance. Collectively, this literature documents China's rising structural importance within international trade networks while recognising the multifaceted and evolving nature of global economic integration.

Complex network analysis has also been applied to the study of international trade in natural resources. Zhu et al. (2023) analysed global boron mineral trade using an integrated framework that combines complex network analysis, core–periphery structures, and link prediction techniques. Cong et al. (2023) investigated the temporal and spatial evolution of global energy trade networks, while Wang et al. (2019) applied similar methods to examine developments in international coal trade. Soyyiğit et al. (2020) analysed global coal trade flows between 2000 and 2017 using multiple network metrics, and Hao et al. (2018) explored the competitive structure of iron ore imports through network-based approaches. Despite extensive application of network analysis across various natural resource markets, relatively little attention has been paid to the international trade network for marble. This gap in the literature motivates this study, which applies complex network analysis to the global marble trade.

The global distribution of marble, along with its extensive use in construction and artistic and decorative activities, has supported the development of a broad international trade network. Beyond its functional and aesthetic value, marble represents a significant source of export revenue and employment for countries endowed with substantial marble reserves. Over the past two decades, the value of the global marble trade has increased markedly. According to UN Comtrade data, global marble exports rose from approximately 2.1 billion USD in 2000 to around 6.9 billion USD in 2021 (UN Comtrade, n.d.). Despite marble's economic importance, widespread industrial use, and growing contribution to national income and employment, a systematic review of the existing literature reveals that no study has explicitly examined global marble trade relations within a network-analytical framework. In particular, analyses that model the structure, connectivity, and relational patterns of the global marble trade as an international trade network have not been identified. This apparent absence in the literature provides the primary motivation for applying complex network analysis to the global marble trade in the present study.

Methodology

Complex network analysis has become an established methodological approach for visualising and interpreting systems characterised by intricate relational structures (Liu et al., 2016). It facilitates the examination of the interactions between nodes and edges within a given network, enabling a deeper understanding of connectivity, centrality, and structural patterns (Yang & Yang, 2008). Accordingly, this study employs complex network analysis to investigate the evolution of the international marble trade over time.

Network construction and analysis were conducted using Gephi, a commonly used software for large-scale network visualisation and computation. For visual representation, the Fruchterman–Reingold force-directed layout algorithm was used (Fruchterman & Reingold, 1991). This algorithm positions nodes based on simulated attractive and repulsive forces to improve visual clarity. Notably, the layout algorithm is employed solely for visualisation and does not affect the calculation of network metrics. All analytical interpretations in this study are based on quantitative network indicators rather than the spatial positioning of nodes in graphical layouts.

The study focuses on a set of standard network metrics, including degree-based centrality measures, network density, and modularity, which are used to characterise the structure and evolution of the GMTN over time. These metrics enable systematic comparisons of network properties across years and support the identification of structural changes within the global marble trade system.

Data Source

The trade data used in this study were obtained from the United Nations Comtrade Database (UN Comtrade, n.d.). The analysis is based on export flows, where reporting countries are treated as exporters (source nodes) and partner countries as importers (target nodes). This approach ensures that the network weights represent the actual economic value of marble commodities at the point of origin, excluding extraneous costs such as international freight and insurance.

To capture the temporal evolution of the GMTN, trade data were analysed at distinct intervals spanning 1995, 2000, 2001, 2006, 2011, 2016, and 2021. The inclusion of the years 1995 and 2000 provides a pre-WTO benchmark, while 2001 marks China's accession to the WTO. Subsequent observations at approximately 5-year intervals allow for the examination of longer-term structural developments in the network.

Trade values are recorded in current USD, as reported in the database. While current values do not account for inflation, they are standard in network analysis when the primary research focus is on the relative structural positions, topological rankings, and proportional shifts within the network rather than absolute longitudinal purchasing power. The dataset encompasses marble-related commodities classified under the Harmonised System (HS) codes (specifically covering raw blocks and processed products), as detailed in Table 1. To ensure the robustness of the network metrics and to mitigate "noise" caused by transient or economically marginal transactions, a thresholding procedure was applied: only bilateral trade flows with an annual value of USD 1 million or more were included. This cleaning step preserves the backbone of the GMTN, focusing the analysis on substantively relevant and stable trade relationships. The resulting network is a directed, weighted graph in which edge weights reflect the intensity of trade flows.

Table 1

Harmonised System Codes of Goods Used in the Study

HS commodity codes	Commodity Descriptions
2515	Marble, travertine, cassine, and other calcareous stones; of an apparent specific gravity of less than 2.5, alabaster, whether cut by sawing, etc., into blocks or slabs of a rectangular (square) shape
680221	Marble, travertine, and alabaster; simply cut or sawn, with a flat or even surface.
680291	Marble, travertine, and alabaster; articles thereof (other than simply cut or sawn, with a flat or even surface)

Key indicators for complex network analysis

The GMTN is modelled as a directed and weighted graph G = (V, E), where $V = \{ v_i \mid i = 1, 2, ..., n \}$ represents the set of nodes corresponding to countries, and $E = \{ e_{ij} \}$ denotes the set of directed edges representing bilateral marble trade relationships. An edge from node i to node j exists when country i exports marble products to country j. The weight of each edge, w_{ij}, corresponds to the monetary value of trade (in USD) between the two countries. This representation allows the network to capture both the direction and intensity of trade flows.

Network density provides a general measure of overall connectivity in the network and reflects the proportion of realised trade links relative to all possible links. For a directed network without self-loops, density is defined as follows:

$$D = \frac{m}{n(n-1)} \tag{1}$$

where m is the number of observed trade links and nnn is the total number of countries in the network. Density values range between 0 and 1, with higher values indicating a more interconnected trade structure (Liu et al., 2022).

