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How does the Belt and Road Initiative reshape the regional trade network? - Evidence from Equipment Manufacturing Industry

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Abstract

One of the objectives of the Belt and Road Initiative, launched by China in 2013, is to expand the market and establish mutually beneficial cooperation between countries. Taking a look back, does the initiative benefit the participating countries? How does it reshape the regional trade network? To answer these questions, this paper constructs a regional trade network based on the equipment manufacturing data of 63 participating countries from 2011 to 2021. The structure and characteristics of this network are then scrupulously analyzed through several indicators, such as network density, reciprocity index, centrality and agglomeration coefficient. The research results show that the trade scale of the Belt and Road Initiative equipment manufacturing industry is expanding, that this growth is relatively uniform between countries and that the different trade control forces balance each other. The dominance of the BRI has increased, and neighboring countries tend to be incorporated into "small groups".

JEL classification numbers: F13.
Keywords: Belt and Road Initiative, Equipment manufacturing sector, Regional trade network, Structure and characteristics, Topological structure.

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1. Introduction

The Belt and Road Initiative (BRI), launched by China in 2013, supports a major strategic goal of global trade liberalization (Ohashi, 2018; Shen and Chan, 2018). It is widely recognized by various countries and implemented globally, and it plays an important role in reshaping the world trade pattern and the international monetary system (Huang, 2016; Zhang et al., 2019; Nugent and Lu, 2021; Bandiera and Tsiropoulos, 2020). Unimpeded trade is an important content and core link of the joint construction of the BRI, and it is directly related to the actual effectiveness of BRI construction. Therefore, to effectively promote BRI economic and trade cooperation and achieve high-quality development from the network perspective, it is of great significance to carry out research on the trade connectivity of the BRI and explore the structural characteristics and evolutionary process of the BRI trade network.

With the further deepening of the global division of labor, international trade tends to be networked, eventually forming a world trade network system. The interconnected trade flows formed between countries in space interweave to form the structure of an international trade network. In this context, the study of trade networks has gradually become an important path to understanding the international trade system. Therefore, on the occasion of an 11-year progress review, to assess the BRI impact, this paper analyses the feedback we have in the equipment manufacturing sector, which is a representative and strategic industry providing various technologies and equipment for economic construction and national defense security, including the manufacturing of consumers. To measure how connected a country is to the BRI trading system, the paper considers the pattern of international trade linkages as a network. Based on trade data from 63 countries from 2011 to 2021, this paper constructs the trade network of the BRI equipment manufacturing industry and explores the structural characteristics of the network pattern and the rules of network change. Moreover, a reasonable and feasible policy suggestion is further put forward and is of great significance for promoting the improvement of global trade patterns and enhancing the overall trade competitiveness for BRI participants.

The paper is organized as follows. Section 2 presents the BRI, reviews related works on equipment manufacturing trade, and concludes on the international trade network. Section 3 presents the research methodology adopted to construct the international trade network along the BRI based on the social network analysis (SNA) method and to construct the BRI regional trade network. Section 4 presents the research data and the evolution of the trade network from 2011 until 2021. The results and implications are also discussed in Section 4. Section 5 concludes and provides some perspectives.

2. Literature review

The BRI has been described as the largest infrastructure program in human history; the promised investments are over USD 8000 billion, and the countries that it will be implemented in will contain half of the world's population a third of global GDP (Leverett and Bingbing, 2017; Kirchherr et al., 2018; Hurley et al., 2019; Williams et al., 2020). The BRI was formulated to meet the need for countries to secure supplies of raw materials and to facilitate international exchanges (Djankov and Miner, 2016; Zhang, 2019; Bird et al., 2020). It results in a policy of building port, rail, and land infrastructures (Chaisse, 2018; Zou et al., 2022; Schulhof et al., 2022). It is an evolving project that progressively becomes a reference framework for globalization (Khan et al., 2018; Baniya et al., 2020). To give an idea of the growth of the project, at the geographical level, it involved approximately sixty countries at the outset and now involves approximately one hundred countries. At the sectoral level, the BRI was initially focused on transport, but it has broadened its scope to include energy, telecommunications, industrial parks, and tourism (Yang and Ni, 2022; Wei et al., 2023; Lall and Lebrand, 2020). According to Thomas Gomart (Gomart, 2019), Director of the French Institute of International Relations, "This initiative must be understood as a tool for restructuring global governance": Europe, China, and Central Asian countries are engaged in the construction of a major new trade network, and the BRI can redistribute the economic and political cards.

Existing research mostly focuses on bilateral trade relations, often neglecting that trade relations between countries are trilateral and have network characteristics. In recent years, an increasing number of researchers have used network analysis methods to study the determinants of structure and international trade networks (Cassi et al., 2012; Cranmer et al., 2017). Since its launch in 2013, the BRI has been studied by researchers from the perspective of trade networks (Liu et al., 2018; Song et al., 2018; Li et al., 2021). After some scholars (Chong et al., 2019) calculated the network index based on the trade flow data of different countries, they found that the BRI significantly improved the connectivity of trade networks. As the initiator of the BRI, China's massive import demand has significantly promoted the exports of the Belt and Road economies (Bastos, 2020). Another aspect related to the content of this study is the equipment manufacturing industry trade network. The BRI encourages the construction of infrastructure, such as ports, railways, and roads, among participating countries to improve connectivity. It has to some extent promoted the development of the equipment manufacturing industry trade. Many scholars have conducted in-depth research in many branches of the equipment manufacturing industry, including the structure and evolution of the export trade network in the equipment manufacturing industry (Wang et al., 2021), the impact of international investment on industrial total factor productivity (Li et al., 2021), and how the digital economy promotes the development of equipment manufacturing trade (He et al., 2022; Li and Zhang, 2025).

Through the literature review above, it appears that research on equipment manufacturing trade has been relatively in depth, both through the input–output method and measuring the relevant demand rate, added value rate, total factor productivity, and other aspects using the DEA method to evaluate the current situation and influencing factors of equipment export. Additionally, some scholars link it with the global value chain to explore the technical complexity of equipment export and its industrial upgrading. Meanwhile, based on SNA, there is abundant research on the trade networks of countries along the BRI, and most evaluate structural characteristics and influence by measuring network-related indices. However, there are still few related studies on equipment manufacturing trade and trade networks according to the background of the BRI. Additionally, the measurement indices of related studies are quite different, and most of the networks are trade networks without weight. Therefore, aiming at the description of the trade network structure, this paper puts forward the use of the SNA method to construct the entitled trade network of the equipment manufacturing industry under the background of the BRI and further measures and analyzes indices to offer reasonable suggestions for strengthening the trade import and export of the equipment manufacturing industry around the BRI.

