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Competitive pattern of global tin products trade from the perspective of industry chain

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With the application of tin in photovoltaic power generation, new energy vehicles, and other emerging industries, the contradiction between the supply and demand of tin resources has become increasingly prominent, which further exacerbates the competition between tin resource importing and exporting countries. According to the global trade data from 2002 to 2022, this paper classifies five kinds of tin-containing products into three commodity types, namely, upstream, midstream, and downstream, and constructs the international trade network, import competition network, and export competition network. This paper selects key competitive countries and relationships, examines the characteristics of specific communities, and analyzes the network's structural features and evolution patterns over time. The results showed that: (1) The distribution of the intensity of competition in tin products is very uneven, the trend of oligopoly in upstream product competition is obvious, and the competition in midstream and downstream products is getting more and more intense. (2) The tin industry chain has developed a tripartite pattern of import competition in Asia, Europe, and North America. Developed countries primarily compete in midstream tin products, while developing countries focus on importing upstream and downstream tin products. (3) The export competition for tin products is primarily concentrated in Asia, with Malaysia losing its centrality and Myanmar, Indonesia, and China gaining the centrality. (4) The competition communication in upstream tin products is more evident than in midstream and downstream products, and their stability is stronger. The above analysis can help countries identify their trade competitors and provide suggestions for finding new partners.

KEYWORDS

tin products, industry chain, complex network, tin trade, competition pattern

1 Introduction

Tin (Sn) is one of the earliest metals used by humanity and is a fundamental material in the advancement of industry and technology in the contemporary world (Howe and Watts, 2005). In recent years, the range of tin applications has been expanding from traditional fields such as solder, tin plates, and chemicals to new high-tech areas such as batteries, solar photovoltaics, thermoelectric materials, the generation of hydrogen, carbon capture catalysts, and water treatment (USGS, 2023).

Constrained by real-world circumstances and socioeconomic factors, the disparity between the global supply and demand for tin resources has gained significant prominence.

In 2022, the total global demand for tin was 383,000 tons, with chemicals (23%), tinplate (22%), alloys (11%), solder (10%), babbitt, brass and bronze, and tinning (7%) and bar tin (2%), while the remaining 25% found use in other sectors (USGS, 2023). However, the global production, amounted to a mere 300,000 tons (USGS, 2023). Furthermore, the distribution of these resources is highly concentrated, the primary players in this market are Indonesia (17%), China (15%), Myanmar (15%), and Australia (12%) (USGS, 2023). Many countries heavily rely on international trade to access tin resources. In addition, global tin reserves were estimated at approximately 4.6 million tons in 2022. Yet, these reserves are projected to last for just 22 years (Izard and Müller, 2010) given the current extraction rates. Despite ongoing prospecting activities in recent years, they have not stimulated a significant increase in reserves.

Given the critical significance and limited availability of tin, nations across the globe are increasingly focusing their attention on this precious resource. In 2016, China included tin in its list of 24 strategic metal minerals, and the US Geological Survey (USGS) ranked tin ore as one of 50 critical minerals in 2022. In recent years, the global landscape has grown more complex, with the surge of international trade protectionism and anti-globalization sentiments directly impeding the smooth flow of mineral resources on a global scale. This trend poses a direct threat to national resource security. Consequently, it becomes vital to examine the competitive dynamics within the tin industry from the perspective of the industrial chain.

In recent years, research on tin resources has achieved rich results in aspects such as trade, supply and demand, material flow, etc. Schütte conducted a detailed analysis of the global tin ore trade in North and East Africa and noted that this trade can be stabilized if the market regulation is effective (Schutte, 2019). Zeng Tao and his team also explored the supply and demand pattern of tin resources in the countries along the “Belt and Road” (Zeng et al., 2019). They paid close attention to the extent of resource extraction, international trade, etc. Furthermore, Li and colleagues expounded on the flow of tin in various countries during the period of 1999–2018, which fills the gap in the global data on the flow of tin substances (Li et al., 2021b). Diprose and his team explores the challenges and limits of voluntary supply chain governance as it interacts with an entrenched “extractive settlement” in Indonesia’s major tin producing islands of Bangka and Belitung (Diprose et al., 2022). Bradley and his team critically assess the circularity and criticality indicator values for tin and calculate new values using material flow analysis (Bradley et al., 2024). Robertson give a wide-ranging picture of the word tin market (Robertson, 2024).

With the rise of the complex network approach, there is more and more research on the complex network of resource trade. Complex networks, often used as abstractions for various intricate real-world systems, currently stand as a focal point of interest within the international academic community (Cao et al., 2006; Watts and Strogatz, 1998). Complex network modeling has found its way into numerous international and regional research endeavors concerning resource and energy trade. Scholars have utilized the complex network method to analyze the trade structure characteristics of petroleum (An et al., 2014; Ji et al., 2014), natural gas (Geng et al., 2014), lithium mineral products (Tian et al., 2021; Shao et al., 2022), and other products, revealing the information implied by the relevant trade.

Building upon existing primary trade networks, some researchers have delved into the competitive dynamics within these networks. For example, Zhang et al. (2014) studied global oil trade competition, propagation, and evolution from the perspective of importing countries using complex network theory. Wang et al. (2019) established a global graphite import competition network and examined the factors affecting the intensity of competition. Shao et al. (2021) used the trade data from 2009 to 2018, complex network theory was adopted to analyze the global lithium import competition pattern and used a panel regression model to analyze the impact of lithium trade network characteristics on lithium import competition pattern.

In recent years, there has been a growing emphasis on industry chains, leading to an upsurge in research on trade networks within the mineral resources industry chain. For instance, Zhong et al. (2018) proposed the use of material flow analysis and complex network methods to investigate the international trade encompassing the entire iron industry chain. Additionally, Li et al. (2021a) examined the trade characteristics of the global copper industry chain and key countries, taking a comprehensive approach by constructing trade networks for various links within the copper industry chain. In a similar vein, Li X. et al. (2022) scrutinized the current state of cobalt trade from a holistic industry chain perspective. Furthermore, Zhang et al. (2022) analyzed the evolving import competition patterns in the rare earth industry, considering the intricate dynamics from an industry chain viewpoint.

In summary, previous research on tin resource trade generally concentrates on the exploration of supply and demand and material flow. In contrast, the research related to the competitive relationship of tin resources trade triggered by the contradiction between supply and demand is relatively weak. Therefore, this study applies the international trade data of tin products from 2002 to 2022 constructs the international trade network of tin products and its derived import and export competition network, and conducts a study on the import and export competition pattern of tin products, thereby shedding light on policymakers to improve the existing policy measures for tin resource management and development.

2 Data and method

2.1 Data

The trade data used in this paper were sourced from UN_COMTRADE and encompassed the period from 2002 to 2022. This dataset includes the import and export flows involving all countries and regions engaged in the international trade of tin resources, hereafter referred to as “countries.” Trade volume is quantified in kilograms.

To facilitate our analysis, we considered the full spectrum of products across the tin industry chain, categorized into upstream, midstream, and downstream segments. Specifically, we selected the following product categories: Tin ores and concentrates (HS Code: 260900), Tin, not alloyed (HS Code: 800110), Tin, alloyed (HS Code: 800120), Tin bars, rods, profiles, and wire (HS Code: 800300), and Other articles of tin (HS Code: 800700) are chosen as representative products to denote the entire tin industrial chain. The latter category, “Other articles of tin,” encompasses various products not specified

TABLE 1 HS coding, industrial chain tin-containing coefficient of tin-containing commodities.

Link	Product	HS code	Tin content (Gu and Liu, 2022)
upstream	Tin ores and concentrates	260900	0.1654
midstream	Tin, not alloyed	800110	0.999
	Tin, alloyed	800120	0.7
downstream	Tin bars, rods, profiles, and wire	800300	0.999
	Other articles of tin	800700	0.7

elsewhere, which includes items for household, table, kitchen, or bathroom use, as well as all tin-containing products not coated or plated with precious metals.

The volume of tin trade contained within each product, identified by its HS code, is determined by multiplying the total trade volume of that specific product by the corresponding tin content factor, as outlined in Table 1. The total tin trade volume within each link of the tin industry chain is then calculated as the aggregate of the tin trade volumes associated with all HS code products included in each major category (Gu and Liu, 2022).

The UN_COMTRADE database exhibits asymmetric import and export data due to slight differences in statistical caliber between countries' trade data. Nonetheless, these disparities are typically minor when considered in the context of the overall trade volume. As a result, this study selects the dataset linked to the party with the greater import and export volume of tin products in each country as the basis for analysis.

2.2 Method

2.2.1 Complex network construction

International trade networks represent intricate systems of trade interactions among countries, serving as valuable tools for uncovering the underlying patterns and evolution of this system. These insights, in turn, offer a foundation for shaping pertinent governmental policies and decisions (Fan et al., 2014). In the complex network model, denoted as $G = (V, E)$, it comprises nodes represented as $V = \{v_i; i = 1, 2, \dots, n\}$, where 'n' signifies the total number of nodes, and edges as $E = \{E_j; j = 1, 2, \dots, m\}$, where 'm' signifies the number of edges (Barabási, 2013). The complex network model's matrix is as follows in Equation 1:

$$G = (V, E) = \begin{bmatrix} 0 & w_{1,2} & \cdots & w_{1,n} \\ w_{2,1} & 0 & \cdots & w_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,1} & w_{n,2} & \cdots & 0 \end{bmatrix} \quad (1)$$

The international trade network of tin products consists of nodes representing countries and edges representing trade relations between these nations. The weight of the edges corresponds to the trade volume of tin products, while the direction of the edges indicates the flow direction (Fagiolo et al., 2008).

The tin products import and export competition network emerges as a derived network from the tin products international trade network. Due to various factors like price disparities, international relations, and industry distribution, countries typically source tin products from multiple exporting nations, leading to intense import competition among tin product importing countries. Similarly, export competition arises among countries exporting tin products.

