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Using Social Networks to Analyze the Spatiotemporal Patterns of the Rolling Stock Manufacturing Industry for Countries in the Belt and Road Initiative

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Abstract: The new wave of modern rail transit and the proposal of the Belt and Road Initiative (BRI) have complicated the business patterns of the rolling stock manufacturing industry (RSMI) and the export of rolling stock products, especially in the case of countries participating in the BRI. Based on the analysis of trade patterns—which focuses on the evolution of trade links, community structures, and intraregional export competitiveness—this study aims to explore the changes in the RSMI within the BRI region from 2003 to 2017. Sequential clustering was applied to the creation of a three-phase timeline. The network models of the cumulative trade of the rolling stock products and trades of two typical categories of products were constructed in each phase for the evolution analysis. Social network analysis methods, such as the analysis of network indices and community detection, were also applied. The results show that from 2003 to 2017, the connectivity of the rolling stock trade in this region significantly increased. China was the largest exporter, with increasing trade influence and technological strength. Ukraine and Russia were less competitive and highly mutually dependent. Czechia and Austria's competitiveness remained prominent, but compared with China they lacked expansive vitality. South Korea was also an active and competitive country with strong technological prowess. These countries accounted for the majority of the exports, and were always at the center of their own separate communities, over which they maintained a sphere of influence. The grouping of countries far from any such spheres of influence changed frequently.

Keywords: social network analysis; rolling stock; manufacturing industry; spatiotemporal pattern; Belt and Road; trade

1. Introduction

1.1. Background

Rail transit is crucial for intercity and urban public transport. It is efficient, safe, energy-saving, and less polluting [1,2]. The development of modern rail transit began in the first half of the 19th century and has raised the efficiency of freight and passenger transportation. It has also stimulated the rise of related industries such as the rolling stock manufacturing industry (RSMI) [3] and the development of the national economy. Since the 1960s, rail transit, which had been affected by the development of highways and airlines, has regained its position in the global transport system. With the expansion of cities and the growth of the economy, intercity high-speed rail (HSR) and modern urban railway systems have been thriving in Japan and other developed countries in Europe and North

America [4,5]. Rail transit has improved accessibility and convenience for citizens and revitalized the inner city and intercity economic circles [6]. In the context of global climate change, the environmental effects of various transport modes have started to receive greater attention. Rail transit is considered comparably environmentally friendly during the operation phase [2]. However, whether it is so in the infrastructure-construction phase remains debatable [7,8]. Generally, rail transit has proven to be irreplaceable compared with other means of transportation and is potentially crucial in the 21st century [1].

Many countries have attached importance to the development of the RSMI, which is considered the technological core for manufacturing rail transit equipment. The development of the modern RSMI can support domestic rail transit construction, enhance industrial strength, and provide employment [9]. Developed countries such as Japan, Germany, France, and Canada began research and development on the RSMI decades ago. There are many technologically advanced and richly experienced leading companies in this industry, such as Kawasaki (Japan), Siemens (German), Alstom (France), and Bombardier (Canada). China has realized that an efficient transportation network is crucial for economic prosperity [10]. In addition, developing HSR, which is one of the emerging technologies, is an important opportunity for enhancing innovation capability, building Chinese brands, and integrating China into the global innovation system [11]. While designing trains with transnational corporations, Chinese firms have successfully assimilated HSR technology and then improved the designs with their own innovative and independent capabilities by effectively utilizing innovative domestic and international resources. China has also gradually established a relatively complete HSR technology innovation system and created an internationally competitive HSR brand [11,12]. The China Railway Rolling Stock Corporation Limited (CRRC), which is the leading manufacturer in the RSMI in China, has established complete product lines and leading technologies.

International trade competitiveness is an important performance indicator of the development of the manufacturing industry. Traditional leading countries in the RSMI, such as Japan, France, and Canada, once accounted for the largest portion of the global market and earned large amounts of foreign revenue through export. China has also gradually become one of the largest suppliers of rail transit equipment. Thus, the patterns of the international RSMI and rolling stock trade are becoming increasingly complex. Although the global demand for rail transit equipment is rapidly increasing, domestic demand in some traditional rail transit technological powerhouses has shrunk. Overcapacity has become a problem for many manufacturers due to the maturity of domestic rail transit systems. Hence, the global rail transit market is highly competitive, and the technological and trade interactions among countries are gradually growing. In this field, as is the case more generally, countries are becoming increasingly interconnected and interactive.

Interactions in the "Belt and Road Initiative" (BRI) region are substantially increasing [13], which further accelerates the changes in rolling stock trade patterns. China is actively taking advantage of its production capacity in the RSMI to upgrade domestic infrastructure and promote the export of Chinese HSR. It aims to facilitate the construction of transregional rail networks and economic exchanges, especially in the BRI region. China proposed the initiative of jointly building the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" in 2013. According to Chinese officials, the initiative aims to establish an international exchange and cooperation platform for BRI countries and strengthen intraregional economic ties, political mutual trust, and cultural exchanges. However, the fundamental goal and possible consequences of the BRI are still widely debated in academic circles [14–16]. To expand the Chinese HSR foreign market, accomplish the task of "facility connectivity", and provide a basis for other tasks such as "Unimpeded Trade" in the BRI region, China regards HSR as a core export product and actively promotes the construction of cross-border HSR and package exporting. Although the gains of other BRI countries are debatable [17–19], some of them may achieve development in the RSMI because, while collaborating with BRI countries such as Kyrgyzstan and Tajikistan in rail construction, China emphasizes the localization of manufacturing and tries to involve local suppliers depending on the conditions in the host countries [20–22]. These measures lead to RSMI patterns of competitiveness and interactions among the BRI countries that are actively changing and increasingly becoming complex. Understanding the characteristics and trends of this pattern is crucial to enhancing technology and trade cooperation in the rail industry and promoting the development of rail transit in the BRI countries.