3. Construction of the trade network

In this study, we consider the BRI region as an independent system. The establishment of regional trade networks and an analysis of the characteristics and evolution of the trade pattern of equipment manufacturing goods can reflect the spatiotemporal trends of trade patterns with the implementation of the BRI strategy. We propose using the SNA method to study the characteristics of the topological structure of the entire network and then analyzing the influence of each node on the entire structure (not only each node but also the characteristics of the whole network). Unlike causal analysis, SNA considers bidirectional interactions within the network (Tsugawa, 2019; Camacho et al., 2020). It is a quantitative analysis method developed by sociologists based on mathematical methods and graph theory (Vishnu, 2020). It is also a mature tool that can analyze business relationships among multiple agents and the structure of complex business systems (Sun et al., 2020). Due to these advantages, SNA has been increasingly popular for studying the interactions between actors in a network formed by a certain relationship (friendship, cooperation, trade, among others) (Emirbayer and Goodwin, 1994; Newman, 2001; Scott, 2011; De Andrade and Rêgo, 2018). After years of development, a series of relative methods and tools can be applied to establish and visualize trade networks and perform network and node-level analyses. As a result, many researchers have performed SNA on established trade networks to analyze the structure and evolution of global or regional trade. Therefore, in line with our objectives, the SNA method will be used in our research.

A brief introduction to SNA is provided in Section 3.1. Section 3.2 presents the construction of the equipment manufacturing trade network model. The detailed analysis indices will be introduced in Section 3.3, including the cohesion analysis, centralization analysis and clustering analysis.

3.1 Employee Stock Ownership Plans and Corporate Digital Technology Innovation

Since the 1980s, with the rapid rise of the new network economy, the total global trade volume has grown rapidly, and connectivity has become an important measurement index for the economy. Trade network research covers fixed networks, undirected networks, unweighted adjacency matrices and dynamic trade networks. With an increasing number of countries and trade relationships, the combination of trade research and network methods has become a development trend.

Graphics is a basic form for representing social networks. Different from variable diagrams, network diagrams are mainly composed of nodes and edges. The network diagram can be binary or multivalued, directed or undirected. The SNA method consists of the description and analysis of the networks. When there are many nodes involved in the network, the intuitive graphic representation method is relatively complex, and it is difficult to analyze the relationship structure intuitively. Therefore, a matrix is employed to represent the social networks based on the nodes and edges. If the rows and columns of the matrix represent "social actors" belonging to a set of actors, each component of that matrix represents the relationship among the members. In this case, the most commonly used matrix is a square matrix, in which rows and columns represent the same social participants in the same order, and the elements in the matrix are often binary. Graph theory experts often call such a matrix an adjacency matrix. In addition to the adjacency matrix, many other kinds of matrices can also describe networks, such as the occurrence matrix, membership matrix, directed matrix, and multivalued matrix. In this paper, we use the adjacency matrix to represent the equipment manufacturing trade network.

According to the "nature of relations", social network research includes three categories. The first focuses on the research of the "structural form" of relations and pays attention to the "system" of relations between actors, that is, how the connection pattern or structure between actors will affect the behaviors of actors and how actors in turn affect the structure. The second focuses on the research of relation "content" and "social situation" of the relationship. This kind of research pays attention to the specific "situation" of the network and how it affects the behaviors of actors. The third focuses on research on the "channel effect" of the relationship itself.

There are three types of network research scopes, including individual networks, local area networks and overall networks. The individual network mainly refers to the network composed of a core member and its associated nodes and studies the influence of core members on the attributes of its associated nodes; LAN mainly refers to the study of a single network and its members, mainly the influence of a certain node on the members around the network. Composed of a single network and other points associated with a single network member, LAN mainly studies the influence of a certain node on the members around the network. Based on the characteristics of this study, this paper will build an overall network based on intercountry trade relations and analyze the structure of the network according to the nature of the relations. In the expression of a network, the weighted directed community graph is used to represent the network evolution of cross-sectional data, and the multivalued relation matrix is used to measure the network index.

3.2 Modeling the equipment manufacturing trade network

As a matrix set composed of multiple nodes and edges, social networks can be divided into indirect networks and directed networks according to whether the network has a direction or not. They can also be divided into unweighted networks and weighted networks according to whether edges are given weights or not. In this study, the 63 countries along the BRI can be taken as network nodes, and the trade exchanges can be taken as network edges. We then construct the weighted directed network structure diagram of economic and trade cooperation between them, and these network data are visualized by Ucinet software. Among them, the nodes represent countries, and the connections between nodes represent the trade relations between countries. According to the data symmetry, the import of one country is the export of the other party. The export trade data are selected to analyze the trade relationships in this study. In other words, the export trade volume is used as the weight of the connecting edges of the directed network diagram, where the direction is from the exporting country to the importing country.

In this way, the equipment manufacturing industry trade network can be modeled by the set $G = (N, W)$, where N represents the number of nodes (countries), denoted as $N(t)$, indicating the number of countries engaged in equipment trade in the world in the t^{th} year, and W represents the export trade volume for the edges in this trade network. Therefore, the BRI trade network of the equipment manufacturing trade network consists of 63 nodes (countries in the trade relationship) and many edges (trade relationships between the countries). To have different analysis angles, this paper constructs unweighted and weighted directed networks. The unweighted directed network is presented by adjacency matrix A as follows:

$$A_{ij}(t) = \begin{bmatrix} a_{11}(t) & \cdots & a_{1n}(t) \\ \vdots & \ddots & \vdots \\ a_{n1}(t) & \cdots & a_{nn}(t) \end{bmatrix} \tag{1}$$

where a_{ij}=1 if there is an export relationship of equipment manufacturing goods from the i^{th} country to the j^{th} country; otherwise, a_{ij}=0.

The trade-weighted directed networks are:

$$A_{ij}^{w}(t) = \begin{bmatrix} a_{11}^{w}(t) & \cdots & a_{1n}^{w}(t) \\ \vdots & \ddots & \vdots \\ a_{n1}^{w}(t) & \cdots & a_{nn}^{w}(t) \end{bmatrix} \tag{2}$$

where $a_{ij}^{w}(t)$ is the trade amount of equipment manufacturing goods from the i^{th} country to the j^{th} country.

3.3 Construction of the network analysis indexes

Network analysis is based on cross-sectional data. That is, the network relationship of bilateral import and export quotas of countries along the BRI in each year, which, like a photo, depicts the whole network state in a certain year. There are many topological structure properties worth exploring, and subtle characteristic changes can be analyzed through various index measures. Multiple network snapshots intercepted can be used to explore the change rules. In this study, network density, reciprocity, degree centrality, proximity centrality, intermediary centrality and clustering coefficient are used to measure the topological characteristics of the network. The definition, calculation formula and index meaning of each measure index are shown as follows.