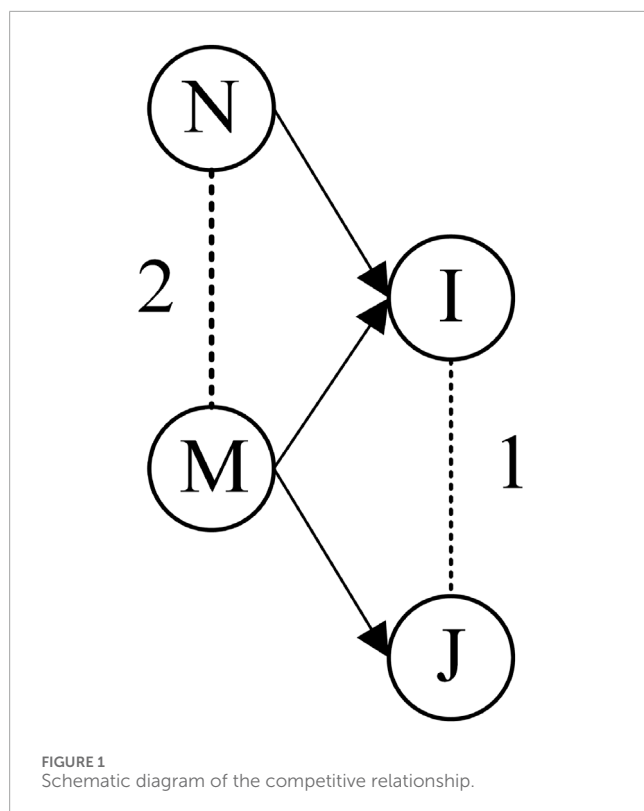
The model illustrating the import and export competition network for tin products is presented in Figure 1. When countries I and J both import tin products from country M within the same year (indicated by solid lines with arrows), it signifies that I and J are engaged in import competition. The import competition network features I and J as its nodes, and the corresponding connecting lines (dotted line 1) represent the edges within this network. Similarly, when countries M and N concurrently export tin products to country I in a given year (as shown by solid lines with arrows), it implies that M and N are in export competition. In this export competition network, M and N serve as the network's nodes, while the connecting lines (dotted line 2) represent the network's edges.

This paper proposes a tin products competition network based on whether importers share the same tin products import source. The network is denoted as $G = (V, E)$, where the node $V = \{v_i; i = 1, 2, \dots, n\}$ represents the importing countries of tin products. The competition relationship between v_i and v_j is represented by e_{ij} . If competition exists between v_i and v_j , $e_{ij} = 1$, otherwise $e_{ij} = 0$. The set $S = \{S_{ij}\}$ denotes the weight of the edge, signifying the intensity of competition between v_i and v_j . Similarly, this paper also constructs the export competition network of tin products.

Drawing from Glick and Rose's indicators and incorporating a measure introduced by Wang et al. for gauging the degree of direct competitive intensity in graphite trade, we define the competitive intensity within the import and export network of tin products as follows in Equation 2 (Glick and Rose, 1999; Wang et al., 2019):

$$S_{ij} = \sum_0^m \left\{ \left(\frac{W_{mi} + W_{mj}}{W_w} \right) * \left[1 - \frac{\left| \left(\frac{W_{mi}}{W_i} \right) - \left(\frac{W_{mj}}{W_j} \right) \right|}{\left(\frac{W_{mi}}{W_i} \right) + \left(\frac{W_{mj}}{W_j} \right)} \right] \right\} * 100 \quad (2)$$

Where S_{ij} is the intensity of competition between tin product importing countries v_i and v_j , and m represents the common tin product importing country v_m . W_{mi} signifies the quantity in kilograms (kg) of tin products imported by country v_i from the common source v_m . W_{mj} signifies the quantity in kilograms (kg) of



tin products imported by country v_j from the common source v_m . W_i and W_j correspond total imports of importing countries v_i and v_j . W_w represents the aggregate global imports of tin products. The procedure for constructing the global competitive network for tin exports follows the same steps as described above.

The competition intensity indicator comprises two parts. The first part indicates the proportion of trade competition volume from the source country m to total world trade volume. The larger the proportion, the greater the competition pressure between importers i and j . The second part measures the import structure of importers i and j . The more similar the import structure, the more intense the competition. Table 2 and Table 3 shows the top five competition intensity values for 2002, 2012 and 2022.

2.2.2 Network structural characteristics indicators

2.2.2.1 Degree

In a network, a node's degree signifies the count of connections it has with other nodes in the network, serving as an indicator of the competitive relationships between countries in the context of tin products. A country with a higher number of competitive ties with other nations will exhibit a larger degree. The average degree is the average of all nodes' degrees throughout the network (Barabási and Albert, 1999). The formula is as follows in Equations 3, 4:

$$k_i = \sum_{j=1}^n e_{ij} \quad i = 1, 2, \dots, N \quad (3)$$

$$\bar{k} = \frac{\sum k_i}{N} \quad i = 1, 2, \dots, N \quad (4)$$

Where k_i is the degree of node v_i ; \bar{k} is the average degree of all nodes, and N is the total number of nodes in the network.

2.2.2.2 Weighted degree

The weighted degree w_i of a network node v_i shows the competitiveness. This degree is the sum of all the competition intensity with its competitors (Garlaschelli and Loffredo, 2005). The average weighted degree reflects the global competition level of the tin products trade. The formula is as follows in Equations 5, 6:

$$w_i = \sum_{j=1}^{v_N} (t) e_{ij} \times w_{ij} \quad (5)$$

$$\bar{w} = \frac{\sum w_i}{N} \quad (6)$$

Where w_i denotes the weight of node v_i , w_{ij} denotes the weight of edge e_{ij} , \bar{w} is the flat weighted mean of all nodes, and N is the total number of nodes in this network.

2.2.2.3 Betweenness centrality

Betweenness centrality is a measure of the number of weighted shortest paths through nodes, reflecting a country's resource control. It also symbolizes the state of a network's connectedness and the importance of the node as a network bridge. A larger value of betweenness centrality implies greater resources control by a country (Freeman, 1977). The formula is as follows in Equation 7:

$$BC_i = \sum_{s \neq i \neq t} \frac{n_{st}^i}{g_{st}} \quad (7)$$

Where g_{st} refers to the number of paths from nodes s to node t ; n_{st} refers to the number of the shortest paths from node s to node t and through the node i .

2.2.2.4 Clustering coefficient

The clustering coefficient is used to measure the probability that any two countries that have competitive relationships with tin products importer or exporter v_i also have a competitive relationship with each other. The cluster coefficient measures the tightness of competition between importing and exporting countries of tin products, with values ranging from 0 to 1. A larger clustering coefficient indicates a tighter competition relationship, while the average clustering coefficient represents the average of all nodes in the tin products import competition network (Blondel et al., 2008). The formula is as follows in Equations 8, 9:

$$c_i^w = \frac{1}{s_i(k_i - 1)} \sum_{j,k} \frac{(w_{ij} + w_{ik})}{2} e_{ij} e_{jk} e_{ik} \quad (8)$$

$$\bar{c}_i^w = \frac{1}{N} \sum_{i=1}^N c_i^w \quad (9)$$

Where c_i^w represents the clustering coefficient of node v_i ; s_i is the node strength of node v_i ; k_i is the degree of node v_i ; w_{ij} and w_{ik} represent the weight of edges from node v_i to nodes v_j and v_k respectively; $e_{ij} e_{jk} e_{ik} = 0$ represents that nodes v_i , v_j and v_k cannot be connected as triangles, $e_{ij} e_{jk} e_{ik} = 1$ represents that they can be connected as triangles; \bar{c}_i^w is the average clustering coefficient.

TABLE 2 The top 5 importers ranked by competitiveness.

upstream					
Rank	1	2	3	4	5
2002	Malaysia	Thailand	Bolivia	Singapore	China
2007	Mexico	Malaysia	Thailand	Belgium	United Kingdom
2012	Malaysia	China	Thailand	France	Belgium
2017	China	Russian	Singapore	Thailand	Malaysia
2022	China	Malaysia	Thailand	UAE	Belgium
midstream					
Rank	1	2	3	4	5
2002	Thailand	Luxembourg	Singapore	Japan	Malaysia
2007	Singapore	Japan	Thailand	Netherlands	Germany
2012	Singapore	China	United States	Japan	Netherlands
2017	United States	Netherlands	Japan	Germany	Singapore
2022	Singapore	China	Japan	United States	Netherlands
downstream					
Rank	1	2	3	4	5
2002	China	Australia	China, Hong Kong	Singapore	Japan
2007	China	United States	India	Canada	United Kingdom
2012	Mexico	United States	China	United Kingdom	New Zealand
2017	United Kingdom	Qatar	United States	Myanmar	Australia
2022	United States	Nigeria	UAE	Myanmar	United Kingdom

2.2.2.5 Average shortest path length

The average shortest path length is the mean distance between two nodes, serving as an indicator of the efficiency and performance of information transmission within the competition network (Watts and Strogatz, 1998). The formula is as follows in Equation 10:

$$L = \frac{\sum_{i>j} d_{ij}}{\frac{N(N+1)}{2}} \quad (10)$$

Where d_{ij} is the distance between two nodes i and j in the network; N is the number of nodes in the network; L is the average path length.

2.2.2.6 Modularity

Due to differences in regional competition, certain communities may exist in the competitive network for the import and export of tin products. Therefore, we use the algorithm developed by Blondel et al. (2008) to divide the network into communities. Modularity serves as a metric for quantifying the extent of network community division. It falls within the range from -1 to 1 . The higher modularity values

indicate a more pronounced network division. The formula is as follows in Equations 11–13:

$$Q = \frac{1}{2m} \sum_{i,j} \left[w_{ij} - \frac{w_i w_j}{2m} \right] \delta(c_i, c_j) \quad (11)$$

$$m = \frac{1}{2} \sum_{i,j} w_{ij} \quad (12)$$

$$A_i = \sum_j w_{ij} \quad (13)$$

where w_{ij} denotes the weight of the edge between node v_i and node v_j ; w_i is the weighted degree of node v_i ; c_i refers to the community where node v_i is assigned; $\delta(c_i, c_j) = 1$ represents that node v_i and v_j are in the same community, while $\delta(c_i, c_j) = 0$ is the opposite.