1.2. Literature Review

In the context of thriving rail transit construction, many studies have been conducted on the RSMI's development or current situation within individual countries. Related studies have mainly reviewed the starting process of some countries in Europe, North America [23], and East Asia [9,24], such as in Japan and South Korea [25,26]. These countries started developing the RSMI decades ago, and their experiences have been summarized. Some scholars have focused on the development process of emerging countries in the HSR industry, which mainly began with technology transfer, such as in the cases of China and Turkey [27–29]. These studies considered Chinese HSR important in the discussion of the factors of technology transfer and the enhancement of national strength in scientific and technological innovation [30]. However, they mainly involve case studies focusing on a single country. Competitive or cooperative relationship patterns among countries and their effects have not received much attention. There are some exceptions such as Andersen [31], who did note that countries in the rolling stock market are closely tied and analyzed the rolling stock trade flows and commodity structure of the United States with UN Comtrade data to reflect the position and connection of the United States in the global rolling stock market. In general, however, as economic globalization and international production fragmentation are continuously developing, and patterns in the multinational relations in the BRI region are undergoing active changes, there lacks an overall analysis of the patterns and productive links in the RSMI of a group of countries within the BRI or any other region. In addition, trade relations, which are a common perspective to quantitatively reflect the manufacturing industry's competitiveness, have not been comprehensively analyzed in the literature on RSMI.

Social network analysis (SNA) is a mature tool that can analyze the trade relations among multiple agents and the structure of the complex trade systems. A social network is a network system formed through relationships such as friendship, cooperation, and trade. Among these, social networks formed through trade relationships can be called trade networks. SNA studies the interaction among a group of actors in a social network system [32–35]. It is the best way to study the social structure from a relational perspective [36]. SNA originated from the sociological analysis of social relationships and the introduction of graph theory, which is a branch of mathematics. After years of development, a series of relatively mature methods that could be applied to establish and visualize social networks and perform analysis at the network and node level, such as community detection [37], network structure [38–41], or node attributes [42], have been developed. In recent years, findings related to complex networks (networks with nontrivial topological features that do not occur in lattice, random, or other simple networks but that often occur in real system network models [43,44]) have also enriched SNA [45]. In addition, scholars have proposed different approaches to assess the structural or dynamic robustness of complex networks [46,47] and conducted strategic attack experiments [48]. Thus, through the establishment and analysis of trade networks, the complex trade system can be seen as a whole to graphically and analytically represent the trade pattern features and interactions among traders.

Therefore, many scholars have established trade networks and conducted SNA to analyze the structure and evolution of world or regional trade [49–52]. Some researchers have paid attention to the global trade patterns of typical categories of goods, which cover a wide range but are mainly focused on energy [53–55], crops [56], and virtual water [57]. After the proposal of the BRI, scholars turned their attention to the trade links in this region. These scholars analyzed the network structure [13], commodity structure [58], network evolution and influencing factors [59], and topological relationships to global trade [60]. The findings show that the proposal of the BRI effectively influenced the intraregional trade pattern and led to rich dynamics [59]. Among studies on the trade networks of some typical products in the BRI region, products such as oil and gas resources [61,62], agricultural products [63], and virtual water [64] are still hotspots. However, high-tech sophisticated products' trade networks in manufacturing industries have not been analyzed in previous studies. The complex structure, differentiated technical contents of components, and transnational division of labor in the production process of these products call for different perspectives in the trade network analysis.

In summary, there are two gaps. First, there is a lack of studies on the overall pattern and productive links of countries in the RSMI within the BRI region which are undergoing active changes. Although the overall level of the manufacturing industry in the BRI region is low, there are some emerging economies, such as China and India, whose manufacturing strengths are actively developing in this region. Following the development of these countries and the changes in trade relations in the BRI region, the regional trade patterns of high-end manufacturing industries need to be analyzed. Second, regarding global and regional trade studies, the SNA method has been seldom utilized in the context of high-added value sophisticated industrial products, such as rolling stock products. Considering the complex structure, the differentiated technical contents of components, and the transnational division of labor in the production process of these products, the trade network's analysis perspective needs to be enriched.

1.3. Aim and Objects

Therefore, in this study, we considered the BRI region an independent system. Through the establishment of regional trade networks and an analysis of the characteristics and evolution of the trade pattern of rolling stock products, it is evident how this situation reflects the spatiotemporal pattern of RSMI in this region. This study mainly focuses on two areas: (1) the characteristics of the trade links and community structure among the BRI countries and (2) the intraregional export competitiveness of the BRI countries evaluated according to export volume and range and the changes in position in international production fragmentation. In this study, a sequential cluster method was used to divide the period 2003-2017 into three phases according to the characteristics of the trade data. We then established the networks of the cumulative trade of all the rolling stock products and two typical categories of the rolling stock products in each phase and performed the SNA on the evolution of the trade pattern. This study's findings can provide an understanding of not only the difficulty and impact of China's rolling stock exports under the BRI, but also the cooperation and international trade decision-making in this industry for the BRI countries.

The rest of this paper proceeds as follows. Section 2 briefly explains the selection principle and range of the BRI countries. Section 3 introduces the methodology utilized to establish and analyze the trade networks. Section 4 describes the three phases and their characteristics. Section 5 presents the evolution of the trade pattern during the phases. The results and implications are discussed in Section 6. Section 7 discusses the conclusion and directions for future studies.

2. Study Area

The range of the BRI region stated in this study includes not only countries spatially located along the "Belt and Road" but also countries that signed in the BRI with China but that are out of the primary spatial region. This is because the BRI is an international, inclusive, and open economic cooperation network, and the spatial links among the BRI countries should be elastic. The BRI is not limited to sub-regional cooperation among neighboring countries but focuses on cooperation across a wider range. In short, countries located along the "Belt and Road" are important anchors to China for the promotion of the BRI. In addition, countries that are not spatially along the "Belt and Road" but that are signatories are also important partners with China. Although these signatory countries are not spatially located within the narrow definition of the geographically situated BRI, they have nonetheless shown strong intension and sincerity with regard to economic and political cooperation and ought to be included in the range of research. With reference to the accounting units in the trade database [65] and the BRI signing records [66], the range of the BRI regions recognized in this study includes 128 countries or regions (Figure 1).