Degree centrality captures the number of direct trade connections of a node. In a directed trade network, degree centrality is decomposed into out-degree and in-degree. Out-degree reflects the number of export connections, whereas in-degree represents the number of import connections. For node i in year t, these measures are defined as

$$k_i^{\text{out}}(t) = \sum_{j=1}^{n} a_{ji}(t) \tag{2}$$

$$k_i^{\text{in}}(t) = \sum_{j=1}^{n} a_{ji}(t) \tag{3}$$

where $a_{ij}(t)$ indicates the existence of a directed trade relationship from country i to country j in year t. Higher in-degree or out-degree values indicate greater trade connectivity and interaction potential (Zhong et al., 2016).

Eigenvector centrality extends the concept of degree centrality by accounting for the number of connections and the importance of neighbouring nodes (Thasni & George, 2022; Soh et al., 2010). A country is considered more central if it is connected to other highly central countries. The eigenvector centrality score x_i node i is defined as

$$x_i = \lambda_1 \sum_{j=1}^{n} w_{ij} x_j \tag{4}$$

$$\lambda x = A\, x \tag{5}$$

where A is the weighted adjacency matrix, x is the eigenvector corresponding to the largest eigenvalue λ, and w_{ij} denotes the weight of the trade link between nodes i and j.

Betweenness centrality measures the extent to which a node lies on the shortest trade paths between other nodes, capturing its potential role as an intermediary in the network. It is defined as

$$C_B(i) = \frac{2}{(n-1)(n-2)} \sum_{j \neq k \neq i} \frac{g_{jk}(i)}{g_{jk}} \tag{6}$$

where g_{jk} denotes the number of shortest paths between nodes j and k, and $g_{jk}(i)$ represents the number of paths that pass through node i.

Closeness centrality reflects how close a node is to all other nodes in the network based on the length of the shortest paths. It is defined as

$$C_C(i) = \frac{n-1}{\sum_{j \neq i} d_{ij}} \tag{7}$$

where d_{ij} is the shortest path distance between nodes i and j (Hossain & Alam, 2017; Ghali et al., 2012).

Modularity measures the extent to which a network can be divided into densely connected communities with relatively sparse connections between them (Wang et al., 2019). Community detection was performed using the Louvain algorithm (Blondel et al., 2008). For a weighted network, modularity is defined as

$$Q = \frac{1}{2m} \sum_{ij} \left[w_{ij} - \frac{k_i k_j}{2_m} \right] \delta(c_i, c_j) \tag{8}$$

where w_{ij} is the weight of the edge between nodes i and j, k_i and k_j denote the weighted degrees of nodes i and j, m is the total weight of all edges in the network, and $\delta(c_i, c_j)$ equals 1 if nodes i and j belong to the same community and 0 otherwise.

Results

This section presents the empirical findings of the study based on the network measures and visualisations described in the methodology. The results are organised to highlight the temporal patterns and structural characteristics of the GMTN across the selected years.

Visualisation of the Network Structure

The visual representations of the GMTN are presented in Figure 1 for the years 1995, 2000, 2001, 2006, 2011, 2016, and 2021. The networks were visualised using the Fruchterman–Reingold force-directed layout algorithm, which is employed solely to enhance graphical clarity and facilitate visual inspection of the network structure. In these visualisations, node size is scaled by out-degree centrality, representing the number of export connections each country maintains within the GMTN. Accordingly, countries with more export linkages are depicted by larger nodes. The thickness of the edges reflects the monetary value of bilateral marble exports, measured in USD, with thicker edges indicating higher trade volumes. The node border colours denote the modularity classes identified by community detection; nodes with the same colour belong to the same modularity group.

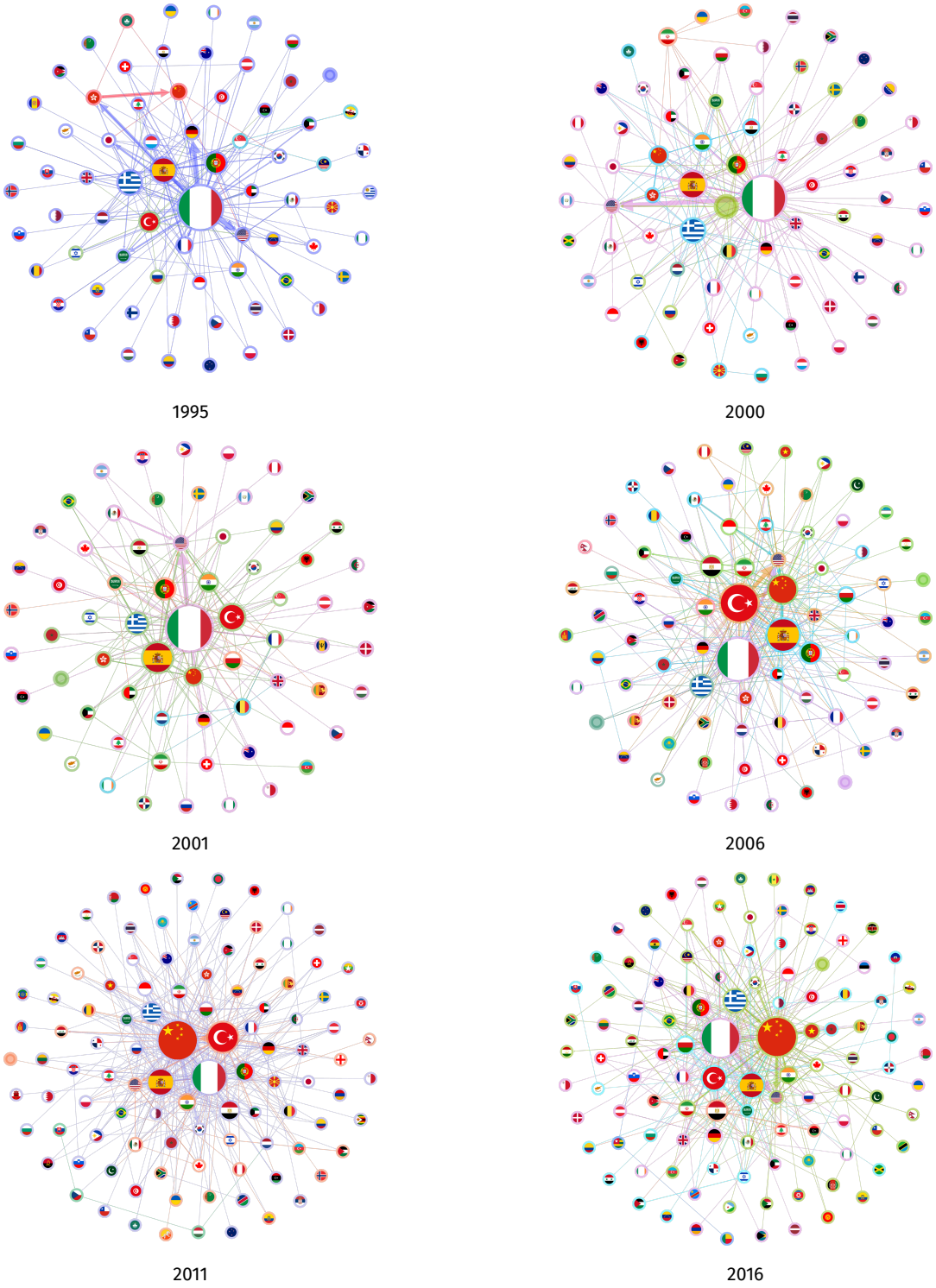
An examination of the network visualisations reveals distinct differences between the pre- and post-WTO periods. In 1995 and 2000, the pre-WTO benchmark years, Italy appears as a visually prominent exporter within the GMTN, characterised by a relatively large node size and multiple outward trade connections. During the same period, China is represented by a comparatively minor node, indicating a more limited number of export linkages and suggesting that it had not yet emerged as a significant export centre in the GMTN.