2.2.2.7 Normalized mutual information

Normalized Mutual Information (NMI) serves as a quantitative gauge of the information shared between two clustering outcomes, providing insight into the similarity between results generated by different algorithms. A higher NMI value indicates a greater

TABLE 3 The top 5 exporters ranked by competitiveness.

upstream					
Rank	1	2	3	4	5
2002	Indonesia	Australia	Peru	Singapore	Nigeria
2007	Myanmar	Congo	South Africa	Singapore	Bolivia
2012	Myanmar	Australia	Bolivia	Rwanda	Congo
2017	Myanmar	Peru	Sierra Leone	Kyrgyzstan	Russian
2022	Myanmar	DR Congo	Australia	Nigeria	Brazil
midstream					
Rank	1	2	3	4	5
2002	Malaysia	China	Indonesia	Singapore	Peru
2007	Indonesia	Singapore	China	Peru	Thailand
2012	Indonesia	Malaysia	Peru	Singapore	Bolivia
2017	Indonesia	Malaysia	Peru	Singapore	Bolivia
2022	Indonesia	Peru	Bolivia	Malaysia	Singapore
downstream					
Rank	1	2	3	4	5
2002	Malaysia	China	China, Hong Kong	Japan	China, Taiwan
2007	China	United States	Japan	China, Taiwan	Rep. of Korea
2012	China	Japan	Rep. of Korea	Indonesia	United States
2017	China	Japan	Malaysia	Rep. of Korea	Italy
2022	China	Malaysia	UAE	Australia	Thailand

similarity between these outcomes. NMI values fall within the range from 0 to 1, where a value of 1 denotes that the two clustering results are identical, and a value of 0 signifies complete dissimilarity (Cover, 1999; Zhong et al., 2014). The formula is as follows in Equation 14:

$$NMI(y^{(a)}, y^{(b)}) = \frac{\sum_{h=1}^{k(a)} \sum_{l=1}^{k(b)} n_{h,l} \log \left(\frac{n \cdot n_{h,l}}{n_h^{(a)} n_l^{(b)}} \right)}{\sqrt{\left(\sum_{h=1}^{k(a)} n_h^{(a)} \log \frac{n_h^{(a)}}{n} \right) \left(\sum_{l=1}^{k(b)} n_l^{(b)} \log \frac{n_l^{(b)}}{n} \right)}} \quad (14)$$

Where $y^{(a)}$ is the year a , $n_h^{(a)}$ is the number of nodes in the community h at year a , $y^{(b)}$ is the year b , and $n_l^{(b)}$ is the number of nodes in the community l at year b . $n_l^{(b)}$ is the number of nodes in community h at year a that are the same as in community l at year b and n is the total number of nodes in the network.

The NMI research methodology employed in this paper can be outlined as follows:

If $b = a + 1$ and community h and community l are in a network for the same commodity, then NMI calculates the similarity between the division of year t and year $t + 1$ in the same network, indicating the stability of the network during the evolution.

2.2.2.8 Core-periphery model

Due to the different import volumes and sources of different importing countries, the importing countries may play different roles in the tin productions import competition network. Core-periphery model can be used to detect closely connected core nodes and sparsely connected peripheral nodes in the network, in which the core node often plays a more important role in the network (tin productions import competition network as above). The main idea of the core-periphery model is to test the adaptability of the core-periphery structure of the actual structure and the ideal structure, which can be realized by the unnormalized Pearson correlation coefficient. The formula is as follows in Equations 15, 16 (Borgatti and Everett, 2000; Li Y. et al., 2022):

$$\rho = \sum_{ij} e_{ij} \delta_{ij} \quad (15)$$

$$\delta_{ij} = \begin{cases} 1 & \text{if } c_i = \text{CORE and } c_j = \text{CORE} \\ 0 & \text{if } c_i = \text{PERIPHERY and } c_j = \text{PERIPHERY} \\ . & \text{otherwise} \end{cases} \quad (16)$$

Where ρ_{ij} is the unnormalized Pearson correlation coefficient; e_{ij} is the actual connection between nodes v_i and v_j . If there is a connection $e_{ij} = 1$, otherwise $e_{ij} = 0$. δ_{ij} denotes the ideal core edge structure connection, and δ_{ij} denotes the missing value.

3 Brief analysis of international trade networks

Using two key indicators, namely, the trading countries and the count of trade relations, we delved into the dynamics characterizing the evolution of the global tin trade pattern from an industrial chain perspective. Between 2002 and 2022, the international trade of upstream tin products engaged 69 to 96 countries, resulting in 138–255 trade relationships. Midstream tin products saw participation from 152 to 173 countries, yielding 1,107 to 1,430 trade relationships. As for downstream tin products, roughly 198 to 217 countries were involved, resulting in a substantial 2,145 to 2,732 trade relationships. Among these categories, the number of countries engaged in the international trade of downstream tin products, along with the number of countries conducting trade and the total trade relationships, took the lead. This was followed by the midstream tin products category in terms of the number of trading countries and trade relationships. Meanwhile, the upstream tin products category featured fewer countries involved and fewer trade relationships.

Utilizing complex network indicators, we conducted a deeper investigation into the evolving characteristics of the global tin trade network, with a specific focus on the industrial chain (as depicted in Figure 2, using the years 2002, 2012, and 2022 as illustrative examples). In a broad context, the international trade network associated with midstream and downstream tin products exhibits a higher degree of complexity compared to the network for upstream tin products. This paper contends that a country's position within a trade network hinges on three essential factors, which are import capacity, export capacity, and intermediation capacity. Weighted indegree indicates a country's import capacity, weighted outdegree indicates a country's export capacity, and betweenness centrality indicates a country's intermediation capacity.

Supplementary Material gives the top five countries in the tin products international trade network, ranked according to their performance in weighted degree, weighted indegree, weighted outdegree, and betweenness centrality from 2002 to 2022. This paper assesses each country's standing in the international tin product trade network by referencing. From this analysis, several key conclusions emerge:

Between 2002 and 2022, a pronounced oligopoly emerged in the trade of upstream tin products, gradually consolidating itself within a trade network centered around China and Myanmar. Starting in 2011, China superseded Malaysia as the primary importer of upstream tin products, while Myanmar took the place of Australia as the principal exporter of these products. Noteworthy countries exhibiting substantial betweenness centrality within the upstream tin product trade network encompass China, Thailand, Malaysia, and the United States.

Indonesia has witnessed a notable decline in its position within the international trade network for upstream tin products, while concurrently experiencing a substantial increase in its position

within the international trade network for midstream tin products. Currently, Indonesia holds the distinction of being the largest exporter of midstream tin products, with Singapore, the USA, and Japan serving as the primary importers of these products. Notably, Singapore held the title of largest importer of midstream tin products before 2015, a position that was later taken over by the United States. Countries exhibiting elevated betweenness centrality in midstream tin products encompass Germany, the United Kingdom, the United States, and China. It is worth highlighting that the betweenness centrality of the United States is on an upward trajectory.

Between 2002 and 2022, China has emerged as the paramount importer of downstream tin products. Beginning in 2010, China outpaced the United States and Japan, claiming the top position as the exporter of downstream tin products. Consequently, the core country within the international trade network for downstream tin products transitioned from Malaysia to China. Simultaneously, Middle Eastern countries are steadily augmenting their influence within the international trade network for downstream tin products. Noteworthy countries exhibiting substantial betweenness centrality in the downstream tin product trade network include the United States, China, Germany, and the UAE. Particularly, China's betweenness centrality is on the ascent.

4 Analysis of competition networks

4.1 Analysis of overall characteristics

Importing countries typically do not rely on a single exporting country for their tin product needs, owing to a myriad of factors such as resource distribution, pricing, and international geopolitical dynamics. Similarly, exporting countries diversify their tin product exports across multiple importing countries. This diversification naturally gives rise to competition among importing and exporting nations. Competitiveness serves as a metric for gauging the level of competitive intensity, with higher competitiveness signifying fiercer competition between two countries. Consequently, this section involves the creation and analysis of both import competition networks and export competition networks for tin products.

In this paper, the weighted degree of tin products is used to indicate the competitive intensity of tin products. Figure 3 depicts the characteristics of the import and export competition networks for upstream, midstream, and downstream tin products in 2002, 2012, and 2022. In these figures, the size of network nodes corresponds to the competitive intensity of a country's tin products, with larger nodes indicating greater competitive intensity. The width of network edges represents the competitive intensity between two countries, with thicker edges signifying greater competitive intensity. Nodes of the same color denote membership in the same competitive group.

Figure 4 shows the evolving competition network and dynamics of tin products, revealing the changing number of countries and relationships. Competition networks are more intricate than native trade networks, involving intricate international competition in import and export.

When examining the import and export competition network of tin products from an industrial chain perspective, it becomes evident that downstream products exhibit the highest number of competing participating countries and competitive relationships.