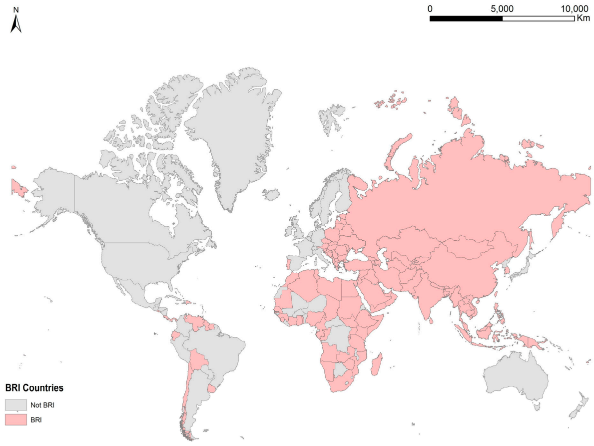


Figure 1. Study area: 128 countries or regions in the region of the "Belt and Road Initiative" (BRI).

3. Methodology

3.1. Phase Division with Sequential Clustering Method

In this study, we examine the evolution of trade patterns from 2003 to 2017. This is a long time period witnessing significant changes in annual trade volume. A sequential clustering method is utilized to further divide the period 2003–2017 into several phases. We use this method to merge adjacent years into several phases, based on the physical features of the trade data, to present phasic trends during which the time proportions of the export volume of BRI countries are similar. Thus, we are able to judge the overall trend of trade patterns, especially the patterns of export and competitiveness, by comparing the characteristics of nodes and networks in the phase.

Chronologically constrained clustering is conducted in this study based on the algorithm of constrained clustering analysis using the incremental sum of squares (CONISS), which is an essential sequential clustering method. This method can ensure the continuity of the clustering result. The algorithm is relatively simple compared with other sequential clustering methods. It is useful for many types of linearly ordered or transect data, such as vegetation zones along a natural gradient [67]. The algorithm of this method is described as follows.

First, we regard each of the ordered samples as separate, independent clusters. We define the within-cluster dispersion or the sum of squares for the p^{th} cluster as follows [67]:

$$D_p = \sum_{i=1}^{n_p} \sum_{j=1}^{m} \left(x_{pij} - \overline{x}_{pj}\right)^2, \quad (1)$$

where n_p is the number of samples ("years" in this paper) in the p^{th} cluster; m is the number of variables, which is the number of BRI countries under examination; and x_{pij} is the value of variable j of sample i in cluster p, which is the proportion of country j's intraregional export volume to the total intraregional export volume in the i^{th} year within the p^{th} phase. $\overline{x}_{pj}$ is the mean value of variable j in cluster p, which is the mean value of the annual proportion in the p^{th} phase.

Then, we calculate the total within-cluster dispersion for g clusters:

$$\mathrm{D} = \sum_{p=1}^{g} D_p. \quad (2)$$

Based on the principle of minimizing the increase in total dispersion, adjacent clusters are merged. If cluster p and cluster q are merged to form cluster pq, the rise of dispersion is as follows:

$$I_{pq} = D_{pq} - D_p - D_q. \quad (3)$$

At each step, the cluster p and cluster q that give the least increase in I_{pq} are merged until all the clusters have been merged into one cluster.

3.2. Construction of Trade Networks

We build two kinds of trade networks in each phase to illustrate the evolutions of the overall trade pattern of rolling stock products as well as the trade patterns of specific, typical categories of rolling stock products separately in the BRI region.

- **Networks of the cumulative trade of all rolling stock products:**

The first kind of trade network $G_t(V_t,\ E_t)(t = 1,\ 2,\ 3)$ is a weighted and directed network built to analyze the overall trade pattern and its evolution. The node-set V_t includes all the BRI countries involved in the trade of any categories of rolling stock products within this region in the t^{th} phase. The edge-set E_t consists of the trade flows among those countries (V_t) in the t^{th} phase. The edge direction is indicated by the direction of the trade (from exporter to importer). Considering that the length of each phase as divided by the sequential clustering method is different, we calculate the total trade volume in a phase between two countries and divide it by the number of years in this phase. The result is used as the weight of the edge between these two countries in this phase. The data used in this study comprise trade records from UNComtrade [65]. To exclude the effect of shipping, tariffs, double counting, and other factors, we use records of export volume uniformly. The cumulative trade volume of all the rolling stock products is the trade volume of the commodities in chapter 86 of the HS Code (an internationally standardized system of names and numbers to classify traded products which is also called "Harmonized Commodity Description and Coding System").

- **Networks of typical categories of rolling stock products:**

The second kind of trade network $G_{i,\ t}(V_{i,\ t},\ E_{i,\ t})$ (i represents categories of products, and i=1, 2..., 5. t = 1, 2, 3) is a weighted and directed network. The node-set $V_{i,\ t}$ includes the BRI countries participating in the intraregional trade of the i^{th} category of rolling stock products in the t^{th} phase. The edge-set $E_{i,\ t}$ includes the trade flows of i^{th} rolling stock products among the nodes. There is a wide range of products related to rolling stock under item 86 of the HS code. In addition, the technological strength, labor, and other conditions required for manufacturing these products tend to vary. Based on the characteristics of the products, we merge some of the products under items 8601 to 8608 of the HS code and reclassify the rolling stock products into five categories (Table 1). Typical categories of products are chosen to constitute trade networks separately in order to illustrate the export patterns and competitiveness of BRI countries based on the differences in products. Due to a lack of space, only the trade patterns of the first and fourth categories are analyzed in detail in this paper. The calculation method of edge weights and the other settings are the same as those for the first kind of trade network.

Table 1. Classification of rolling stock products.

Category Number	Category Name	Products Included (HS Code)
1	Rail locomotives and self-propelled coaches and vans	8601, 8602, 8603
2	Maintenance or service vehicles	8604
3	Not self-propelled coaches and vans	8605, 8606
4	Parts	8607
5	Track fitting, signaling, and auxiliary traffic control equipment	8608

3.3. Analysis of Trade Networks

3.3.1. Analysis of Network and Node Characteristics

Node Characteristics

To analyze the role and significance of each node n_i, we calculate some centrality indices on the node level, including out-degree centrality, in-degree centrality, strength centrality, out-strength centrality, in-strength centrality, and betweenness centrality. These indices are mainly used for network visualization and the description of the characteristics of important nodes. Out-degree centrality represents the number of export destinations of country n_i in the BRI region. In-degree centrality represents the number of import sources of country n_i in the BRI region. Out-strength centrality and in-strength centrality, respectively, indicate the intraregional export and import volume of country n_i. Strength centrality is the sum of both these factors. Betweenness centrality measures the load that a country bears for ensuring that countries are sequentially connected across the network in an unbroken chain [68]. It is computed by counting the number of times a country of interest intercepts the shortest pathway between all the other country pairs in the network, divided by the number of shortest paths between all the country pairs, before finally summing all these proportions for every country in the network [69]. In this study, we normalized the betweenness centrality by dividing it by the total number of country pairs in the network (excluding the country of which the centrality is calculated) [69].