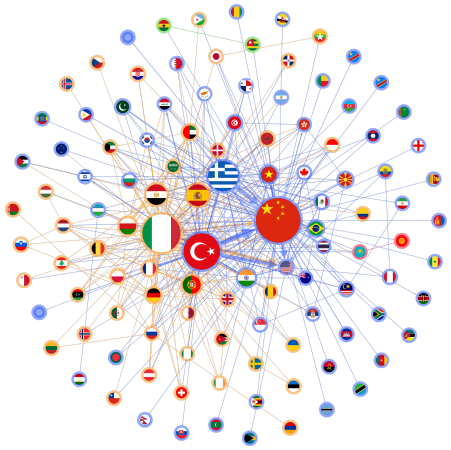
In the years following China's accession to the WTO, the visual structure of the GMTN changes noticeably. Over time, China's node size increases and its export connections expand to a broader set of trading partners, making its presence within the network visually more pronounced. This pattern indicates a substantial expansion in China's export linkages within the GMTN. At the same time, some countries that appeared visually prominent in earlier periods are represented by relatively minor nodes in later years, reflecting changes in their export connectivity within the evolving network structure.

These visual observations provide a descriptive overview of how the GMTN configuration has evolved. A more detailed and systematic evaluation of these patterns, including their magnitude and comparative significance across countries, is presented in the following subsection through the analysis of quantitative network indicators.

Figure 1

Spatial Evolution of the GMTN





2021

Key indicators of GMTN

Figure 2 presents the evolution of the GMTN in terms of the number of nodes, number of edges, and network density for the selected years. In network analysis, nodes represent countries participating in trade, whereas edges denote bilateral trade relationships between them. Examining changes in these indicators over time provides a quantitative overview of how the structure of the GMTN has evolved.

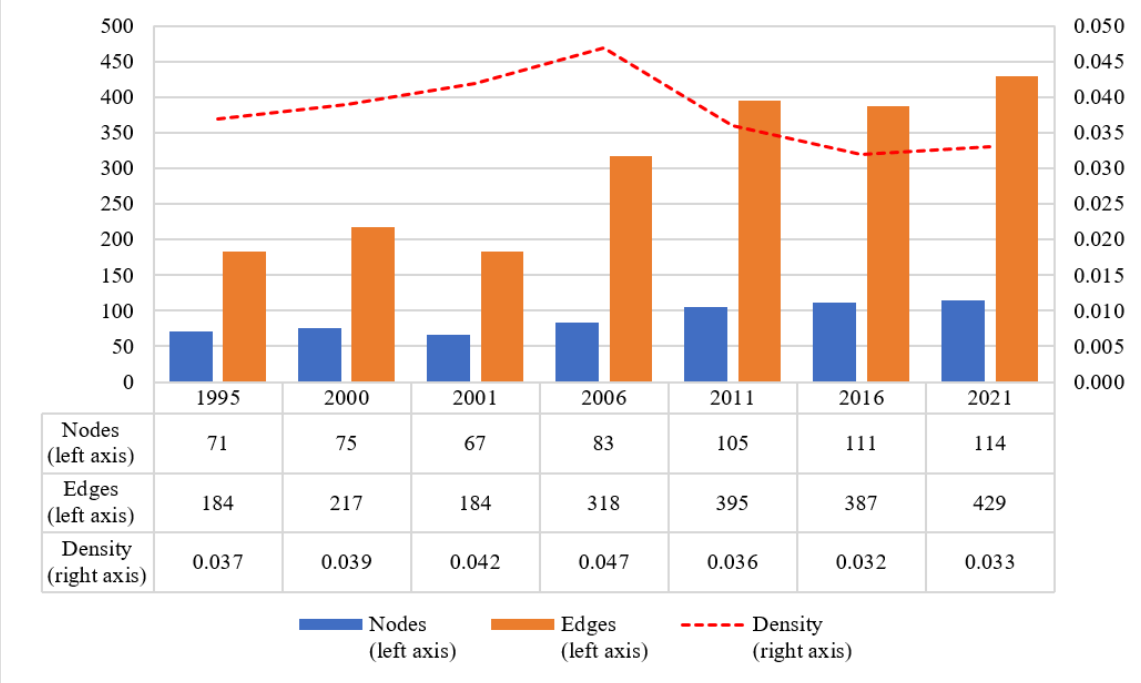
Before China acceded to the WTO, the GMTN consisted of 67 nodes (corresponding to 67 participating countries) and 184 trade links. In subsequent years, the number of nodes gradually increased, reaching 114 countries by 2021. Although a temporary decline in the number of nodes was observed in 2001, the overall trend reflects an expansion in the set of countries involved in global marble trade over the study period.