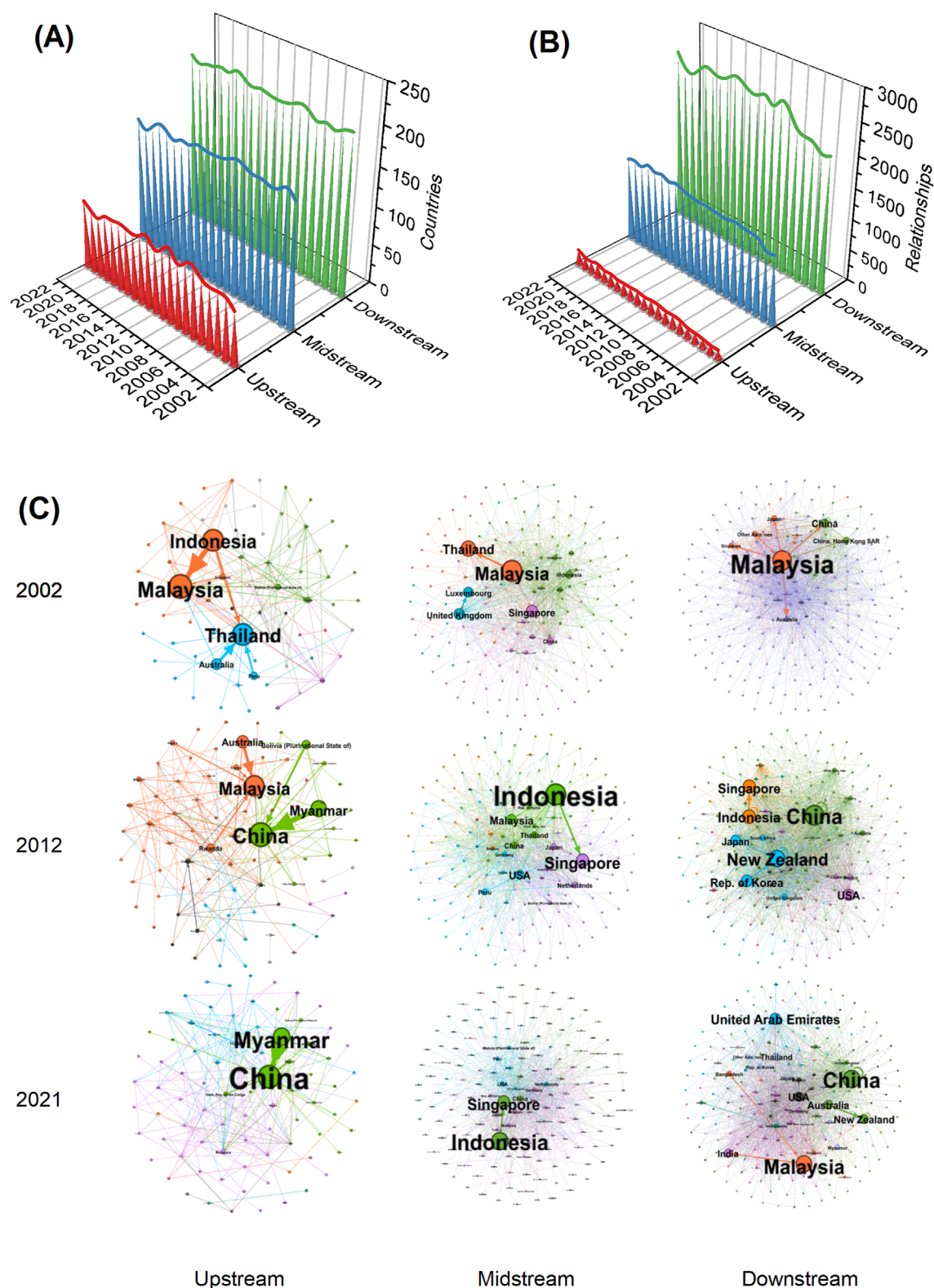


FIGURE 2

Trade countries and trade relations numbers of tin products and international trade network of tin products. (Note: (A) shows the number of trading countries, (B) shows the number of trading relationships and (C) shows international trade network of tin products).

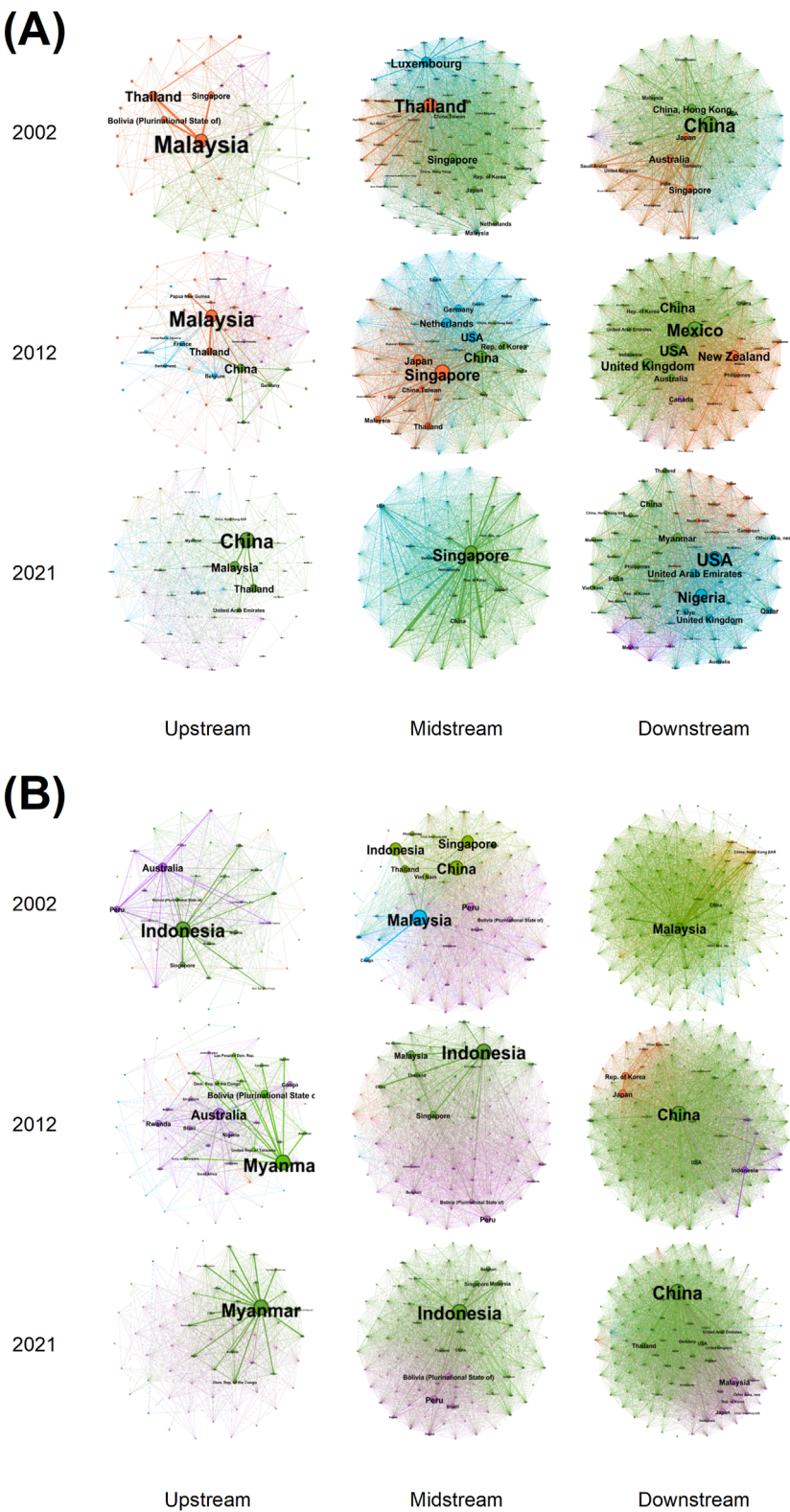


FIGURE 3 Global tin chain import competition network and global tin chain export competition network (Note: For the readability of the graphic, this paper filters the import competition network of the global tin industry chain. (A) shows the global tin chain import competition network and (B) shows global tin chain export competition network).