Characteristics of Networks

To analyze structural characteristics on the network level and to describe trade patterns and evolution, we also calculate network-level indices, including network density, modularity degree, clustering coefficient, and average path length of the networks in each phase. To mitigate the impact of the differences in the duration of each phase, we calculate the annual node-level and network-level indices of annual trade networks in the period 2003–2017, and consider the mean value within each phase as the phasic value to make comparisons and analyze changes.

- Network Density:

Network density can be used to reflect the degree of closeness among nodes in the network, which is the closeness of trade links of rolling stock products among BRI countries as identified in this study. Network density is measured as the ratio of the number of actual edges in the network to the possible or potential number of such edges [41]:

$$\mathrm{D} = m/g(g-1), \tag{4}$$

where D is the network, m is the actual number of edges (trade flows), and g is the number of nodes (countries) in this network.

- Modularity Degree:

The modularity degree can be applied to quantify the quality of partitions obtained by different community detection methods [38,39]. The larger the modularity degree, the more significant is the community partition within the network. The modularity degree is a scalar variant from −1 to 1, and is defined as follows [39]:

$$\mathrm{Q} = \frac{1}{2m}\sum_{ij}\left[w_{ij} - \frac{A_iA_j}{2m}\right]\delta\left(c_i, c_j\right), \tag{5}$$

where w_{ij} is the weight of the edge between node i and node j, which is the volume of the trade flow between country i and country j in this paper. $A_i = \sum_i w_{ij}$ is the sum of the weights of all the edges linking node i, which is the total trade volume of country i. Similarly, A_j is the sum of the weights of the edges of node j. $\delta(c_i, c_j)$ is the function of whether node i and node j are in the same community. c_i and c_j are the communities of node i and node j, respectively. If node i and node j are in the same community, $\delta(c_i, c_j) = 1$; otherwise, $\delta(c_i, c_j) = 0$. $\mathrm{m} = \frac{1}{2}\sum_{ij} w_{ij}$.

- Clustering Coefficient:

The clustering coefficient can reflect the degree of the clustering of edges into tightly connected neighborhoods [40]. The clustering coefficient of node i is defined as the number of triangles in which node i participates, normalized by the maximum possible number of such triangles:

$$C_i = \frac{2n_i}{k_i(k_i - 1)}, \tag{6}$$

where k_i is the number of nodes that directly link with node i, and n_i is the number of such triangles around node i. $C_i \in [0, 1]$. The clustering coefficient of a whole network is the mean value of all the nodes within it.

- Average Path Length:

The average path length is defined as the average number of steps along the shortest path for all possible pairs of nodes and can be used to describe the sparseness of networks. Networks with high clustering coefficients and short average path lengths are thought to have small world effects [70]. The average path length is as follows:

$$\mathrm{L} = \sum_{i,j} d_{ij} / g(g - 1), \tag{7}$$

where d_{ij} is the length of the shortest path for node i and node j. Networks in this paper are entirely connected networks based on trade links. Hence, all the nodes within a network are linked directly or indirectly, and the length of the shortest path can be calculated. g is the number of nodes in the network.

3.3.2. Community Detection Analysis

Communities are sets of nodes in the network within which connections are close but between which they are sparser [39]. Through community detection, we can explore and visualize the inner structure of complex networks. To describe the structural characteristics of rolling stock trade within the BRI region, we conduct community detection analysis on the first kind of trade networks (networks of the cumulative trade of all rolling stock products) based on the method proposed by Blondel, Guillaume, Lambiotte and Lefebvre [37]. This method is based on the idea of maximizing the modularity degree (Formula (5)), which is the quality of the partition and an objective function to be optimized [38,39]. The method can be divided into two steps, which are repeated iteratively.

First, we assign every node in the network to a single community. For each node i we evaluate the increase in the modularity degree (ΔQ) after moving it into one of the communities of its neighbor node. ΔQ can be evaluated as:

$$\Delta \mathrm{Q} = \left[\frac{\sum C_{in} + 2A_{i,in}}{2m} - \left(\frac{\sum tot + A_i}{2m} \right)^2 \right] \tag{8}$$

where $\sum C_{in}$ represents the sum of the weights of all the edges inside community C. $\sum tot$ is the sum of the weights of the edges connected to nodes in community C. A_i is the sum of the weights of the edges connected to node i. $A_{i,in}$ is the sum of the weights of the edges between node i and other nodes within community C. m is the sum of all the edges in the network.

Node i is placed in the community of node j, for which ΔQ is maximum and positive. If ΔQ is always negative, node i stays in the original community. The above process is applied repeatedly and sequentially for all the nodes within the network until no further increase can be achieved.

Second, we regard the communities found during the first step as new nodes. The weights of the edges between them are given by the weights of the edges between nodes in the two corresponding communities. The two steps are iterated until the maximum modularity degree is attained and we obtain the final result of community detection.

3.3.3. Visualization of Trade Networks

In visualizing the trade networks based on the centrality indices on the node level and community detection, the trade pattern can be represented more intuitively. We draw graphs of the above two kinds of trade networks at each phase with Gephi0.9.2. For the visualization of the first kind of trade network, node sizes are given by the values of strength centrality, node colors represent the communities to which they belong, and edge diameters represent the weights of the edges. For the second kind of trade network, node sizes are given by in-strength centrality, node colors represent out-strength centrality (nodes with a reddish color have a larger out-strength centrality, while blueish nodes have a smaller value), and edge diameters are still given by edge weights. The layouts of both kinds of trade networks are based on the algorithm proposed by Fruchterman et al. [71], within which countries with more trade links are located in the center of the network, while countries with fewer trade links are located on the periphery. Edges in the networks bend at angles ($\theta < 180°$) and extend from exporters to importers. For each category of products, we also keep the edge thickness the same in each phase for the sake of comparison.