3.3.1 Cohesion

1. Network density

Network density is an indicator to measure the closeness between nodes in the whole network. The network density is calculated as follows: The ratio of the actual number of relationships of each node contained in the network to the maximum number of relationships that may exist in the network. The maximum number of relationships in each network is fixed and related to the network scale, which refers to the number of nodes contained in the network. The larger the scale is, the larger the possible maximum number of relationships and the larger the actual number of relationships will be. This indicates that the more closely the nodes are connected and the more exchanges are connected, the higher the effectiveness of the whole network will be. Meanwhile, the greater the influence of the change in the whole network on nodes is, the more obvious the inhibition of the network on individual development will be. If there are n nodes in the network, the possible maximum number of network relationships is $n*(n-1)$. However, no two nodes can be connected in practice. The actual number of relationships is expressed by m. Then, the calculation formula of network density is:

$$D = \frac{m}{n(n-1)} \tag{3}$$

In the weighted trade network, the actual network relationship is replaced by the trade volume weight, that is, the total trade volume of the whole network, while the number of relationships in the denominator is still the number of possible relationships measured by the network size, that is, the maximum number of connections in 63 countries, so its calculation result is not between 0 and 1. Therefore, the larger the value is, the greater the network density will be. The closer the trading countries are, the deeper the influence of the network structure on each trading country will be.

2. Network reciprocity

Trade relations between countries in trade networks are often asymmetric. Reciprocity is manifested in whether the trade exchanges happen or not and the difference in trade volume degree. It is obviously not a good trade structure and not a sustainable development state for a country to import or export only. A large trade balance or international trade balance or a deficit may indicate problems in the trade structure. Excessive foreign exchange reserves accumulated by exports are more likely to lead to the loss of domestic resources. Foreign exchange reserves exchanged by worse terms of trade are not conducive to the long-term development of the country, which can be understood as mercantilism of classical trade theory. Therefore, the reciprocity of trade networks is equally important politically. Only when both sides have trade exchanges can they achieve mutual benefits and win-win results. When two countries live in peace, reciprocity not only is conducive to the transmission of economic benefits but also may accelerate the spread of economic crisis and increase the probability of reaching the destination country from the originating country. Second, the existence of bidirectional edges tends to balance each other's energy and make the network evolve into a more orderly structure. The reciprocity and correlation coefficient between adjacent matrix nodes of a directed network is defined as:

$$\rho = \frac{\sum_{i \neq j}(a_{ij} - \bar{a})}{(a_{ij} - \bar{a})^2} \tag{4}$$

where $\bar{a} = \sum_{i \neq j} a_{ij} / N(N-1)$; the larger ρ is, the more orderly the network structure is.

3.3.2 Centrality

1. Degree centrality

Degree centrality can be used to measure the core position and role of a node in the network. In the BRI trade network, its trade influence ability on neighboring countries shows a trend of concentration to a certain point. In network analysis, directed networks are divided into out-degree and in-degree. The in-degree refers to the number of edges entering a node, and the out-degree refers to the number of edges emitted from this node. In the trade network, it can be understood as the number of exporting countries and importing countries for a country. In the weighted network, the trade volume is regarded as the weight, which can be understood as the total export volume and the total import volume of a country. At this moment, the out and in degree will be deformed into out intensity and in intensity. The out-degree is defined as:

$$D_i^{out} = \sum_j^n a_{ij} \tag{5}$$

The in-degree can be calculated as:

$$D_j^{in} = \sum_i^n a_{ij} \tag{6}$$

2. Network centralization

The network centralization of the existing graph in the whole network refers to the measurement of the trend of a graph to a certain core node. The trade network can be understood as several very core trading powers that tend to monopolize the trade products of the equipment manufacturing industry or form structures such as oligarchies (as found in Qatar). Or a country that imports and exports a lot may be that there are many port cities of entrepot trade. Therefore, network centralization is also of research significance. The network centralization can be calculated as:

$$C = \frac{\sum_i (D_{max} - D_i)}{(n-1)(n-2)} \tag{7}$$

The output intensity can be calculated as:

$$S_i^{out} = \sum_{j=1}^n a_{ij}^w \tag{8}$$

The input intensity can be calculated as:

$$S_j^{in} = \sum_{i=1}^n a_{ij}^w \tag{9}$$

3. Betweenness Centralization

Betweenness centralization reflects the control degree of one node over others, that is, the possibility that this node is on a shortcut to the contact of other nodes. For example, a node can be associated with others via a specific node, indicating that the node has great power as a communication intermediary. The more it communicates with other nodes, the higher its betweenness centralization will be. The greater the betweenness centralization value is, the greater the power of the node in the trade network and the stronger the network control ability will be, and vice versa. Specifically, the number of shortcuts between point j and point k is represented using g_{jk}, and the number of shortcuts that pass through the third point i between point j and point k is represented using $g_{jk}(i)$. The ability of the third point i to control the communication between these two points is represented using $b_{jk}(i)$, which is equal to the probability of i on a shortcut between point j and point k; that is:

$$b_{jk}(i) = g_{jk}(i)/g_{jk} \tag{10}$$

The absolute betweenness centralization of a point can be obtained by adding up the intermediate degrees of point *i* corresponding to all pairs of points in the graph (denoted as C_{ABi}):

$$C_{ABi} = \sum_j^n \sum_k^n b_{jk}(i) \qquad j \neq k \neq i, \text{and } j < k \tag{11}$$

Betweenness can be calculated as:

$$C_B = \frac{\sum_{i=1}^n (C_{AB_{max}} - C_{ABi})}{n^3 - 4n^2 + 5n - 2} \tag{12}$$

4. Closeness

The closeness of a point is the measurement of the degree to which a node is not controlled by others. The closer a point is to other points, the more easily information is transmitted. Therefore, it may be in the center of the network. If the distance between a point and all other points in the network is very short, the more directly it is associated with other nodes or the closer it is to the central point. When the proximity centralization of a point is high, it is less easily controlled by others and obtains fewer information resources and lower power and prestige. Closeness is defined as:

$$C_i^{-1} = \sum_{j=1}^n d_{ij} \tag{13}$$

Among them, d_{ij} is the sum of the shortcut distances between *i* and *j* (the number of lines contained in the shortcut).

3.3.3 Clustering

The clustering coefficient, the possibility of combining with its adjacent points to form a "small group", can effectively explain its property. The large clustering coefficient indicates that nodes in the network are more likely to gather into small groups and easily form trade groups in the trade network, which can promote some countries to reach trade agreements, customs unions and other interest communities and the development of international trade. For a node with *k* neighbors, the formula for calculating the average network clustering coefficient is:

$$C(\acute{k}) = \frac{1}{NP(k)} \sum_{k_i} 2n_i / k_i(k_i - 1) \tag{14}$$

where n_i refers to the number of edges of node *i* connected to its adjacent nodes and *NP*(*k*) refers to the number of nodes with a degree value of *k*.

4. Analysis results

4.1 Data resources

The data source of equipment imports and exports worldwide is the UN comtrade Database, and the trade volume is based on the current price in US dollars. Considering that the trade data of some countries in 2023 have not yet been released and some data for 2022 are still missing, the export data of the equipment manufacturing industry of 63 countries along the BRI over the past eleven years from 2011 to 2021 are collected in this paper. The classification and product number chosen are SITERev.4 and 7, respectively.