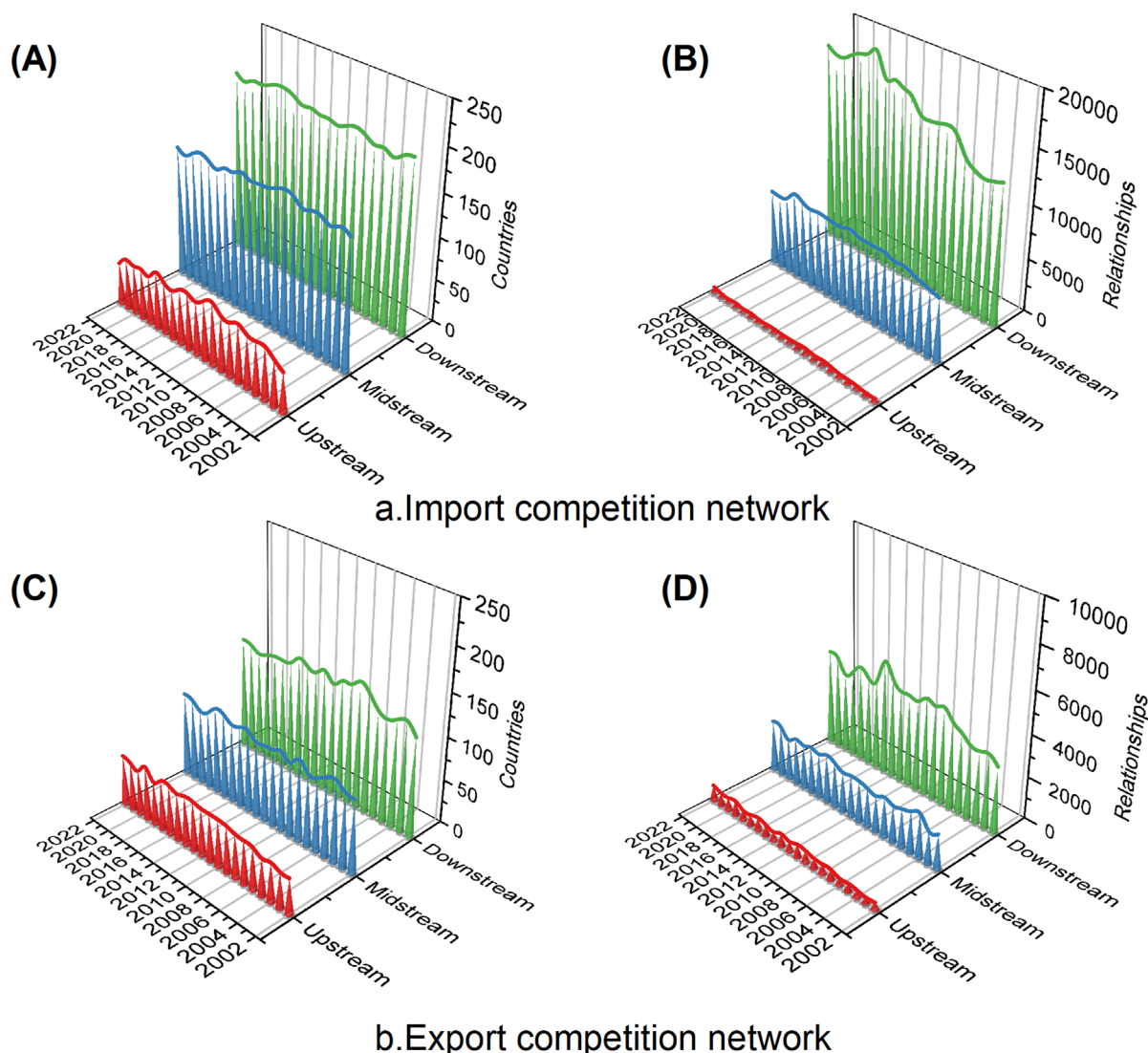


FIGURE 4

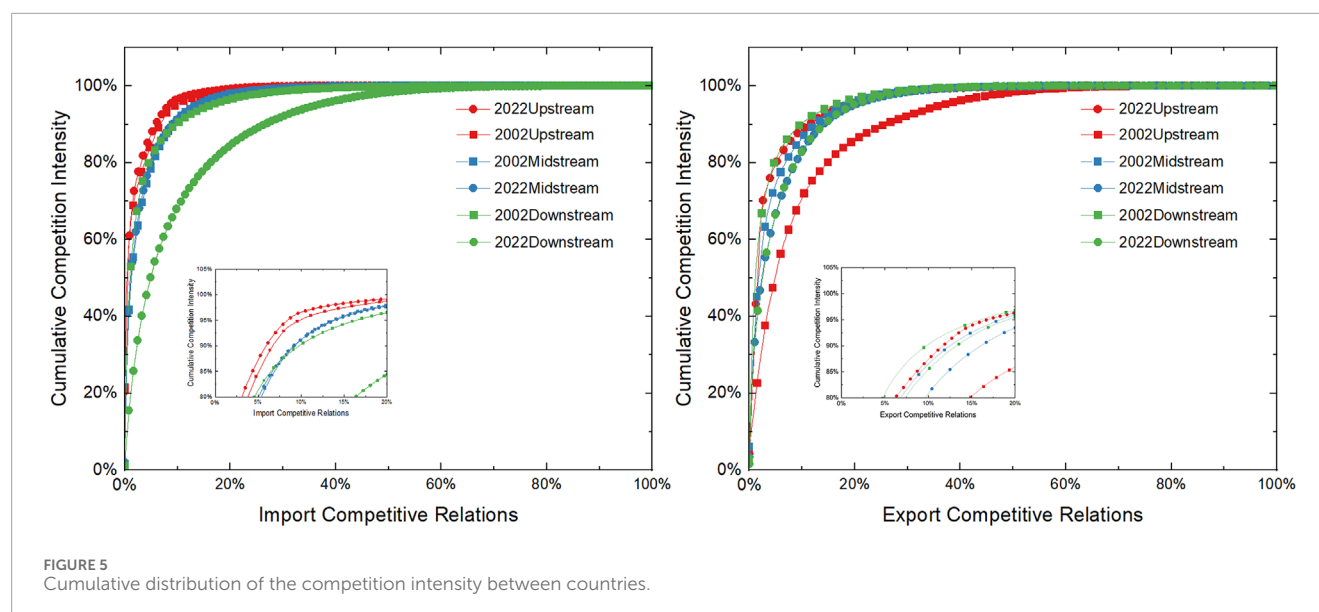
Total number of countries and relationships of competition networks. (Note: (A) shows the number of countries participating in the import competition network, (B) shows the number of competition relationships in the import competition network, (C) shows the number of participants in the export competition network, and (D) shows the number of competition relationships in the export competition network.).

In the second position are midstream products, characterized by their number of competing participating countries and competitive relationships. Conversely, upstream products feature the smallest number of competing participating countries and competitive relationships within this context. Furthermore, within the same production chain, the import competition network is notably more intricate than the export competition network, both in terms of the number of competing participating countries and the intricateness of competitive relationships.

To gain a comprehensive understanding of the competitive landscape in the tin product industry, the cumulative distribution of direct rivalry intensity between importing countries and between exporting countries engaged in the trade of tin products is examined in this study. As depicted in Figure 5, the distribution of competitive intensity within the tin product sector is markedly uneven, with

approximately 80% of competitive intensity stemming from roughly 10% of competitive relationships. This signifies that a select few countries wield significant influence in the realm of global tin import and export competition. In essence, these nations dominate the competitive dynamics among the world's tin importers and exporters. It can be seen that with time, the imbalance in the distribution of competitive intensity in the import and export of upstream tin products and midstream tin products has gradually intensified, and the imbalance in the distribution of competitive intensity in the import and export of downstream tin products has gradually reduced.

The average degree can reflect the evolutionary trend of the import and export competition network of tin products. The evolution trend of the tin products competition network from 2002 to 2022 is shown in Figure 6. In the competition



network of tin products, it is notable that the average degree of downstream tin products surpasses that of midstream tin products and upstream tin products, which hold the largest average degree. In the import competition network of tin products, the average degree of upstream, midstream, and downstream tin products shows an increasing trend. From 2002 to 2022, the average degree of midstream tin products rose by 18%, and the average degree of downstream tin products rose by 35%. This implies that import competition for midstream and downstream tin products is steadily intensifying. During the period 2002–2022, in the export competition network of tin products, the average degree of export competition of upstream, midstream, and downstream tin products has increased by 62%, 29%, and 27%, respectively. This indicates a discernible uptick in export competition for tin products.

The average clustering coefficients and average path lengths of the competitive networks serve as metrics for assessing the tightness of competitive relationships. Notably, the average clustering coefficients for the import and export competitive networks of tin products from 2002 to 2022 range from 0.775 to 0.952, approaching the maximum of 1. This suggests that competitive relationships among competitors within the same importing or exporting country remain highly tight. The highest average clustering coefficient is found in the downstream products, indicating the most competitive relationships among competitors within the same importing or exporting country. However, it is important to note that the average clustering coefficient in the export competition network is relatively smaller than that in the import competition network, signifying that the competitive relationships in the import competition network for tin products are notably more tightly knit.

From 2002 to 2022, the average shortest path lengths within the import and export competition networks for tin products were approximately 1.103–2.212. This implies that two importing or exporting countries involved in tin product trade can establish a competitive relationship by eliminating just one intermediary.

This observation underscores the ease with which competition can develop among competitors within the importing or exporting country as well. The downstream product has the shortest average path length, indicating that the downstream product is most competitive with competitors from the same importing or exporting country.

4.2 Analysis of typical competitive countries

In order to understand the spatial distribution and pattern evolution of the main competition relations, this paper uses the core-periphery structure to divide the core tin productions importing and exporting countries and the periphery tin productions importing and exporting countries, and draws the core-periphery map as shown in Figure 8.

In 2002, 2012, and 2022, due to the high correlation coefficient between the ideal structure and the data, the core-periphery structure of tin product import competition was formed. As shown in Figure 8, The core countries in the competition for upstream tin products have not undergone significant changes, remaining primarily concentrated in Asia and Oceania. However, a few African countries have gradually entered the competition for upstream tin product exports and have become core countries in this export competition. The core countries in the competition for midstream tin products are primarily concentrated in Asia and the Americas. In the downstream tin product trade, the core countries are mainly China and Western countries, with China's core position becoming increasingly prominent over time.

Meanwhile, there are differences in the ρ values for different types of tin products. As shown in Figure 8, the ρ value for downstream tin products is the highest, followed by midstream tin products, with upstream tin products having the relatively lowest ρ value. This indicates that the core-periphery structure

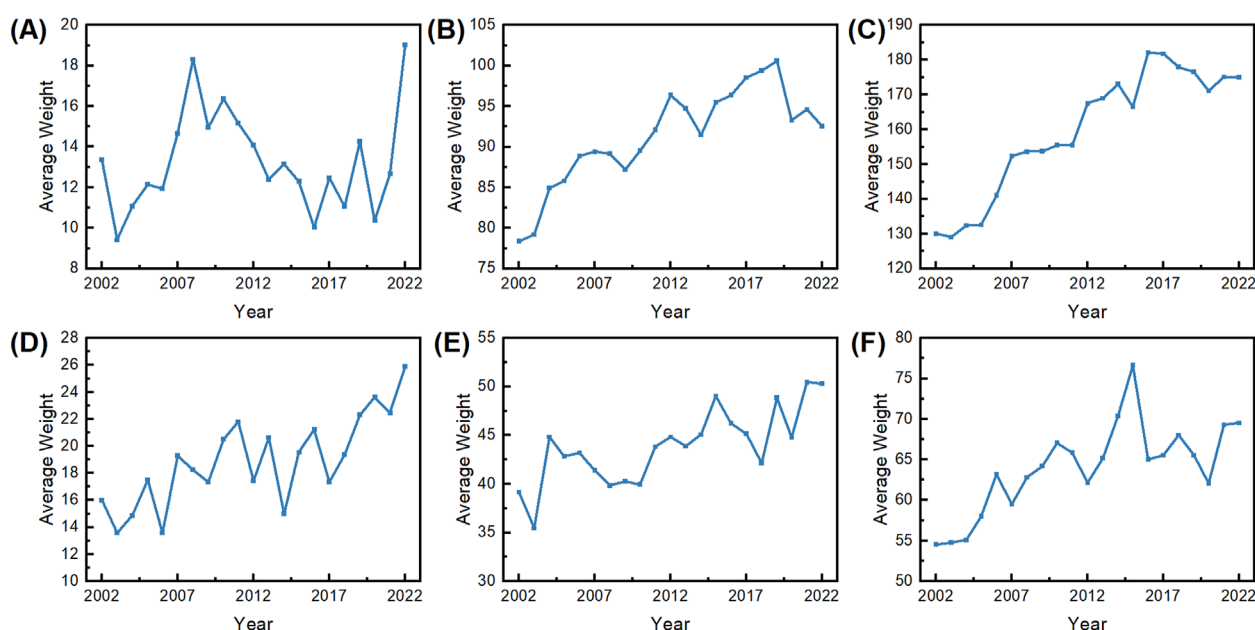


FIGURE 6
The evolution of the average degree of competition networks [(A–C) show the weighted import competition network for upstream, midstream, and downstream tin products, and (D–F) show the weighted export competition network for upstream, midstream and downstream tin products, respectively].

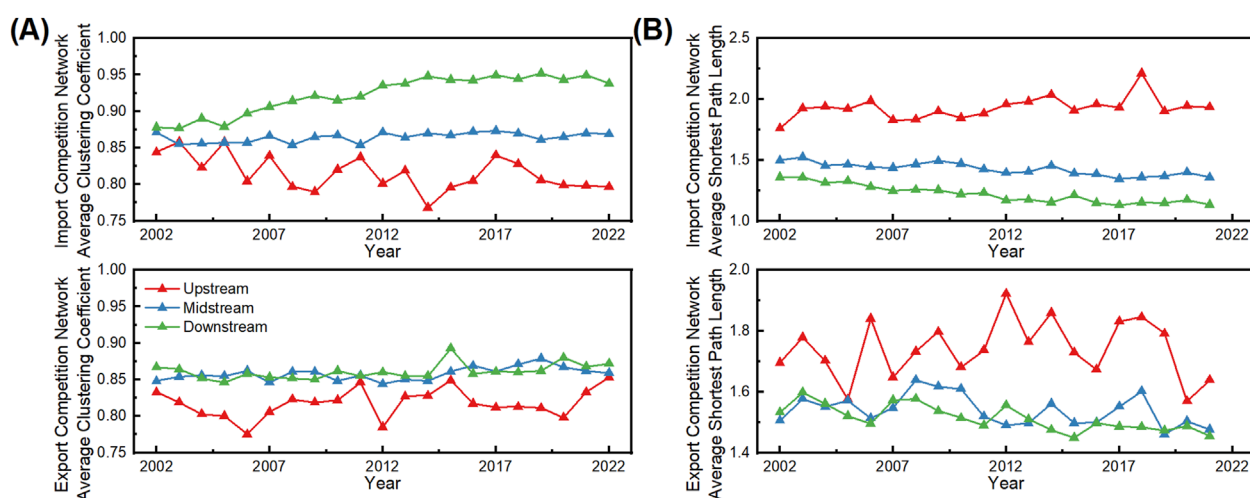


FIGURE 7
The evolution of the Clustering coefficient and shortest path length of the network.

is most distinct for downstream tin products, while the core-periphery structure for upstream tin products is relatively less distinct.