4. Three Phases of the Trade Pattern of Rolling Stock Products in BRI

In this study, the period from 2003 to 2017 is divided into three phases through the sequential clustering analysis (Table 2). As shown in Figure 2, phase 1 represents 2003 to 2008, within which the shares of the intraregional exports of the BRI countries are relatively stable but still have slight fluctuations. As a result of the 2008 Global Financial Crisis (GFC), the export volume of several leading exporters was affected to varying degrees after 2008. During phase 2 from 2009 to 2013, they gradually recovered from the crisis while still moderately fluctuating. Phase 3 began in 2014 due to the outbreak of the Ukraine crisis, which led to political turmoil, split the country, and generated an unprecedented blow to economic and social development [72]. After the regime change, the government implemented a series of measures to weaken Russia's influence on Ukraine, which affected the trade flows between Ukraine and Russia. Following the sanctions from Western countries and the increase in political risks, imports and exports to and from Russia were restricted, and domestic investment and economic growth were also affected [72]. Ukraine's and Russia's export shares dropped significantly (Figure 2), while those of other BRI countries increased to varying degrees. China proposed the BRI in 2013 and gradually mastered mature technology in the RSMI. Its shares increased considerably and remained high.

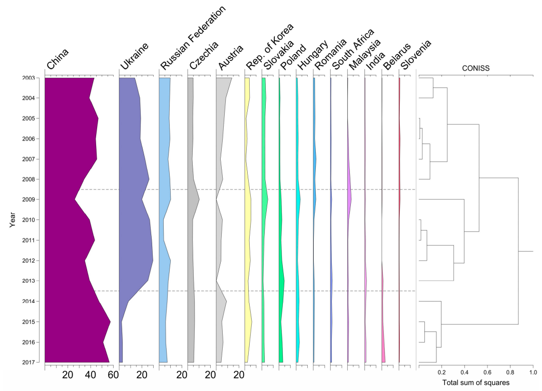


Figure 2. The fluctuation in the proportions of export volume and the clustering result (only the top 15 BRI exporters are listed above).

Table 2. Three phases divided through the sequential clustering method.

	Years	Length
Phase 1	2003–2008	six years
Phase 2	2009–2013	five years
Phase 3	2014–2017	four years

5. Result

5.1. The Overall Trade Pattern of Rolling Stock Products in BRI

5.1.1. Overall Situation and Evolution

The node-level and network-level indices and basic features of networks are counted to analyze the trade patterns, especially the export pattern, which can reflect the trade competitiveness of the BRI countries.

Overall Export Situation

The BRI countries are extensively involved in the export of rolling stock products; however, the gaps among their export volumes are huge. A total of 113 BRI countries had export records, and the volume of the total intraregional exports reached US$ 116.4 billion from 2003 through to 2017. However, these countries' distribution of export shares was severely uneven. The top ten exporters accounted for 85% to 95% of the total intraregional export volume (Figure 3). Based on export volume, China, Ukraine, Russia, Czechia, Austria, and South Korea were the main exporters (Figure 4). As the largest exporter, China's total intraregional exports from 2003 through to 2017 reached US$ 50.2 billion (Table 3), which was 5.8 times that of the third-largest exporter and 43.2 times that of the tenth-largest exporter. Ukraine was the second-largest exporter and exported far more products than any other country except China. Thus, the total intraregional export volume was mainly influenced by China's and Ukraine's exports.

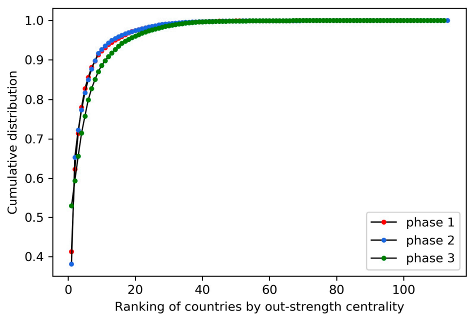


Figure 3. Cumulative distribution of out-strength centrality among BRI countries.

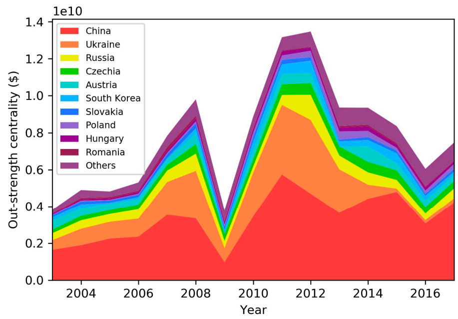


Figure 4. Intraregional export volume of the top 10 BRI exporters.

Table 3. Export of the top 10 intraregional exporters in each phase.

	Phase 1 (2003–2008)			Phase 2 (2009–2013)			Phase 3 (2014–2017)		
Rank	Country	Outdegree	Out-strength ($)	Country	Outdegree	Out-strength ($)	Country	Outdegree	Out-strength ($)
1	China	98	2.5×10^9	China	102	3.7×10^9	China	106	4.1×10^9
2	Ukraine	40	1.3×10^9	Ukraine	48	2.7×10^9	Russian	50	5.1×10^8
3	Russian	60	5.5×10^8	Russian	64	6.7×10^8	Austria	80	4.8×10^8
4	Austria	73	4.0×10^8	Czechia	62	4.9×10^8	Czechia	70	4.6×10^8
5	Czechia	61	2.9×10^8	Rep. of Korea	64	4.3×10^8	Ukraine	47	3.4×10^8
6	Slovakia	35	1.8×10^8	Austria	75	3.2×10^8	South Korea	62	3.3×10^8
7	South Korea	47	1.5×10^8	Poland	64	2.6×10^8	Poland	72	2.2×10^8
8	Romania	43	9.8×10^7	Slovakia	35	2.0×10^8	Hungary	44	1.8×10^8
9	Hungary	45	9.7×10^7	Hungary	45	1.8×10^8	Slovakia	31	1.6×10^8
10	Malaysia	36	6.0×10^7	South Africa	78	9.7×10^7	Belarus	22	1.2×10^8

Evolution of the Export Situation

We compared the features of the first kind of trade networks in the three phases (Table 4). According to the changes in those network-level and node-level indices and the intraregional export volume of the large exporters (Figure 4) from phase 1 to phase 3, we summarized four patterns of the evolution of the intraregional export situation below.