4.2 Cohesion

Comparing the BRI trade network density from 2011 to 2021, the network density and its standard deviation increased in general. The network density increased from 140,483,136 in 2011 to 160,897,264 in 2015 and then to 263,161,616 in 2021, indicating a closer linkage and more diversified strategy among trading countries in this network, that is, increasing import source countries and export target countries. Clearly, with the strengthened economic globalization and the increased linkage between countries, partner countries tend to establish ties directly, transaction links decrease, transaction convenience increases, and interconnection increases. Regarding reciprocal trade relations, 0.5748 in 2015 is larger than 0.5364 in 2011. This may be due to the acceleration of globalization. From the globalization of trade in finished products to the globalization of processing and production, trade in intermediate goods and mutual trade between countries has increased. However, network reciprocity decreased from 2017 to 2021, indicating the weakening of two-way trade. This may be due to unstable trade protection and risk reduction between countries caused by the rise of trade protectionism and others. Meanwhile, for those countries with large exchange rate fluctuations, re-export trade to reduce direct contact will also be their top choice to reduce exchange rate risks.

Table 1: The cohesion of the BRI equipment manufacturing trade network

	Reciprocity	Density	Std variance
2011	0.5364	140483136	1037958784
2012	0.5468	156576704	1094510720
2013	0.5807	162567728	1132067712
2014	0.5613	169114256	1192192256
2015	0.5748	160897264	1179104768
2016	0.5913	156276096	1130385152
2017	0.6266	185392224	1321282688
2018	0.6130	206436464	1464941952
2019	0.6110	209731056	1541631232
2020	0.6080	207994944	1669833216
2021	0.6099	263161616	2126611968

4.3 Centralization

Network centrality can show the number and scale of important nodes in the BRI trade network. This paper will analyze the network centrality from two aspects of the overall network and network nodes.

4.3.1 Overall Network Analysis

From the mean value of node strength from 2011 to 2021 in Figure 1, it can be seen that both out-strengths and in-strengths rise. The out-strengths rise from 8.7 billion in 2011 to 10.0 billion in 2015 and then 16.3 billion in 2021, while the in-strength shows the same change. The continuous expansion of the overall trade scale shows the strong growth vitality of the equipment manufacturing trade. The increased energy cooperation among countries along the BRI has increased infrastructure demand. Due to overcapacity in China, supply-side reform is conducive to exports and satisfaction with the international market's huge demand.

Overall, the standard deviation of out- and in-degree strengths gradually widens. The standard deviation of out-degree strength changes from 26.8 billion in 2011 to 32.2 billion in 2015 and then to 57.5 billion in 2021. The standard deviation of in-degree strength grows from 12.7 billion in 2011 to 13.4 billion in 2015 and 22.2 billion in 2021. Until 2021, both in-std and out-std values in the network show an upward trend. The trade network tends to be centralized and differentiated, indicating an increasing trend of heterogeneity. At this point, as the connections between countries increase, the possibility of network nodes being in a monopolistic position increase, indicating that China's position as a traditional trading power has further improved.

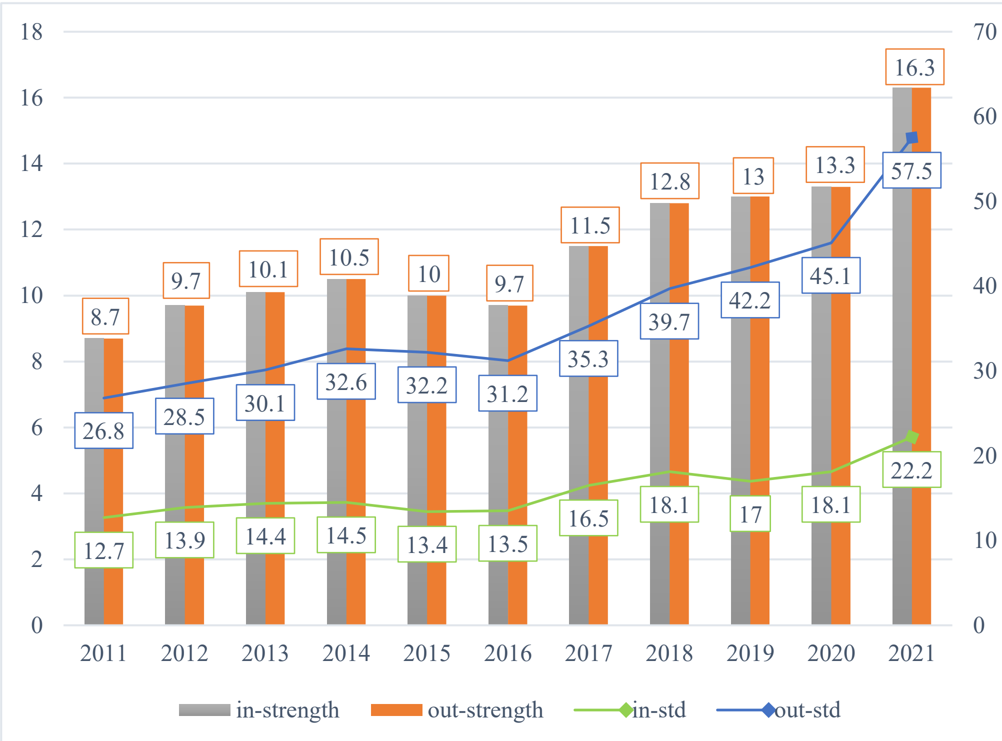

Figure 1: Degree centrality of the BRI equipment manufacturing trade network

As shown in Table 2, both the out-degree and in-degree network centralization increased slightly from 2011 to 2015, indicating that the trend of the trade network centralizing to some core nodes is gradually strengthened. A core country has become a large trading country in the equipment manufacturing industry. However, from 2015 to 2021, the out-degree value decreased, while the in-degree showed the same trend from 2017 to 2021. This means that trade relations were no longer concentrated on a few nodes but were scattered to more nodes. Economic activities and trade in the export network are becoming more dispersed and diversified. The reason for that phenomenon is largely attributed to the BRI. The BRI encourages multilateral trade cooperation so that countries along the Belt and Road can cooperate with more trade partners. It helps to reduce excessive dependence on certain trading partners and reduce trade risks. At the same time, the transportation of the equipment manufacturing industry has high requirements for infrastructure, such as roads and electricity. Promoting infrastructure construction and economic cooperation projects helps improve trade circulation efficiency, reduce trade costs, and increase opportunities for imports and exports.

Table 2: Degree centralization of the BRI equipment manufacturing trade network

	Out-degree (%)	In-degree (%)
2011	12.452	2.910
2012	13.335	3.223
2013	13.058	3.714
2014	13.189	3.150
2015	13.324	2.566
2016	12.867	3.009
2017	11.786	3.362
2018	12.192	3.228
2019	11.764	1.860
2020	10.099	1.810
2021	10.877	1.850

Betweenness centrality indicates the control ability of a node. From 2011 to 2021, the average probability of network nodes taking shortcuts to other nodes decreased. The average betweenness centrality value declines from 14.127 in 2011 to 13.571 in 2021, indicating that the overall effective connectivity of intermediary markets is declining. As found in previous studies, countries tend to contact directly. Naturally, fewer choose to contact through intermediary markets, which also shows the weakened control ability of the overall network in a draw for oligopoly markets. The standard deviation decreases from 18.035 in 2011 to 13.903 in 2021. As time passes, the difference in the betweenness centrality of nodes decreases. The possible reason lies in the network's increased number of connected edges, which makes large intermediaries transform into small intermediaries to contact countries. The importance of core powers decreases, and those marginal countries tend to approach core powers.