As the competitive pattern of tin products evolves, specific countries gradually establish dominance in the import and export competition network of tin products. In this paper, the total competition intensity (weighted degree) of all tin productions importing and exporting countries is ranked, and Table 2 and Table 3 list the top 5 countries with total competition intensity in 2002, 2007, 2012, 2017 and 2022.

The following results can be obtained from Figure 4 and Table 2:

- (1) The focal point of import competition concerning upstream tin products has consistently resided in Asia and has undergone a transition from Malaysia to China. Since 2013, China has consistently held a central position in the import competition for upstream tin products, both within Asia and globally. Being the world's largest producer of tin solder, China's demand for upstream tin products has displayed consistent growth, rendering it the foremost importer in the global

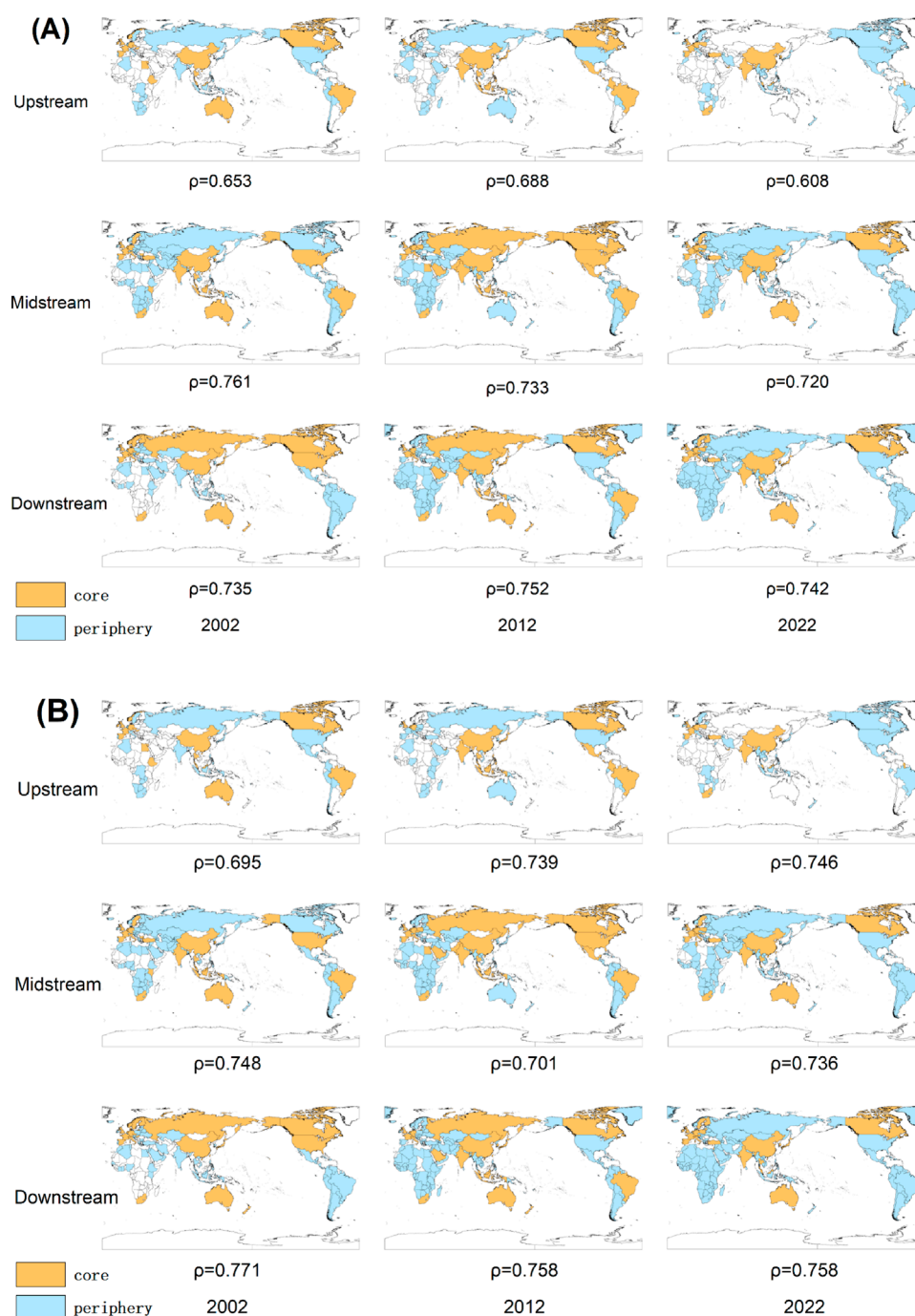


FIGURE 8

The evolution of the Clustering coefficient and shortest path length of the network (Note: (A) shows the global tin chain import competition network and (B) shows global tin chain export competition network).

trade of upstream tin products. According to the United Nations Commodity Trade Statistics, China's tin ore imports constituted 80% of the global tin ore imports in 2022. China, Malaysia, and Thailand emerge as the primary import competitors for upstream tin products, and these three countries collectively dominate nearly the entirety of upstream tin imports.

(2) The focal point of import competition concerning midstream tin products has transitioned from Thailand to Singapore and the United States. Situated at the gateway of the Malacca Strait, Singapore serves as a pivotal maritime transport hub connecting Asia, Australia, Europe, and Africa. It handles substantial quantities of midstream tin products, functions as a prominent intermediary nation,

re-exports goods, plays a significant role in transit, and closely collaborates with neighboring countries. In alignment with its “Industrial Internet” strategy, the United States has deepened its involvement in the industrial chain’s downstream sectors, stimulating the demand for midstream tin products and consequently increasing its competitiveness over the years. While Singapore operates as a transit point for midstream tin products, the United States stands as a major consumer. Moreover, developed countries, including Japan, the Netherlands, and Germany, occupy central positions in the import competition for midstream tin products.

- (3) The main regions of import competition for downstream tin products are North America, Europe, and Asia. From 2002 to 2009, China occupied a central position in the competitive import network for downstream tin products. Following China’s accession to the World Trade Organization (WTO), its industry underwent a transformation, transitioning from being the largest importer to becoming the largest exporter of downstream tin products. Consequently, China’s prominence in the competitive import network for downstream tin products saw a substantial decline after 2009. In contrast, the United States, the United Kingdom, New Zealand, the UAE, and Saudi Arabia experienced significant increases in their positions within the competitive network of downstream tin product imports.

The following results can be derived from [Figure 4](#) and [Table 3](#):

- (1) The focal point of export competition for upstream tin products has consistently resided in Asia, with a notable shift from Indonesia to Myanmar. Since 2011, Myanmar has established its dominance in the export competition network for upstream tin products. This shift is attributed to the stabilization of the political landscape in Myanmar’s Wa Special. Myanmar’s rapid ascent as the world’s third-largest tin miner and leading exporter. In 2022, Myanmar accounted for 63% of the world’s upstream tin product exports, with the majority directed to China. Myanmar has emerged as a significant and somewhat unexpected player in the tin market, often referred to as a “Black Swan” in recent analyses ([Gardiner et al., 2015](#)). Additionally, countries with substantial tin reserves, such as Australia, Bolivia, Rwanda, and the DR Congo, have become noteworthy exporters of upstream tin products. They exhibit robust competitiveness in the import network for upstream tin products ([USGS, 2023](#)).
- (2) The core of export competition for midstream tin products has consistently been in Asia and has shifted from Malaysia to Indonesia. In the early 21st century, Malaysia primarily dominated the export of midstream tin products. However, as its tin reserves began to dwindle, Malaysia’s exports of midstream tin products experienced a gradual decline. However, as its tin reserves began to dwindle, Malaysia’s exports of midstream tin products experienced a gradual decline ([Li et al., 2021b](#)). Notably, Indonesia possesses the world’s second-largest tin reserves. In 2014, the Indonesian Ministry of Trade implemented Trade Regulation No. 44, prohibiting the export of raw tin. This decision aimed to combat the substantial loss of tin resources at low

prices and foster the development of the midstream downstream tin industry ([Chatchawanchanchanakij et al., 2019](#)). Consequently, Indonesia’s standing in the export competition network for upstream tin products saw a significant decrease, while its position in the export competition network for midstream tin products witnessed substantial growth. Singapore, functioning as a transshipment hub for midstream tin products, has demonstrated remarkable competitiveness in the export competition for this product.

- (3) The central hub of export competition for downstream tin products has traditionally been situated in Asia and has transitioned from Malaysia to China. Before 2010, Malaysia consistently held the position of the largest importer of upstream tin products nearly every year. These upstream tin products were subsequently processed to manufacture midstream and downstream tin products for export. In 2010, China surpassed the United States, Japan, and South Korea to emerge as the primary exporters of downstream tin products, establishing itself as the core of export competition for these products. This transformation is primarily attributed to Chinese accounts for approximately 65% of global tin solder production. The diverse forms of tin solder, including tin wire, tin bars, and tin paste, are all classified as downstream tin products. Concurrently, the Middle Eastern countries have been steadily increasing their influence on the import competition network for downstream tin products. Presently, the export competition for downstream tin products is predominantly concentrated in East Asia, with China, Japan, and Rep. of Korea playing significant roles.

4.3 Analysis of typical competitive relationships

This section analyzes the typical competitive relationships in the import and export competition of the global tin products industry chain, focusing on the intensity of competition between countries, with different colors representing competition between different continents, as shown in [Tables 4, 5](#).