Table 4. Features of intraregional rolling stock trade networks (means of annual values in each phase).

Items	Phase 1 (2003–2008)	Phase 2 (2009–2013)	Phase 3 (2014–2017)
Nodes	109.0	110.4	109.8
Edges	962.7	1189.2	1269.3
Export Countries	84.8	91.0	80.8
Total Intraregional Export ($)	6.1×10^9	9.7×10^9	7.8×10^9
Total Export Share of the Top Ten Exporters	93.2%	92.6%	88.9%
Network Density	0.0815	0.0986	0.1063
Modularity Degree	0.5427	0.4698	0.5305
Clustering Coefficient	0.4390	0.4604	0.5010
Average Path Length	2.4625	2.3362	2.1643

From 2003 to 2017, the connectivity of the intraregional rolling stock trade increased considerably. However, the growth was fast at first and then slowed. As shown in Table 4, the number of countries involved in the rolling stock trade was stable, but the number of links and the network density increased considerably. A gap in network density between phases 1 and 2 was evident, which suggested that the BRI countries were more interconnected in the trade and production of rolling stock during phase 1. However, from phase 2 to phase 3 the growth decelerated. Limited by the overall regional level of development, only a few countries within the BRI region had a relatively strong comprehensive economic strength. Thus, the connectivity of the network may become temporarily saturated after reaching a certain level. Moreover, the enhancement of trade links decelerated.

The intraregional export of rolling stock products first developed in a dispersed manner and then became concentrated. According to Table 4, from phase 1 to phase 3, although the trade links continued to increase, the number of exporters first increased to 91 in phase 2 and then decreased to 81 in phase 3. The modularity degree first decreased and then increased but always fluctuated at approximately 0.5, which suggested a high level of community partitioning. In phase 2, with relatively more exporters and a lower modularity degree, the network structure was complex and the community partition was insignificant. In phase 3, the community partition became distinct again and the export pattern became more concentrated.

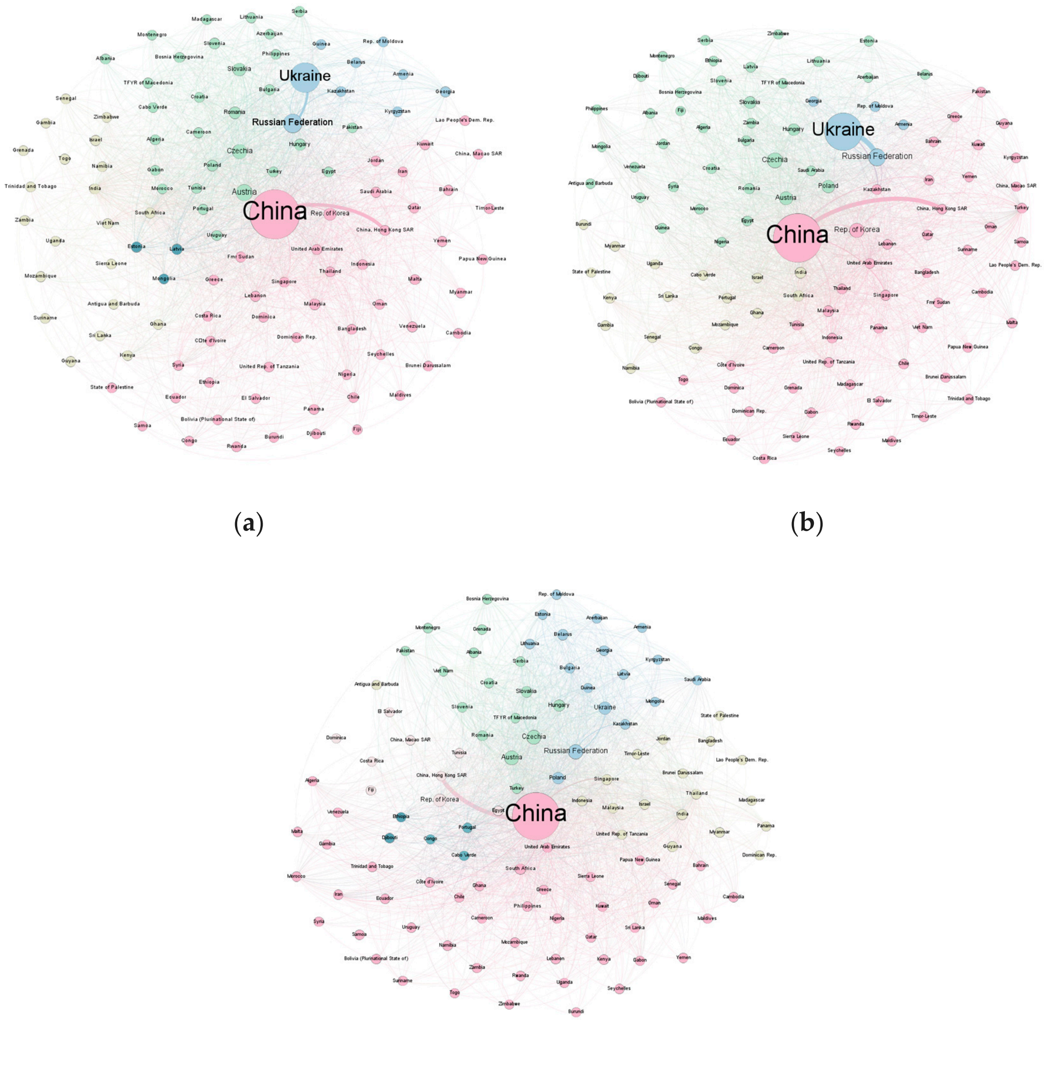
The small-world effect of the rolling stock products' intraregional trade pattern is continuously being enhanced. The trade network's clustering coefficient showed an overall upward trend. As shown in Table 4, from phase 1 to phase 2 the coefficient increased by 0.02, then by 0.04, and exceeded 0.5 in phase 3. The average path continuously decreased from 2.46 to 2.16, which indicated the accelerating grouping of the BRI countries and the enhancement of the small-world effect. The trade fluctuation of a single country could increasingly and precipitously affect other countries within this region.