Changes in the number of edges are more pronounced than those observed for nodes. The total number of trade links increased from 184 in 1995 to 217 in 2000, before declining again to 184 in 2001. Following this year, the number of edges rose sharply, reaching 318 in 2006, 395 in 2011, and ultimately 429 in 2021. This steady increase indicates a substantial expansion in the number of bilateral trade relationships within the GMTN, reflecting greater interaction among participating countries over time.

Network density, reported on the right axis of Figure 2, captures the proportion of realised connections relative to all possible connections in the network. Density increased from 0.037 in 1995 to 0.047 in 2006, indicating that the GMTN became relatively more interconnected during this period. After 2006, network density declined to 0.036 in 2011 and 0.032 in 2016, before stabilising slightly at 0.033 in 2021. This pattern suggests that, despite continued growth in the number of nodes and edges, the relative level of interconnectedness among all possible country pairs evolved differently as the network expanded.

Figure 2

Network Characteristics of the GMTN



	1995	2000	2001	2006	2011	2016	2021
Nodes (left axis)	71	75	67	83	105	111	114
Edges (left axis)	184	217	184	318	395	387	429
Density (right axis)	0.037	0.039	0.042	0.047	0.036	0.032	0.033

Figure 3 presents the spatial distribution of in-degree, out-degree, and overall degree centrality values for countries participating in the GMTN, visualised on a geographic map for the selected years. These indicators provide a comparative overview of countries' trade links within the network from both import and export perspectives and allow for a descriptive assessment of changes in network connectivity over time.

In directed trade networks, in-degree centrality is the number of incoming trade connections a country receives and reflects the breadth of its import relationships within the GMTN. In the marble trade, higher in-degree values indicate a greater number of sourcing partners. The map-based visualisations show that certain countries, including the United States and China, are represented with relatively high in-degree values across different periods, indicating extensive import linkages within the network. A comparison between the pre- and post-WTO periods reveals a visible shift in China's incoming representation. In the maps for pre-2001 years, China is characterised by relatively lower in-degree values, reflecting a more limited set of import connections within the GMTN. In contrast, in the post-2001 visualisations, China appears with progressively higher in-degree values, indicating an expansion in the number of countries from which it imports marble-related products. This pattern suggests that China's import connectivity within the network has broadened over time.

Out-degree centrality measures the number of outgoing trade connections a country maintains and captures the extent of its export relationships. Within the GMTN, higher out-degree values correspond to a broader set of export destinations for marble-related products. The spatial distribution of out-degree values highlights several European countries—such as Italy, Türkiye, and Spain—as visually prominent exporters in the earlier periods of the analysis. Regarding China, the out-degree-based maps show a notable change over time. Before China acceded to the WTO, it was represented with relatively modest out-degree values, suggesting a limited number of export destinations within the GMTN. In the subsequent years, China's out-degree representation becomes increasingly prominent, reflecting an expansion in the number of countries

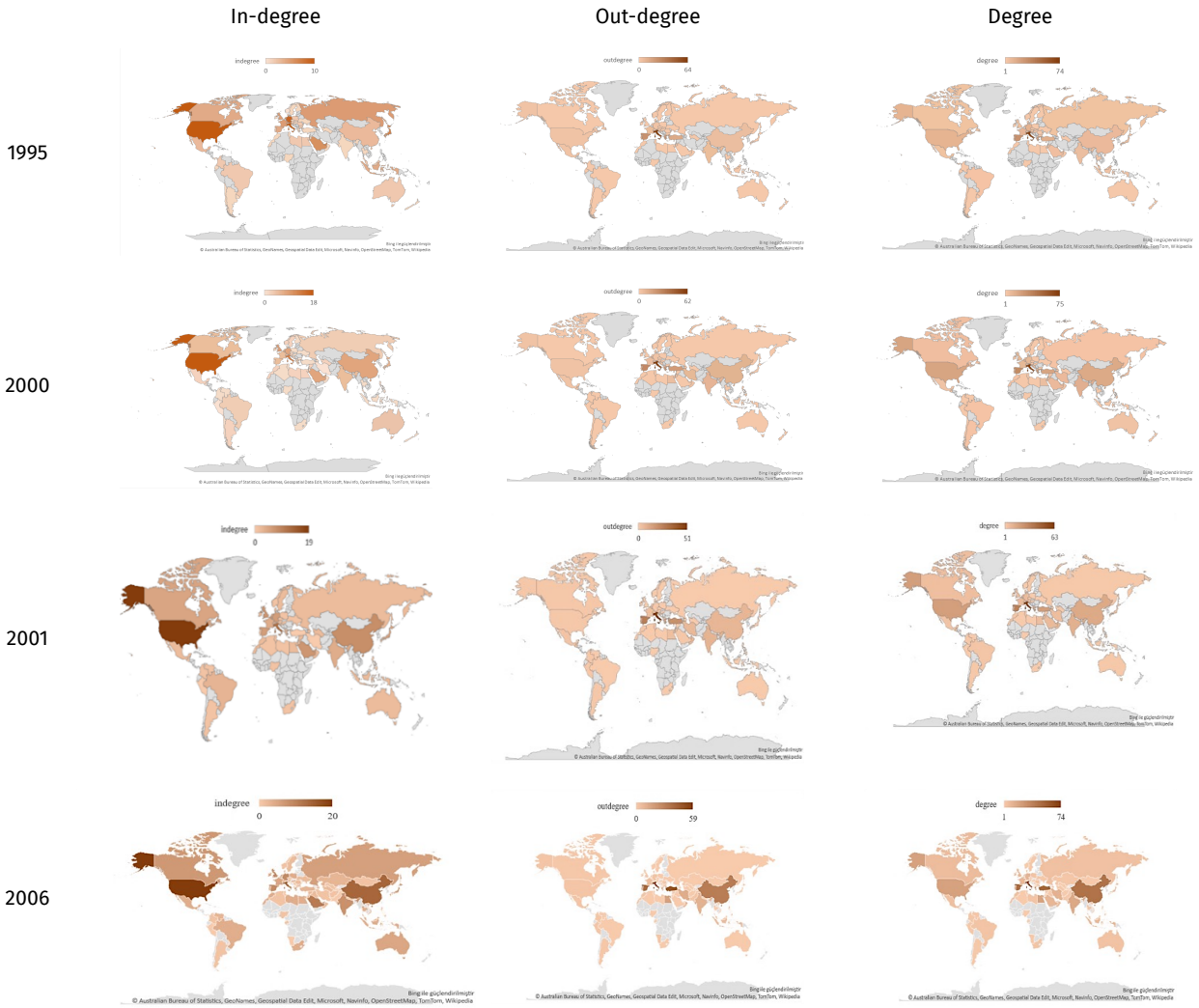
to which it exports marble products. This visual progression points to a substantial widening of China's export connectivity within the GMTN following the early 2000s.