Closeness centrality can be divided into in-closeness centrality and out-closeness centrality. Because imports and exports are two relative concepts in the trade network of the equipment manufacturing industry, total imports equal total exports. Therefore, the sum of the distances from the average node to other nodes in the network is equal in the inlet and outlet directions. When calculating closeness centrality, the average in-closeness of the overall node is exactly equal to out-closeness. As shown in Figure 2, by observing the trend of the mean value of closeness centrality each year, we can find that both in-closeness and out-closeness centrality are generally increasing. The out-closeness and in-closeness centrality increased to 45.65 in 2015 from 44.12 in 2011 and finally to 47.34 in 2021. The results in the international equipment manufacturing trade network mean that the average trade distance is shortening. In other words, countries' trade convenience and transaction effectiveness in the trade network are significantly improved. It also means that these countries are more dependent on the core countries when they engage in trade.

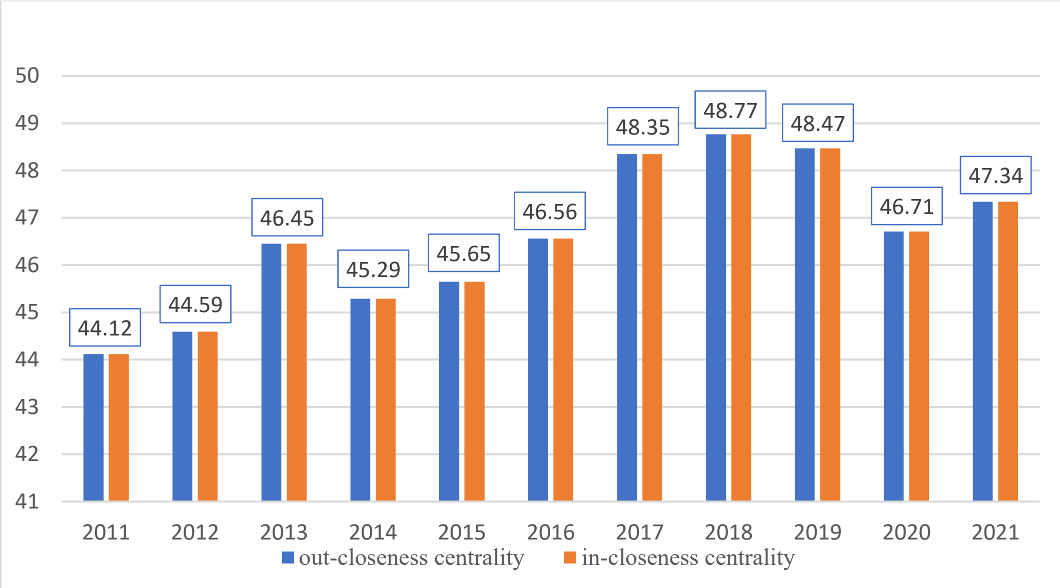

Figure 2: Closeness centrality of the BRI Equipment Manufacturing Trade Network

4.3.2 Network node analysis

From Table 3, it can be seen that the top 10 countries of the BRI out-degree are stable. Among the networks from 2011 to 2021, China always ranks first, with the largest export volume. China's exports increased from 192.4 billion dollars in 2011 to 240.9 billion in 2015 and then to 445.0 billion in 2021. It is expected to exceed 500 billion dollars in the future. Singapore ranks second among the largest exporters. Singapore has an excellent deep-water port and is a gathering place for the re-export trade, and its export volume has increased. However, its growth rate is slower than that of China. China's market share expansion is fast. It is worth noting that Vietnam ranks number 8 in 2013, number 6 in 2017, and then number 4 in 2021, having only 2.3 billion dollars less than Malaysia. Vietnam has become the fastest-growing exporter in the network.

From Table 4, the top 10 countries of the BRI in-degree are also basically stable. China and Singapore are the top 2 in most of years. The import volume of China increased from 51.6 billion to 54.4 billion in 2015 and then to 75.9 billion in 2021. However, its import volume is lower than its export volume. The import volume of the top 2 countries is lower than 100 billion, and that of the top 3 countries will also be at most 75 billion with a slow growth rate. In the equipment manufacturing industry, there is the phenomenon of a trade surplus, and the increase in import value is not as large as that in export value. The equipment manufacturing industry as a whole is a seller's market. The top 5 countries have larger imports and exports, while the bottom five differ. It is possible that there is more interindustry trade among those countries with more imports and exports to meet each country's diversified market needs and technical requirements.

Table 3: Degree ranking of the BRI Equipment Manufacturing Trade Network (out-degree)

2011		2012		2013		2014		2015		2016	
Country	out-degree	Country	out-degree	Country	out-degree	Country	out-degree	Country	out-degree	Country	out-degree
CHN	192.4	CHN	205.0	CHN	220.2	CHN	242.4	CHN	240.9	CHN	234.7
SGP	85.8	SGP	86.9	SGP	88.9	SGP	88.3	SGP	84.7	SGP	77.2
MYS	42.2	MYS	42.6	MYS	42.6	MYS	42.8	THA	39.9	THA	39.5
THA	38.7	THA	41.1	THA	40.7	THA	41.8	MYS	39.3	MYS	38.6
CZE	21.6	ARE	35.5	CZE	24.3	CZE	25.3	CZE	22.2	CZE	23.2
HUN	20.4	CZE	22.8	POL	22.1	IND	23.8	VNM	20.8	VNM	22.7
IND	19.2	POL	18.7	IND	21.3	POL	23.2	IND	19.9	IND	20.0
POL	18.1	IND	17.7	VNM	18.0	VNM	19.1	POL	19.9	POL	19.4
SVK	14.4	HUN	17.0	SVK	17.9	ARE	18.7	HUN	17.8	HUN	15.8
TUR	12.7	SVN	15.4	RUS	17.3	SVK	16.9	ARE	14.8	ARE	14.9
2017		2018		2019		2020		2021			
Country	out-degree	Country	out-degree	Country	out-degree	Country	out-degree	Country	out-degree		
CHN	265.5	CHN	300.1	CHN	323.0	CHN	347.6	CHN	445.0		
SGP	81.3	SGP	84.6	SGP	82.8	SGP	82.7	SGP	103.0		
MYS	44.5	MYS	51.1	MYS	47.6	MYS	49.8	MYS	59.6		
THA	43.2	THA	45.5	VNM	47.2	VNM	48.6	VNM	57.3		
ARE	37.7	ARE	44.6	ARE	42.1	ARE	42.9	ARE	49.2		
VNM	35.3	VNM	42.8	THA	38.7	THA	37.6	THA	44.6		
CZE	26.7	CZE	30.3	CZE	30.9	CZE	30.9	CZE	31.0		
IND	21.3	POL	24.9	IND	28.0	POL	23.1	IND	28.0		
POL	21.3	IND	24.1	POL	23.9	IND	21.1	POL	27.6		
HUN	17.3	HUN	18.9	HUN	18.6	HUN	18.5	HUN	21.1		