Insofar as they have greatly impacted the trade patterns, the GFC in 2008 and the Ukraine crisis in 2013 are the most critical incidents that form the basis of the three-phase division. However, the intraregional impact of the latter was rather weakened by the rise of China. That is, after the outbreak of the financial crisis, the BRI countries were affected to different degrees. In general, the domestic economy and investment environment deteriorated. Foreign demand also declined. In 2009, the intraregional export volumes of 51 exporters decreased, among which the export of 32 countries decreased more than 50%. The large exporters bore the brunt and suffered significant drops in export volume (Figure 4). The export of the top ten exporters averagely decreased by US$ 0.57 billion in 2009. In 2009, Austria, the most affected country among the large exporters, had less than 0.1% of its exports in 2008 and hence fell out of the top ten. However, after the Ukraine crisis in phase 3, Ukraine became the most affected country, and its export volume decreased precipitously. Its annual average intraregional export volume decreased from US$ 2.65 billion (phase 2) to US$ 0.335 billion (phase 2), which was an 87.3% decline, making Ukraine drop to the sixth place at the end of phase 3. However, the BRI countries, headed by Russia, were still Ukraine's main export destinations. From phase 2 to phase 3, the exports from Russia also decreased by 25%. Czechia's, Slovakia's, and Austria's exports also dropped by different degrees. However, the total share of the intraregional export volume of the top ten exporters did not decrease significantly. One of the most important reasons was China's market expansion in the BRI region. In this phase, China's export share increased from 36.5% (phase 2) to 52% (phase 3) and remained high. China's out-degree also continuously increased. At the end of phase 3, China's market became very extensive and covered 77.8% of the BRI countries.

5.1.2. Community Structure and Evolution

In the following analysis, we visualize the first kind of trade networks and conduct community detection in each phase to illustrate the community structure of the trade networks and the export pattern and evolution.

In phase 1 (2003–2008), the modularity degree of the trade network attained 0.510, which was high and suggested a relatively distinct community partition. Countries gathered into five communities around centers such as China, Ukraine, Austria, and South Africa. As shown in Figure 5a, the China-centered community was the largest and accounted for 46.2% of the total intraregional export volume in this phase. Fifty-one members of this community were primarily countries from Southeast Asia and the Middle East, and some were from Central Africa and South America (Figure 6a). From the perspective of both export volume and export links, China was the most important node in both this community and the whole network. China exported a large number of rolling stock products to 98 countries or regions such as Chinese Hong Kong, South Korea, Singapore, and Iran. South Korea was also an important exporter in this community, as well as the second-largest import source for China. South Korea exported to Turkey, Greece, and India. Austria, China's most important import source, was the center of the second-largest community. There were 29 countries in this community, which accounted for 21% of the intraregional export volume in total. Members in this community are mainly distributed in Central and Eastern Europe, Southern Europe, and North Africa (Figure 6a). Austria had the largest export value and the number of export destinations in this community. In addition to exporting to center countries in other communities, such as China, India, and Ukraine, Austria also had close trade links with countries within its own community, such as Czechia, Slovakia, Hungary, and Poland. The second-largest community was centered on South Africa and India. Twenty-one countries in this community are mainly distributed in South Asia and Southern Africa (Figure 6a). However, their total share of intraregional exports was only 1.3%. The fourth-largest community was composed of only nine former Soviet bloc countries but accounted for 30.8% of the total intraregional exports in this phase and was strongly exclusive. Ukraine and Russia in this regard are closely connected. Russia accounted for 79% of Ukraine's exports and 70% of its imports. Ukraine, likewise, accounted for 70% of Russia's imports. However, the export from Russia was more extensive. The export volume from Russia to Ukraine was much lower than in the opposite direction. Ukraine only accounted for 27% of Russia's exports.



(**a**) (**b**) (**c**)

Figure 5. Trade networks of rolling stock products in the BRI region: (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), and (**c**) phase 3 (2014–2017). The size of the node indicates the strength centrality. Each community is indicated by its given color. The diameter of the edge represents the volume of the trade flow.

The modularity degree of the trade network in phase 2 was 0.507, which indicates that the community partition was still distinct. Countries such as China, Ukraine, Austria, and South Africa were still important exporters and community centers. The spatial distribution of countries in the four communities became relatively dispersed, which suggested that the influence of regionalization was weakened, while that of globalization was enhanced. China was still the largest exporter in both its community and the whole network (Figure 5b), and exported to 102 BRI countries or regions. The China-centered community was still the largest in the network. Its range expanded to 54 countries, but the total share of intraregional exports slightly decreased to 44.8%. Chinese Hong Kong, Singapore, Iran, and South Korea and some other countries in this community were still the main export destinations for China. China enhanced links with Central Asian countries in this phase, in which Kazakhstan and Kyrgyzstan were incorporated into this community (Figure 6b). However, the links among China and West Asian or North African countries were weakened. These countries were incorporated into the second-largest community centered on Czechia and Austria. Austria was still the country with the most export links in this community, which exported a large amount of rolling stock products to important exporters in other communities, such as China, Russia, and South Korea, and other countries within its community. However, the country with the largest export value in this community changed to Czechia, which mainly exported to other Central, Eastern, and Southern European countries in this community. This community, with 37 members in this phase, expanded its range to countries in Southern Africa and South America (Figure 6b). However, its total share of intraregional exports decreased to 18.5%, and trade links with large volumes still existed among Czechia, Austria, Hungary, and other interconnected European countries. Among the import sources for China, the significance of these countries increased; in fact, they became the top three import sources for China. The third-largest community was centered in India and South Africa and shrank to 17 members, which were mainly distributed in Southern Africa and South Asia, but its share of intraregional exports increased to 2.2%. The fourth-largest community was still centered in Ukraine and Russia. Because of the enhancement of influence from China and Central and Eastern European countries, the range of this community further shrank to five former Soviet bloc countries. However, their advanced export and production capacity made them account for 34.3% of the total intraregional exports. The trade link between Ukraine and Russia, which was mainly sustained by the large export from Ukraine to Russia, was further enhanced. Ukraine's exports further strengthened its market dependence on Russia, which accounted for 96% of its exports. The source dependence of Russia's imports on Ukraine was also enhanced. Ukraine accounted for 86% of Russia's imports. However, Russia was no longer the main import source for Ukraine, and it expanded its export market as well.