The overall degree centrality, which combines both incoming and outgoing connections, provides a general measure of a country's total trade linkages within the GMTN. The degree-based maps illustrate how countries' total number of trade connections vary over time, revealing shifts in the spatial distribution of connectivity across network participants. In this context, China's overall degree representation becomes increasingly pronounced in the post-WTO period, indicating its growing involvement in both import and export relationships within the GMTN.

Overall, these map-based visualisations offer a descriptive overview of the evolving centrality patterns within the GMTN. While the figures highlight changes in countries' relative positions—particularly with respect to China before and after WTO accession—a more precise and systematic assessment of centrality dynamics and their magnitude is presented in the following subsection through quantitative centrality rankings and numerical network indicators.

Figure 3

Degree Centralisation Indicators of the GMTN



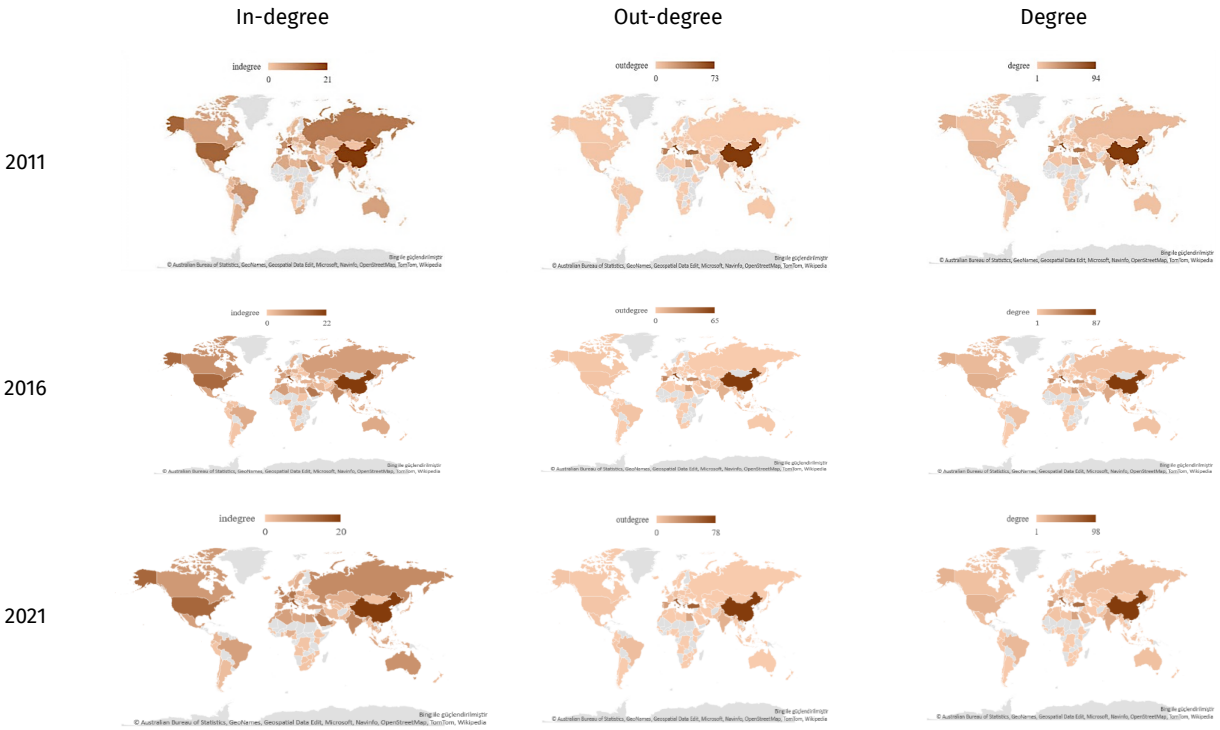


Table 2 reports the eigenvector, closeness, and betweenness centrality values for selected countries within the GMTN over the period 1995–2021. These indicators provide complementary perspectives on countries' structural positions within the network, capturing their relative importance, accessibility, and intermediary roles in global marble trade.