Table 4: Degree ranking of the BRI Equipment Manufacturing Trade Network (in-degree)

2011		2012		2013		2014		2015		2016	
Country	in-degree	Country	in-degree	Country	in-degree	Country	in-degree	Country	in-degree	Country	in-degree
CHN	51.6	CHN	56.9	CHN	61.2	CHN	65.9	SGP	54.4	CHN	62.3
RUS	46.7	RUS	53.0	SGP	53.2	SGP	53.0	CHN	52.6	SGP	48.9
CHN	45.3	SGP	51.2	RUS	51.4	RUS	47.5	MYS	42.7	IND	42.2
MYS	40.3	MYS	42.5	MYS	46.3	MYS	44.2	IND	37.9	MYS	39.8
IND	39.1	IDN	39.8	IDN	38.2	IND	35.5	ARE	37.1	VNM	33.3
IDN	35.6	IND	37.7	IND	35.1	ARE	35.5	VNM	35.2	THA	32.1
THA	26.0	THA	32.0	ARE	32.2	IDN	35.2	THA	33.0	RUS	31.6
ARE	24.8	ARE	26.2	THA	32.1	VNM	32.8	IDN	31.3	IND	30.5
CZE	17.0	SAU	21.1	VNM	26.3	THA	31.1	RUS	28.0	ARE	30.0
VNM	16.3	VNM	18.5	THR	18.5	CZE	20.2	TUR	19.0	PHL	20.1
2017		2018		2019		2020		2021			
Country	in-degree	Country	in-degree	Country	in-degree	Country	in-degree	Country	in-degree		
CHN	84.0	CHN	88.9	SGP	62.0	VNM	73.2	VNM	89.2		
SGP	56.9	SGP	59.8	VNM	61.2	SGP	65.2	CHN	75.9		
IND	50.7	IND	57.8	CHN	57.6	CHN	63.1	SGP	73.2		
MYS	45.9	MYS	52.0	IND	54.3	MYS	50.9	IND	67.4		
VNM	41.0	VNM	48.2	MYS	50.6	IND	49.2	MYS	66.4		
RUS	38.6	RUS	43.5	RUS	44.2	RUS	45.4	RUS	58.7		
THA	36.3	THA	41.1	THA	40.9	HRV	43.2	HRV	50.5		
IDN	32.1	IDN	38.5	IDN	37.0	THA	39.6	THA	49.2		
ARE	30.9	ARE	33.6	HRV	36.2	IDN	35.4	IDN	44.0		
CZE	22.8	CZE	28.1	ARE	32.9	ARE	34.0	ARE	42.5		

Table 5: Betweenness centrality of the BRI Equipment Manufacturing Trade Network

2011		2012		2013		2014		2015		2016	
IND	108.396	IND	109.470	CHN	54.066	CHN	53.415	IND	47.025	CHN	101.728
CHN	52.901	CHN	52.241	SGP	46.928	ARE	49.746	ARE	46.547	ARE	39.508
SGP	52.455	SGP	50.669	THA	46.846	MYS	46.159	CHN	46.284	IND	38.714
MYS	45.120	ARE	47.469	ARE	44.507	THA	43.434	MYS	44.578	RUS	37.282
THA	43.677	THA	46.004	MYS	42.894	IND	42.669	SGP	39.624	MYS	32.215
IDN	43.153	MYS	39.866	IND	40.923	TUR	41.667	THA	39.428	THA	31.604
POL	37.994	RUS	32.948	RUS	37.625	SGP	38.500	IDN	34.593	SGP	30.434
TUR	28.370	TUR	31.429	CZE	36.744	RUS	35.806	TUR	33.003	IDN	29.532
ISR	27.775	POL	25.729	POL	30.763	POL	34.900	CZE	31.156	TUR	29.398
RUS	25.006	HUN	21.757	HUN	29.654	BGR	34.844	ROU	25.585	CZE	28.954
2017		2018		2019		2020		2021			
CHN	53.701	IND	92.106	CHN	103.054	TUR	57.339	CHN	57.118		
MYS	49.919	CHN	72.074	IND	70.132	IND	45.404	ARE	54.120		
IND	49.687	ARE	66.215	MYS	58.650	IDN	41.681	MYS	53.674		
SGP	46.216	TUR	47.868	TUR	50.354	MYS	41.113	IND	37.358		
ARE	37.932	RUS	32.302	ARE	44.266	ARE	35.784	SGP	35.225		
TUR	36.202	SGP	31.906	RUS	36.451	CHN	32.038	RUS	33.155		
ROU	31.973	GRC	30.347	GRC	32.191	CZE	29.641	GRC	31.665		
GRC	29.261	CZE	27.839	SGP	28.345	HUN	28.908	TUR	28.911		
THA	27.006	THA	27.805	THA	27.630	SGP	28.796	THA	28.457		
RUS	25.711	MYS	26.376	POL	27.500	GRC	28.152	LTU	28.036		

Table 5 shows the BRI national betweenness centrality score of the top 10 countries in this metric. It is worth noting that China's rank increases from number 2 in 2011 to number 1 in 2017 and 2021, which may be because China has strengthened its connectivity with neighboring countries and become a powerful intermediary market after proposing the BRI. The betweenness centrality of China increases from 45.901 in 2011 to 53.701 in 2017 and then to 57.118 in 2021. China's betweenness centrality in 2011 and 2012 is much smaller than that of India. From 2011 to 2016, the decline in betweenness centrality of other countries is not because the ties between countries have decreased. The reason is that countries' diversified and decentralized trade strategies have made the network enter a homogeneous development state. Under such a tendency of network development, the betweenness centrality of China continued to increase against the trend, indicating that the network connectivity of China has increased. The BRI has made China an important intermediary node in the trade network that cannot be ignored.

The closeness centrality of a node is a measure of the degree of being controlled or not controlled by others. Table 6 shows the top 10 countries of the BRI national network out-closeness centrality. China always ranked first, with centrality data at 62, indicating that China is at the core of the trade network and has close ties with other countries in the export trade of the equipment manufacturing industry. As a major exporting country, China has strong control over its trading partner countries in terms of exports. Contrary to China, Singapore only ranks number 6 in 2011, but it remained in the first tier in subsequent years. As an industrialized country and the most developed country in Southeast Asia, Singapore is also a necessary place for the "21st century Maritime Silk Road" and plays an important role in the economic development of the entire Asia Pacific region. Due to the improvement of the trade environment brought about by the BRI, Singapore has shortened its trade distance with countries along the Belt and Road by expanding the export of the equipment manufacturing industry. In addition, with the proposal of China's BRI in 2013, the number of countries with an out-closeness centrality of 62 has increased in recent years. The BRI has significantly shortened the distance between countries in the equipment manufacturing export network.