[Table 4](#) lists the top 5 import competition relationships in 2002, 2012, and 2022. This study scrutinizes the fundamental import competition relationships aspects of tin products, yielding the following key findings:

- (1) Upstream tin product import competition is predominantly concentrated among Asian nations. Notably, the “Thailand-Malaysia” relationship stood out as the most competitive in 2002 and 2012. In 2022 China exhibits heightened competition with Malaysia and Thailand. The competition for the import of upstream tin products is primarily concentrated among China, Malaysia, and Thailand. Despite possessing the world’s largest tin reserves, China continues substantial imports of upstream tin products to meet its industrial demands. China’s increasing industrialization, particularly since joining the WTO in 2001, has led to a surge in upstream tin product imports, amplifying import competition.

TABLE 4 Top 4 import competition links.

	2002	2012	2022
upstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Thailand-Malaysia	Thailand-Malaysia	China-Malaysia
2	Malaysia-Bolivia	Thailand-China	China-Thailand
3	Malaysia-Singapore	Malaysia-Papua New Guinea	China-UAE
4	Thailand-Fiji	China-Germany	Malaysia-Myanmar
5	Thailand-Singapore	China-USA	Malaysia-Thailand
midstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Thailand-Afghanistan	Singapore-Thailand	Singapore-China
2	Thailand-Syria	Singapore-Malaysia	Singapore-USA
3	Thailand-Fiji	Singapore-Japan	Singapore-India
4	Thailand-Pakistan	Singapore-China, Taiwan	Singapore-Japan
5	Thailand-Nepal	Singapore-China	Singapore-Rep. of Korea
downstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Australia-Singapore	Singapore-Timor-Leste	India-Bangladesh
2	Australia-Japan	New Zealand-United Kingdom	India-Pakistan
3	China-China, Hong Kong	New Zealand-Indonesia	New Zealand - Papua New Guinea
4	China-Philippines	New Zealand-China, Taiwan	India-Singapore
5	Singapore-Japan	New Zealand-China, Hong Kong	India-Myanmar

(2) The competition for the import of midstream tin products is predominantly concentrated in Asia. In 2002, the top 5 import competitive relationships for midstream tin products included Thailand, while in 2012 and 2022, Singapore played a prominent role. Singapore, as a transshipment hub for midstream tin products, imports a significant quantity of midstream tin products and engages in re-export trade. Import competition for midstream tin products in 2022 is mainly centered on “Singapore-China” and “Singapore-United States”. China and the United States, as the world’s superpower and economic powerhouse, consistently perceive manufacturing as a driver of economic robustness and national security. Against this background, China and the United States, being an industrial juggernaut, has increasingly imported substantial quantities of midstream tin products for the production of electronic components, where tin serves as solder in electronic components.

(3) Import competition for downstream tin products has shifted from competition among developed countries to competition among developing countries. In 2002 and 2012, the import competition for downstream tin products predominantly revolved around developed countries like Australia, Singapore, and Japan. Fast forward to 2022, and developing nations such as India, Pakistan, and Bangladesh are entangled in intense import competition. Constrained by their own industrial capacities, these developing countries face challenges in producing downstream tin products efficiently, leading them to import substantial quantities due to the associated high production cost.

Table 5 outlines the leading 5 export competition relationships for 2002, 2012, and 2022. This study delves into the fundamental export competition relationships of tin products, yielding the following key findings:

TABLE 5 Top 5 export competition links. (Different colors represent the competition between different regions).

	2002	2012	2022
upstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Indonesia-Singapore	Myanmar-Bolivia	Myanmar-DR Congo
2	Indonesia-Nigeria	Myanmar-DR Congo	Myanmar-Bolivia
3	Indonesia-Rwanda	Myanmar-Laos	Myanmar-Russian
4	Indonesia-China	Myanmar-Tanzania	Myanmar-Kyrgyzstan
5	Australia-Peru	Myanmar-Uganda	Myanmar-Nepali
midstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Malaysia-Congo	Indonesia-China	Indonesia-Japan
2	Indonesia-China	Indonesia-Singapore	Indonesia-Malaysia
3	China-Singapore	Indonesia-Malaysia	Indonesia-Peruvian
4	Malaysia-Viet Nam	Indonesia-China, Taiwan	Indonesia-Singapore
5	Indonesia-Singapore	Indonesia-Philippines	Indonesia-United States
downstream			
rank	competitive relationship	competitive relationship	competitive relationship
1	Malaysia-Indonesia	Rep. of Korea-Japan	China-United Kingdom
2	Malaysia-China	Indonesia-Congo	China-Malaysia
3	Malaysia-China, Taiwan	Indonesia-Cambodia	China-India
4	Malaysia-Singapore	Indonesia-Ukraine	China-Thailand
5	Malaysia-Thailand	China-United States	Malaysia-Indonesia

- (1) In 2002, all of the top 5 export competitiveness relationships for upstream tin products included Indonesia, and in 2012 and 2022, all of the top 5 export competitiveness relationships for upstream tin products included Myanmar. Export competition for upstream tin products is primarily centered on Asia, Africa, and South America. Myanmar in Asia, Nigeria, Rwanda, and the DR Congo in Africa, as well as Bolivia and Brazil in South America, boast substantial tin

ore resources. Due to their limited industrialization, these countries predominantly export tin ore, sparking intense export competition among them.

- (2) All of the top 5 export competitive relationships for midstream tin products in 2012 and 2022 include Indonesia. The competition between Indonesia and China, ranking second in 2002 and first in 2012 and 2022, reveals the most pronounced export competition between these two nations. China and Indonesia account for 15% and 17% of the world's tin reserves, respectively. Export competition for midstream tin products is concentrated among Asian countries. With a high level of industrialization, these nations process tin ore into midstream tin products for export, intensifying the competition in the global market.
- (3) In the export competition of downstream tin products, China's export competitiveness has experienced a notable upswing. Almost all of the top 5 export competitive relationships of downstream tin products in 2022 include China. The export rivalry between "China-Germany" and "China-Japan" stands out for its intensity. China, Germany, and Japan are all large industrial countries that export a large number of downstream tin products and have strong competitiveness in the export competition of downstream tin products.

4.4 Analysis of community in competition networks

Community indicators play an important role in comprehending the competitive landscape of tin products within the global industrial chain. Communities exhibit stronger relationships within the same group compared to those between countries in different communities. The higher the value of modularity, the better the partition effect and the more significant the community effect. Figure 9 illustrates the changes in modularity values in the tin products import and export competition network from 2002 to 2022. Notably, the modularity of upstream tin products surpasses that of midstream and downstream products, signifying a significant grouping effect for upstream products. Conversely, midstream and downstream tin products display a less prominent grouping effect. The decreasing trend in the modularity of upstream tin products suggests that as trade in upstream tin products becomes more globalized, trade community barriers are fading, leading to increased integration among importing and exporting countries. Two notable declines in 2008 and 2020 coincide with the global financial crisis and the COVID-19 pandemic, prompting tin-exporting countries to seek additional consumers and mitigate the impact of these crises through market diversification to safeguard their economic interests.

The Normalized Mutual Information (NMI) between year t and year $t+1$ serves as an indicator of the temporal stability in the group differentiation of the tin products competition network. This metric gauges the similarity degree among group members from year t to year $t+1$, and the NMI calculation results are depicted in Figure 9. In the import or export competition network of tin products, the stability of the upstream products of tin is higher than that of the midstream products and downstream products of tin. The stability gap between the respective import

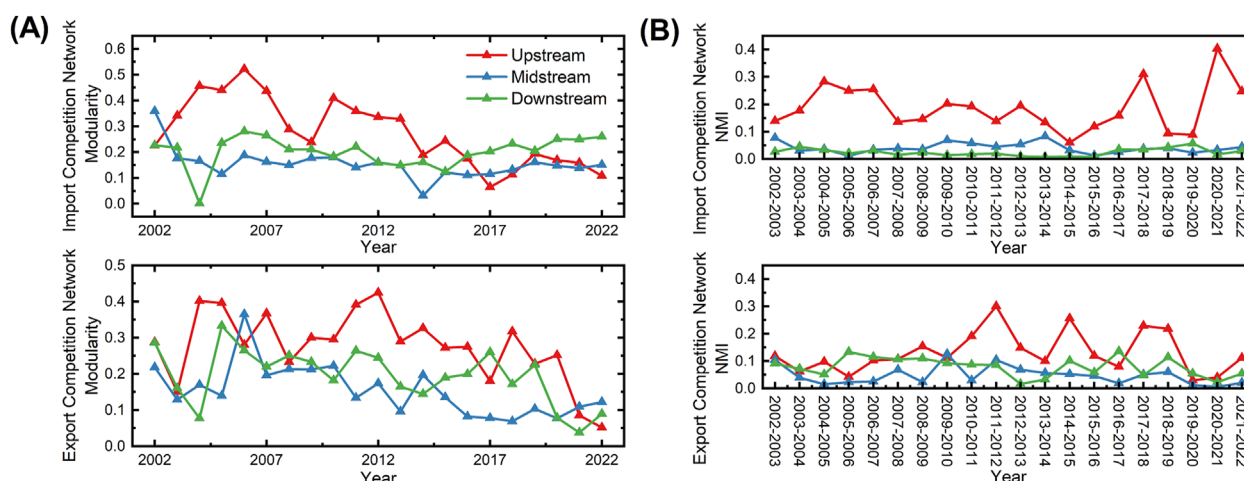


FIGURE 9
The evolution of modularity and NMI of competition network.

and export competitions of upstream and midstream tin products is narrower, while the stability of export competitions for downstream tin products exceeds that of import competitions. Therefore, it is necessary to further analyze the changes in the pattern of country communities in the international import and export network of tin products, and for this purpose, we analyze the country members in the community. The evolution of competitive groups among nations is not solely influenced by policies but is also intertwined with the international market and global economy. The 2008 economic crisis triggered a sequence of fluctuations in the global economic landscape, significantly influencing the international competitive dynamics of tin products. The ensuing global economic slowdown and the escalation of the sovereign debt crisis in Europe and the USA, coupled with insufficient international market demand, led to substantial changes in the competitive groups. Similarly, the 2020 COVID-19 pandemic exerted a profound impact on the international competitive dynamics of tin products.

Figure 10 depicts the evolution of competition network communities in the import and export of tin products. Different colors signify distinct communities, with countries (regions) within the same community represented by the same color. The countries (regions) in the white region do not compete for tin products, so there are no communities of them. Combining the competitiveness of the different countries (regions) in the import and export competitive network of tin products, this paper has the following findings:

The import competition network of upstream tin products is divided into 3–9 communities. Import competition for upstream tin products is mainly in Asia, where the intra-Asian community is divided into the “Thailand-Malaysia” community and the “China” community. The competitiveness of the “Thailand-Malaysia” community is gradually declining, while that of the “China” community is gradually rising. The import competition for midstream tin products is divided into two to six communities. The competitiveness of the “USA” community is on the ascent, while the “Singapore-Thailand” community witnesses a gradual decline.