Eigenvector centrality values reveal substantial cross-country and temporal variation. For China, eigenvector centrality increased from 0.40 in 1995 to 0.48 in 2000, then declined slightly to 0.45 in 2001. A pronounced rise is observed thereafter, with the value reaching 0.76 in 2006 and peaking at 1.00 in 2011. In subsequent years, China's eigenvector centrality remains similarly high (0.99 in both 2016 and 2021), indicating sustained structural embeddedness within the network. Italy displays relatively high eigenvector centrality throughout the period, although its trajectory differs from China's. Italy's eigenvector value declines from 0.77 in 1995 to 0.51 in 2001, then increases to 0.67 in 2006 and reaches 0.95 in 2011. In 2016 and 2021, Italy recorded a maximum value of 1.00, indicating a consistently central structural position in the later years. By contrast, Spain, Türkiye, and Greece exhibit notably lower eigenvector centrality values across all years. Spain's eigenvector centrality ranges between 0.29 and 0.58, peaking in 2006, while Türkiye's values remain below 0.40 throughout the period. Greece follows a similar pattern, with eigenvector centrality values generally below 0.35, despite a temporary increase in 2006. The United States records the highest possible eigenvector centrality value (1.00) consistently from 1995 to 2006, followed by lower—but still relatively high—values in later years (0.84 in 2011, 0.88 in 2016, and 0.85 in 2021).

Closeness centrality values indicate differences in countries' relative proximity to other nodes within the GMTN. China's closeness centrality increases from 0.50 in 1995 to 0.53 in 2000, remains at 0.50 in 2001, and then steadily rises to 0.61 in 2006 and 0.80 in 2011. Although a slight decline is observed in 2016 (0.73), China's closeness centrality increases again to 0.77 in 2021, remaining above its pre-2001 levels. Italy records consistently high closeness centrality values in the earlier years (0.94 in 1995 and 0.93 in 2000), followed by

a gradual decline to 0.70 in 2021. Spain's closeness centrality fluctuates within a narrower range, remaining between 0.54 and 0.65 over the study period. Türkiye and Greece show moderate and relatively stable closeness values, with Türkiye's closeness centrality rising notably in 2006 (0.72) before declining and then increasing again in 2021 (0.68). The United States exhibited the highest closeness centrality values (1.00) from 1995 to 2006, followed by a marked reduction to approximately 0.42–0.43 in the post-2011 period.

Betweenness centrality values highlight countries' intermediary roles within the GMTN. For China, betweenness centrality remains at 0.00 in 1995, increases modestly to 0.02 in 2000 and 2001, and rises to 0.10 in 2006. A peak was observed in 2011 (0.21), followed by lower but still elevated values of 0.14 in both 2016 and 2021. Italy shows relatively stable betweenness centrality values across the period, ranging between 0.11 and 0.21, with the highest value recorded in 2000 (0.21). Spain's betweenness centrality remains low throughout, fluctuating between 0.00 and 0.03. Türkiye and Greece also display low betweenness values overall, although Türkiye's betweenness centrality slightly increases to 0.03 in 2021. For the United States, betweenness centrality values remained close to zero in the earlier years and increased marginally to 0.03 from 2011 onward, indicating a limited but stable intermediary role in the later period.

Overall, the centrality metrics reported in Table 2 document a clear reconfiguration of structural positions within the GMTN between 1995 and 2021. China exhibits a consistent upward trajectory across eigenvector, closeness, and betweenness centrality measures after 2001. In the case of China, this sharp post-2001 increase across all three centrality measures reflects its transformation into a central processing and redistribution hub within the GMTN, in which large volumes of raw marble are imported, processed into higher-value-added products, and subsequently re-exported to final consumer markets.

Table 2

Centralisation Metrics for Selected Countries

Node	Year	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality
China	1995	0.40	0.50	0.00
	2000	0.48	0.53	0.02
	2001	0.45	0.50	0.02
	2006	0.76	0.61	0.10
	2011	1.00	0.80	0.21
	2016	0.99	0.73	0.14
	2021	0.99	0.77	0.14
Italy	1995	0.77	0.94	0.16
	2000	0.58	0.93	0.21
	2001	0.51	0.89	0.19
	2006	0.67	0.79	0.14
	2011	0.95	0.71	0.16
	2016	1.00	0.73	0.14
	2021	1.00	0.70	0.11
Spain	1995	0.31	0.61	0.02
	2000	0.31	0.63	0.01
	2001	0.29	0.63	0.03
	2006	0.58	0.65	0.03

Node	Year	Eigenvector Centrality	Closeness Centrality	Betweenness Centrality
	2011	0.47	0.61	0.01
	2016	0.42	0.58	0.02
	2021	0.45	0.54	0.00
Türkiye	1995	0.19	0.54	0.00
	2000	0.13	0.58	0.00
	2001	0.00	0.59	0.00
	2006	0.27	0.72	0.02
	2011	0.34	0.67	0.01
	2016	0.36	0.54	0.01
	2021	0.38	0.68	0.03
Greece	1995	0.19	0.60	0.00
	2000	0.16	0.60	0.01
	2001	0.14	0.55	0.02
	2006	0.34	0.56	0.02
	2011	0.20	0.56	0.02
	2016	0.16	0.57	0.01
	2021	0.27	0.63	0.01
USA	1995	1.00	1.00	0.00
	2000	1.00	1.00	0.01
	2001	1.00	1.00	0.00
	2006	1.00	1.00	0.00
	2011	0.84	0.42	0.03
	2016	0.88	0.43	0.03
	2021	0.85	0.42	0.03