Table 6: Out-Closeness centrality of the BRI Equipment Manufacturing Trade Network

2011		2013		2015		2017		2019		2021	
CHN	62	CHN	62	CHN	62	CHN	62	CHN	62	CHN	62
POL	62	SGP	62	IND	62	IND	62	IND	62	CZE	62
IDN	62	HUN	62	POL	62	POL	62	PHL	62	IND	62
THA	62	POL	62	SGP	62	SGP	62	POL	62	LTU	62
IND	61.5	SGP	62	THA	62	THA	62	SGP	62	POL	62
SGP	61.5	THA	62	CZE	61.5	TUR	62	SVK	62	SGP	62
MYS	61.5	IND	61.5	HUN	61.5	CZE	61.5	THA	62	SVN	62
CZE	61.5	IDN	61.5	LVA	61.5	HUN	61.5	TUR	62	ARE	62
SVK	61.5	LVA	61.5	MYS	61.5	LVA	61.5	CZE	61.5	TUR	62
TUR	61	MYS	61.5	RUS	61.5	MYS	61.5	GRC	61.5	BGR	61.5

Table 7 shows the top 10 countries of the BRI national network in terms of in-closeness centrality. The BRI encourages infrastructure construction and connectivity, increasing the demand of neighboring countries for infrastructure construction. China has advanced technology and experience in equipment manufacturing and provides the necessary equipment and technical support through cooperation with neighboring countries. This initiative has shortened the trade distance between China and neighboring countries. As shown in Table 7, China has been one of the countries with the highest closeness value since 2017, followed by Malaysia, India, the United Arab Emirates and others. In addition, the facilitation of imports brought about by the BRI has made Russia gradually become one of the core countries in the import trade network after 2017.

Table 7: In-closeness centrality of The BRI Equipment Manufacturing Trade Network

2011		2013		2015		2017		2019		2021	
ARE	51	CHN	53	ARE	51	CHN	54.5	CHN	54	CHN	53
CHN	50	ARE	53	CHN	50.5	IND	53.5	IND	54	MYS	52.5
IND	49.5	MYS	51.5	IND	50.5	MYS	53.5	ARE	53.5	ARE	52.5
POL	49	RUS	51.5	MYS	50.5	ARE	53.5	MYS	53	IND	52
SGP	48.5	SGP	51.5	CZE	50	TUR	53.5	TUR	53	RUS	52
MYS	48	CZE	51	SGP	50	RUS	53	HUN	52.5	POL	51
TUR	48	IND	50.5	THA	50	CZE	52.5	POL	52.5	SGP	51
EGY	47.5	TUR	50.5	TUR	50	PAK	52.5	RUS	52	TUR	51
IDN	47.5	POL	50	HUN	49	SGP	52.5	SGP	52	HUN	50.5
IRQ	47.5	THA	50	POL	49	HUN	51.5	GRC	51.5	IDN	50.5

5. Clustering

From Table 8, it can be seen that the network clustering coefficient increased from 22690.387 in 2011 to 23377.086 in 2015 and finally to 24170.295 in 2021. The weighted clustering coefficient also shows the same trend from 21003.129 in 2011 to 21851.548 in 2015 and 22630.104 in 2021. From the clustering measurement data, network nodes tend to form clumps from 2011 to 2021. That is, the degree of interconnection between adjacent nodes increases, and the interconnection among the countries along the route has been enhanced by implementing the BRI.

Table 8: The BRI equipment manufacturing trade network clustering

	Clustering coefficient	Density
2011	22690.387	21003.129
2012	23064.146	21344.152
2013	23371.436	22036.462
2014	23356.457	21618.089
2015	23377.086	21851.548
2016	23452.359	22025.257
2017	23997.033	22786.800
2018	23994.895	22665.150
2019	23842.365	22447.827
2020	23935.742	22379.096
2021	24170.295	22630.104

Figures 3 and Figure 4 show the trade network diagrams for 2011 and 2015, respectively. The trade network graph shows that these nodes in 2015 were closer and more complex than those in 2011, indicating that the number of trade partners in each country increased to varying degrees. Relatively marginalized trading countries are also interconnected, and the relative concentration of the network has been strengthened. Figure 5 shows the trade network diagram for 2021. In 2021, the connection between nodes remained at its previous level, with countries with closer trade ties with China mainly including Vietnam, Singapore, India, Indonesia, Thailand, Malaysia, among others. It is worth noting that compared to previous years, the Philippines strengthened its trade relations with China in 2021. The BRI has greatly promoted the infrastructure construction of surrounding developing countries. The demand for equipment manufacturing products in various countries in the trade network has significantly increased. The diversified development of demand may further promote interindustry trade.