For downstream tin products, the import competition is divided into 3–6 communities. The “USA-United Kingdom” community exhibits increasing competitiveness, while the competitiveness of the “China” community experiences a gradual decrease.

In the export competition network of tin products, the evolutionary diagram indicates the presence of 3–7 communities for upstream tin products. Export competition for upstream tin products is predominantly situated in Asia, Oceania, Africa, and South America. Notably, the competitiveness of the Asian “Myanmar-Indonesia” community is progressively rising, while that of the Oceania “Australia” community is on the decline. For midstream tin products, the export competition is segmented into 2–6 communities. The competitiveness of the “Indonesia” community is steadily increasing, while the competitiveness of the “Malaysia” and “Bolivia-Peru” communities is gradually diminishing. The export competition for downstream tin products is divided into 2–10 communities. The competitiveness of the “China” community is progressively growing, while that of the “Malaysia” community is gradually declining.

5 Conclusions and policy recommendations

5.1 Conclusions

This paper applies the international trade data of tin products from 2002 to 2022 and applies the complex network method to construct the international trade network of tin products and its derived import competition network and export competition network. The general characteristics of the import competition network and export competition network of tin products, the main competing countries (regions), the main competitive relationships, and the group evolution were analyzed. Based on the above analysis, the conclusions are as follows:

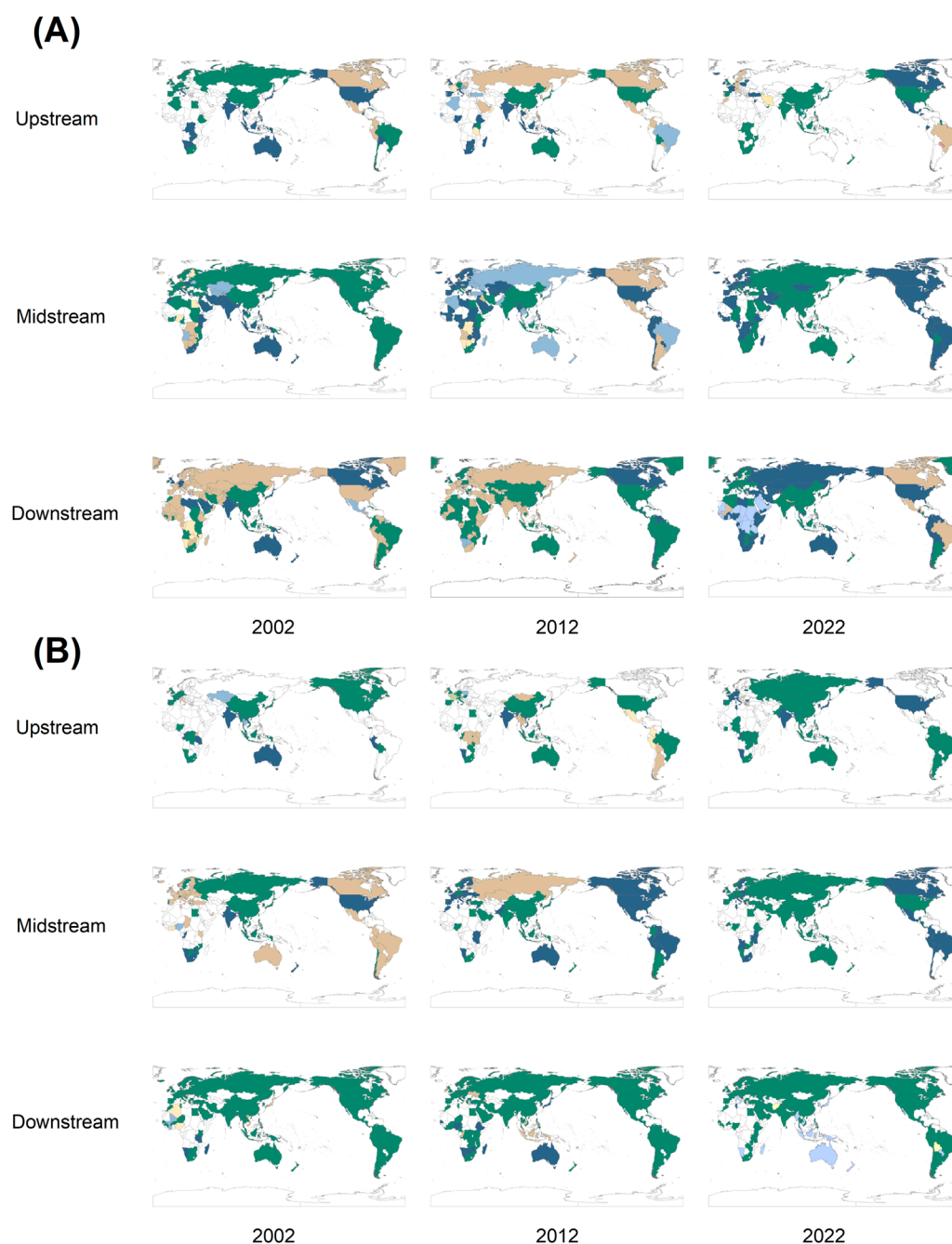


FIGURE 10

The evolution of competition networks communities. (Note: Different colors signify distinct communities, with countries (regions) within the same community represented by the same color.).

(1) The competitive network of trade in tin products is extremely heterogeneous. In the network of import and export competition, countries involved in downstream products and competitive relationships are the most numerous, followed by midstream products, and upstream products are the least numerous. The distribution of the competitive intensity of tin

products is very uneven, with about 80% of the competitive intensity coming from about 10% of the competitive relationships and a few countries dominating the competition among the global tin product import and export countries. The range of tin applications has been expanding from traditional uses, such as soldering, to emerging high-tech fields, including

batteries and solar photovoltaics. The average degree of import competition between importing countries of tin midstream and downstream products has increased year by year, and the competition between importing countries is getting more and more intense; the average degree of export competition of tin products has increased in all, and the export competition of tin products is strengthening. In addition, the average clustering coefficient of the competitive network is high, and the average shortest path length is approximately shorter, which implies that there is very close competition for the import and export of tin products.

- (2) In the tin industry chain, importing countries compete strongly with one another, creating a tripartite import competition between Asia, Europe, and North America. Competition among developed countries mainly centers around midstream tin products, while competition among developing countries is dominated by imports of upstream and downstream tin products. As the world's largest producer of tin solder, China's demand for upstream tin products is growing steadily. These upstream tin products are utilized in the production of midstream and downstream tin products, which are subsequently employed in exports or further industrial processes. Developed countries such as the United States, Japan, Germany, Rep. of Korea, and the Netherlands are the main importers of midstream tin products, and these countries rely heavily on the import of midstream tin products to meet their own tin consumption and production of tin downstream industrial products. At the same time, developing countries such as Pakistan and the Philippines, which are constrained by their own industrial capacity and are unable to produce downstream tin products or have high costs of producing downstream tin products, import large quantities of downstream tin products and face fierce import competition.
- (3) The primary focus of the export competition for tin products is primarily situated in Asia. The centrality of Malaysia is gradually lost, and the centrality of other countries such as Myanmar, Indonesia, and China is gradually coming to the fore. After Malaysia's tin reserves declined significantly, it not only lost its position in the competition for upstream tin exports, but also in the competition for midstream and downstream tin exports. The national policies significantly influence the export competition for tin products. In 2011, after the political stability of Wa State, Myanmar became the core of the global export competition for upstream tin products. In 2014, Indonesia became the core of the export competition for midstream tin products after the Ministry of Trade of Indonesia enacted Trade Regulation No. 44, which banned the export of crude tin. The history of China's midstream and downstream tin exports can be divided into two stages. In the first phase, from 2002 to 2010, the largest share of midstream tin products was exported, and after 2010, midstream tin products were no longer exported and downstream products began to be exported.
- (4) There are typical competitive relationships in the competitive network of trade in tin products. The import competition of upstream tin products is mainly concentrated among

Thailand, Malaysia, and China; the export competition of upstream tin products is concentrated between countries such as Myanmar and Bolivia. The import competition of midstream tin products has shifted from competition among Asian countries to competition among developed countries in Europe and the United States. In the export competition of midstream tin products, the competition between "Indonesia and China" is the most fierce. The import competition for downstream tin products is concentrated among developing countries such as Pakistan and the Philippines, and the export competition between "China-Germany" and "China-Japan" is very fierce.

- (5) There is a clear community effect on the competitive network of trade in tin products. The effect of competitive grouping of upstream tin products is significant, and the effect of competitive grouping of midstream and downstream tin products is not significant. Moreover, the stability of upstream tin product competition is higher than that of midstream and downstream tin products. We also find that the group stability of each competing network is low. This result means that competition between countries for tin products is very active.

5.2 Policy recommendations

Considering the conclusions above, we propose the subsequent recommendations:

- (1) Countries that rely heavily on upstream tin product imports should diversify their import channels. The high concentration of imports means that tin resources are less secure due to the risk of depletion of natural resources in supplying countries, such as Peru and Malaysia, where tin reserves are in steep decline. Policies in supplying countries can also lead to supply risks. The Myanmar government's Notice of Suspension of All Mineral Resource Mining on 15 April 2023, could significantly impact China's upstream tin product imports. As a major importer, China's 90% of imported tin products come from Myanmar. To mitigate risks, importing countries should focus on real-time upstream tin product capacity movement, seek alternative importers, strengthen attention to intermediate countries, and increase risk prediction to cope with future emergencies.
- (2) Countries with abundant tin resources should foster the development of the tin industry downstream. A country rich in upstream tin products, such as Myanmar, possesses a competitive edge in the global market due to its abundant tin resources. Improving the import and export frameworks and modernizing the industrial structure should be the government's main priorities. This will encourage foreign investment to establish factories in places with abundant mineral resources and help to broaden resource advantages. They can boost domestic capacity, raise the value of exported goods, raise their economic income, and provide security by using local labor and cutting-edge machinery and technology from foreign producers.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#), further inquiries can be directed to the corresponding author.

Author contributions

YJ: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. TD: Funding acquisition, Project administration, Supervision, Writing–review and editing.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2024.1501816/full#supplementary-material>

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