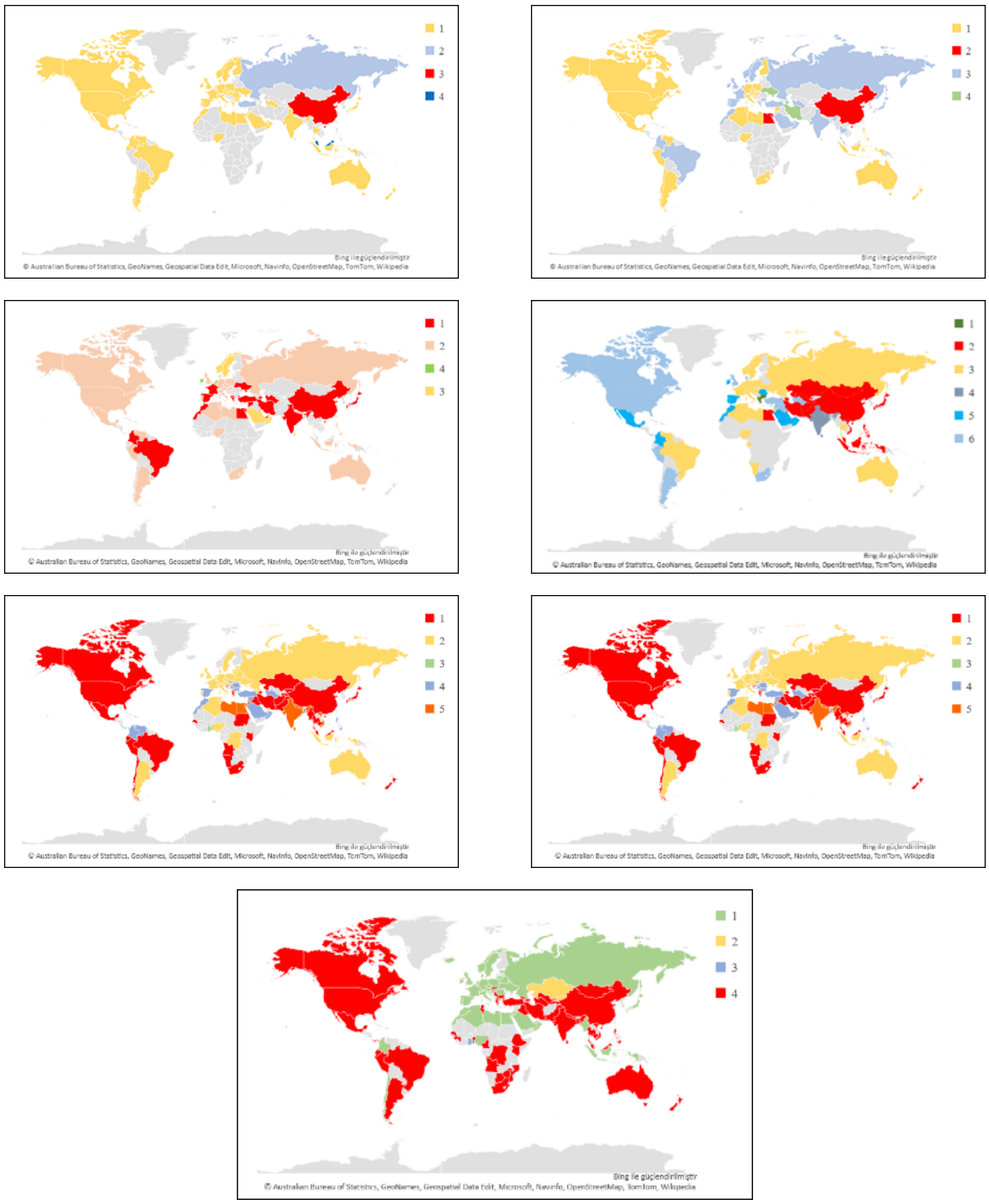
Modularity analysis is a widely used network clustering technique that identifies communities of nodes characterised by dense internal connections and relatively sparser linkages between different groups. The modularity coefficient provides a quantitative measure of the extent to which a network is partitioned into communities, with higher values indicating greater separation between clusters. Figure 4 illustrates the modularity classes of countries within the GMTN, where countries assigned to the same module are represented by identical colours, indicating shared community membership within the global trade structure.

The computed modularity coefficients of the GMTN were 0.127 in 1995, 0.140 in 2000, 0.165 in 2001, 0.203 in 2006, 0.188 in 2011, 0.282 in 2016, and 0.159 in 2021, indicating fluctuations in the degree of community separation over time. The highest modularity value observed in 2016 suggests a period during which the network exhibited relatively stronger community differentiation than in other years.

An examination of the modularity maps further reveals that the number of detected communities ranges from four to six, depending on the year analysed, suggesting a multi-clustered structure in the global marble trade. Across all analysed years, the red cluster consistently represents the modularity group to which China belongs. A visual comparison of the maps indicates that the number of countries assigned to this cluster increases over time, reflecting an expansion in the composition of the modularity group in which China is embedded in the GMTN.

Figure 4

Evolution of Modularity Classes in the GMTN



Discussions

Numerous studies have emphasised the multifaceted factors underlying China's emergence as a significant global manufacturing and production centre (Tang & Wei, 2009; Wu, 2011; Bishop & Xiaotong, 2020).

Within this broader context, China's accession to the WTO in 2001 is frequently discussed as a structural milestone that coincided with its deeper integration into the global economic system. Assessments by the International Monetary Fund suggest that WTO membership facilitated China's participation in international markets by granting MFN status, thereby easing trade frictions and reducing non-tariff barriers (Prasad, 2004; Kim & Xin, 2021). From a network perspective, this enhanced market access contributed to the reconfiguration of China's position in the marble sector. The patterns observed in Figure 3 and Table 2 are consistent with a transition from limited pre-2001 engagement towards structural prominence within the GMTN.

Marble is a geographically constrained natural resource, predominantly concentrated within the Alpine–Himalayan mountain belt (Efe & Sallan, 2017). This spatial concentration produces an inherently asymmetric trade structure, as countries outside this belt are structurally dependent on imports, thereby limiting the potential density and symmetry of the GMTN. Within this context, China constitutes a notable case. Despite lacking marble reserves of comparable quality to several Alpine–Himalayan producers, China appears to have emerged as a central processing centre by importing large volumes of raw blocks and utilising its manufacturing and value-adding capabilities. Rather than reflecting a resource-based comparative advantage, this pattern is more consistent with a processing-driven integration into the global marble value chain. China's network position within the GMTN further reinforces this interpretation. Its relatively high in-degree values indicate a broad and diversified set of import linkages, while rising out-degree values point to an expanding export reach over time. This dual connectivity profile indicates that China holds a key position in redistributing marble flows throughout the network. As a result, trade interactions between producer and consumer countries have increasingly converged around Chinese trade channels, potentially giving rise to asymmetric dependency structures, particularly for economies that rely heavily on China as a principal export destination or sourcing hub.