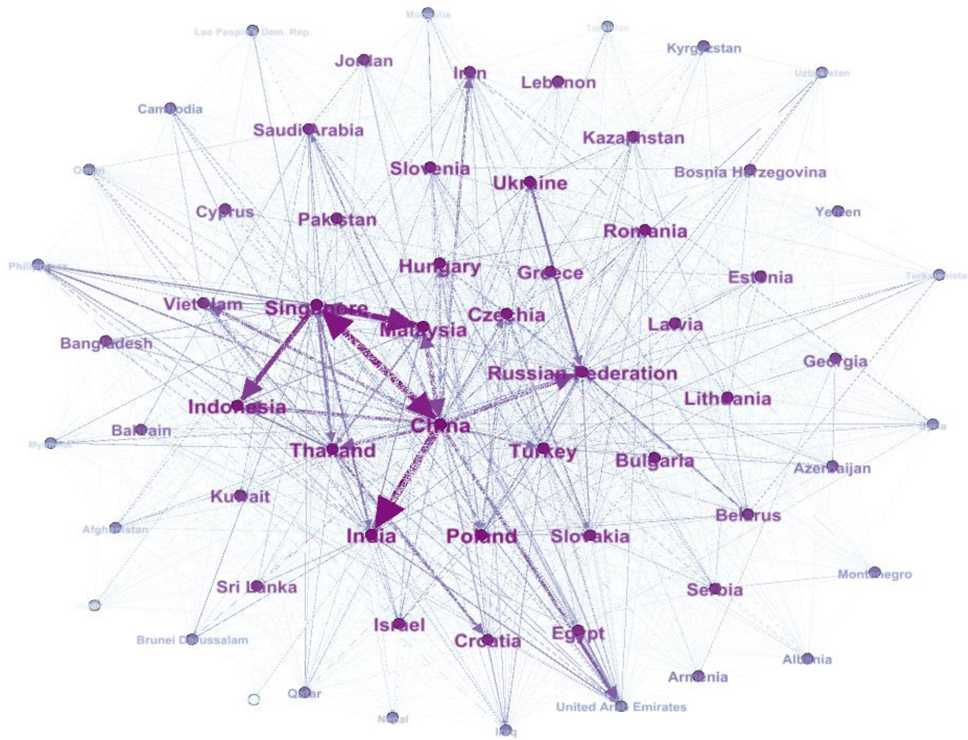

Figure 3: The BRI equipment manufacturing trade network in 2011

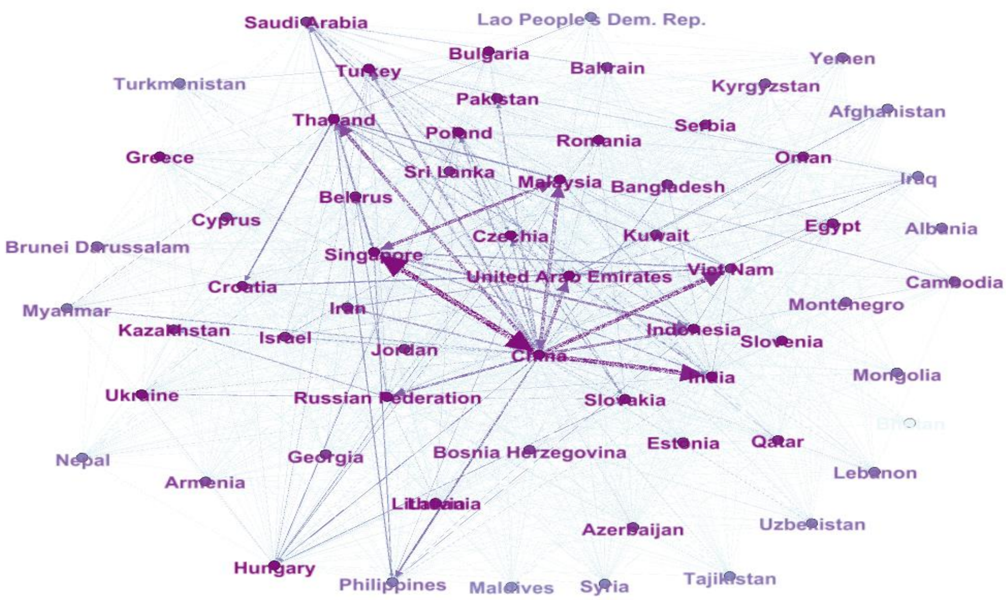

Figure 4: The BRI equipment manufacturing trade network in 2015

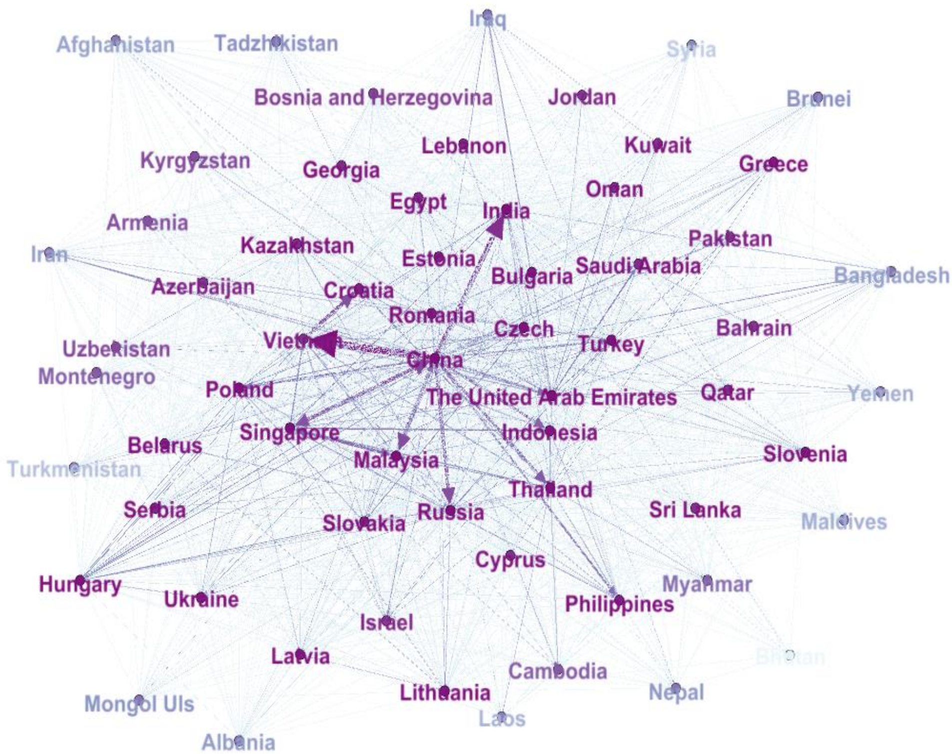

Figure 5: The BRI equipment manufacturing trade network in 2021

6. Conclusions

In the new wave of the proposal of the BRI, there are dynamic changes in the patterns of the manufacturing industry trade in the BRI region, which are becoming increasingly complex. In this study, we explored the characteristics and evolution of the equipment manufacturing industry trade patterns that are fundamental to economic development in the BRI region, especially focusing on the trade links, community structure, and intraregional competitiveness of the BRI countries.

The study found that differences have occurred in the network phase development from the proposal of the BRI in 2013 to its gradual implementation in 2015, especially between 2015 and 2021, which indeed deserves consideration and study. The three types of indices are mainly used to study different characteristics of the network. Cohesion is mainly used to study the overall indices of the network, macroscopically explore the interconnection of the network, and focus on the influence of the network on the nodes. The centrality index can better highlight the effect of a node on the overall network. The centrality index can be divided into three categories, the point intensity (namely, the trade volume), betweenness centrality and proximity centrality, which are used to measure the role of a node from its strength, network control ability and network control releasing ability. In the clustering analysis, nodes and networks are combined to examine the tendency of nodes to condense into “small groups”.

Cohesion indices show the increased trade network density of the equipment manufacturing industry along the BRI, which can be understood as the increase in connections between countries, network connections, and interconnections. However, the reciprocity of the network weakened, and bilateral trade tended to become unbalanced from 2017 to 2019, indicating that there is space for improvement in the network. The conclusions of the performance of centrality indices are consistent: As the intensity of the points increases, the trade volume of countries and the international market demand rise, which will inevitably lead to a rapid increase in trade volume. The overall betweenness centrality is declining, but it rebounded in 2021. The countries tend to connect directly or through small intermediaries. The closeness centrality generally increases, indicating that countries’ trade convenience and transaction effectiveness in the trade network are improved.

From the analysis of nodes, it can be found that the trade volume growth rate and trade volume of China are both in the top place in the network, and market share is also increasing. From multiple cross-sectional data, the future development trend will continue, indicating that the core position of China in the network is gradually rising, the dominance of the BRI has increased, and neighboring countries tend to be incorporated into “small groups” around China, which is conducive to forming our leading trade agreements and customs unions, reshaping the trade pattern of neighboring countries, and enhancing the international status and international voice of China.

However, there are still shortcomings: (1) The data of relevant countries along the BRI are not detailed. Data on different countries cannot be found in the Un Comtrade database and the World Bank and other databases, or relevant countries fail to be recognized as independent tariff countries, causing the BRI trade network to still be incomplete. (2) In this paper, a fixed network scale is used. However, the countries that participate in the BRI vary from year to year, making it a network with a constantly changing trade scale, and future studies could use a constantly changing trade scale to describe the impact of the BRI.

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