From a network-structural perspective, this intermediary role is further reflected in China's rising centrality scores for betweenness and closeness. Increasing betweenness centrality indicates that an expanding portion of the shortest trade routes within the GMTN go through China, strengthening its role as a routing hub. Higher closeness centrality, in turn, indicates improved network reachability, allowing China to redistribute marble flows more efficiently across the system.

Modularity results provide additional insight into this transformation. China's persistent location within the largest modularity community implies close integration with the network's core trading bloc. While this concentration enhances scale economies and reduces transaction costs, it also introduces systemic trade-offs. Heightened reliance on China as a processing and redistribution hub may expose the system to higher risk in the event of trade disruptions or policy shifts. This observation underscores the dual nature of network centrality, which is associated with efficiency gains and fragility risks. Recent evidence indicates a slow reorganisation of these internal dynamics. Domestic demand has been shaped by sustained urbanisation, cyclical stresses within the real estate sector—including surplus housing capacity (ghost cities) and liquidity distress akin to the Evergrande crisis—that introduce downstream risks for construction-material demand (Williams et al., 2019; Lu & Keller, 2022). These fluctuations may moderate China's in-degree intensity and reshape its trade link distribution.

Furthermore, a 2021 modular interpretation shows that China is increasingly aligning with African countries, India, Australia, New Zealand, and South America. This reveals a strategy of redirecting the geographic market. According to StoneNews (2025), China has begun diversifying its marble import base beyond traditional suppliers. Rising customs and tariff frictions with the USA appear to have reinforced this tendency to

seek alternative markets (Bulut et al., 2021). Manufacturers have reportedly expanded into non-US markets in response to regulatory pressures and rising costs. Our analysis suggests that these constraints have developed into a lasting structural force, guiding China to establish new commercial connections by shifting export reliance to different consumer zones. Collectively, these shifts emphasise that China's agency has expanded from high-dependency participation to high-influence mediation, shaping the embeddedness of inter-regional trade and strategic redirection in global marble commerce.

Conclusions

This research investigates evolutionary patterns in the worldwide marble trade following China's accession to the WTO. The primary objective was to identify potential risks and structural transformations, as well as the underlying forces that have shaped the network's evolution over time.

The main findings of this study can be summarised as follows. Over the period examined, the GMTN expanded substantially, with the number of participating countries increasing from 71 to 114 and the number of trade links rising from 184 to 429, indicating a transition towards a more inclusive and structurally complex global network. Within this evolving structure, China moved away from its relatively peripheral position in the pre-2001 period and emerged as one of the most central and influential actors in the network. The significant rise in China's eigenvector and closeness centrality indicates a diversification of trade partnerships and an increasing role as a strategic processing and supply hub in the global marble market. At the same time, several traditionally central countries—including Italy, Spain, Türkiye, and Greece—experienced a relative decline in their network prominence following China's rise, while the reduction in the United States' closeness centrality points to a shift in direct accessibility and a reorientation of the network's topological focus. Finally, modularity analysis reveals that the GMTN has been organised into between four and six major communities over time, with China increasingly positioned at the centre of the largest and most densely integrated community, reflecting an intensification of regional clustering within the global marble trade system.

The findings are consistent with the view that China's accession to the WTO coincided with a range of advantages in global trade. A benefit of MFN status is improved access to international markets, which facilitates easier entry. Additionally, the reduction of certain import restrictions is commonly associated with MFN status. Together, these developments appear to have contributed to China's deeper integration into global markets, particularly in industries such as marble processing, and are accompanied by a noticeable increase in China's marble export activity.

The GMTN is a strong illustration of China's prominent position in the marble trade. Nevertheless, it is crucial to bear in mind that this position also renders China susceptible to the potential ramifications of trade disputes. It is imperative to underscore the potential adverse impact on China's marble trade from the escalation of customs tariffs, particularly with the USA. In addition, the anticipation of forthcoming strategic advancements and trade disputes creates uncertainty for nations involved in the marble product trade with China. The aforementioned potential could give rise to significant challenges in the foreseeable future, particularly in nations such as Türkiye, Italy, and Spain, where unprocessed block marble is exported to China. Hence, it is essential for these countries to closely monitor China's forthcoming trade policies and adapt their strategies accordingly. In addition to existing trade wars, a potential concern is that China may uncover new findings about its domestic marble reserves. The discovery of these recently identified marble deposits could reduce China's imports of block marble. Consequently, there is potential for a deceleration

in the international trade activities of nations that sell goods to China. It might also force these countries to compete fiercely with China in their current markets.

Another factor that we like to emphasise is the strong relationship between the marble trade and the prevailing condition of the construction industry. Nations holding substantial positions in both export and import centrality within the GMTN need to undertake a comprehensive examination of prospective developments in the building industries of the countries with which they trade. For example, prospective crises in the foreseeable future, such as downturns in the building industry similar to those encountered during the COVID-19 pandemic, can affect the marble trade. Within this context, there is a potential risk of countries that cannot expand their markets or supplier base. Particularly affected are those that have substantial trade with some other nations. In addition, the recurrence of crises like Evergrande and ghost cities could profoundly impact China's construction sector. Periods of expansion followed by contraction may become common.

This research makes a significant contribution by analysing the influence of China's accession to the WTO on global networks of the marble trade. To further our understanding, future research should focus on this topic with a country-specific perspective, examine the current and prospects of the marble sector, particularly in light of trade wars, and explore trade in other natural stones. Furthermore, conducting such research may contribute to a deeper understanding of the many determinants shaping trade in marble and other natural stones. This type of research may have a substantial impact on understanding evolving dynamics in trade and effectively adjusting to these transformations.

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