Compared with the first two phases, the community partition in phase 3 was relatively indistinct, with a modularity degree of 0.484. Trends of globalization and regionalization were simultaneously increasing. There were five main communities in this phase centered in China, India, Austria, Russia, and South Korea (Figure 5c). China was still the center of the largest community in this network and exported to 106 BRI countries and regions. The number of countries within the China-centered community decreased to 46, but the share of intraregional exports of this community increased to 55.1%. With the promotion of the BRI, trade links among China and African countries such as South Africa and Cameroon were enhanced (Figure 6c). Almost all the BRI countries in Africa were incorporated into this community in this phase. South Africa and the United Arab Emirates were important exporters in this community as well and maintained close links with African countries and Middle Eastern countries, respectively. In Southeast Asia, the export volume of the Philippines increased substantially. It became the third-largest import source for China. However, except for the Philippines, most of the Southeast Asian countries were incorporated into the second-largest community, which was centered on India. The 19 members in this community were mainly countries from Southeast Asia (Figure 6c). Their total share of intraregional exports increased to 4.5%. From the perspective of both export links and export volume, India was the center of this community. The Russia-Poland-centered community was the third-largest community, which included 17 members that were mainly concentrated in Central Asia and Central and Southern Europe (Figure 6c). However, its share of intraregional exports decreased to 16.6%. As mentioned above, after the outbreak of the Ukraine crisis, Ukraine's exports fell precipitously. Domestic economic stagnation and Western economic sanctions caused Russia's trade to also greatly decrease. However, Russia still had the largest export volume in this community. Poland weakened its trade links with Czechia, Hungary, and Slovakia but increased exports to Russia and was incorporated into this community and became the most connected country in it. The deterioration of the relationship between Ukraine and Russia did not significantly impact trade links among Russia and the former Soviet bloc countries, which were mainly in Central and Eastern Europe. Although Ukraine's dependence on imports from Russia further decreased to only 14%, Russia remained Ukraine's most important export market, accounting for 96% of its exports. Both countries were still in the same community as well. Affected by turmoil, Ukraine's production and export decreased substantially. Russia decreased its import dependence on Ukraine and increased imports from Austria, Poland, Bulgaria, and Belarus. Thus, some Central and Eastern European countries were incorporated into the Russia-Poland-centered community (Figure 6c), which saw the Austria-Turkey-centered community shrink to 16 members and account for 18.9% of the intraregional export volume in total. Moreover, there was a small community centered on South Korea which was distributed in a dispersed manner.

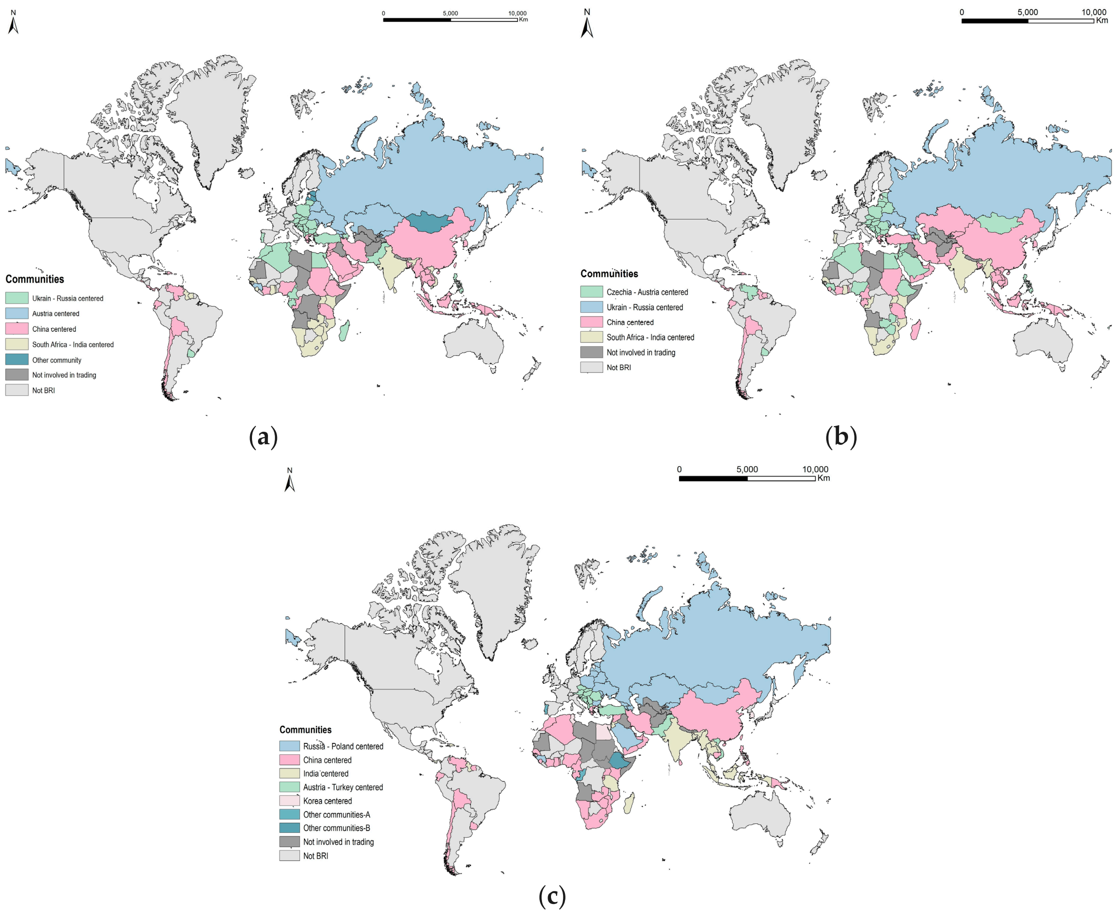


Figure 6. Community structure of trade of rolling stock products in the BRI region: (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014–2017).

5.2. Trade Patterns of Some Typical Categories of Rolling Stock Products in BRI

Here, we visualized the second kind of trade network in each phase and analyzed their characteristics (Table 5) to illustrate the trends of the trade patterns. Due to space limitations in this paper, we only described the trade patterns of two categories of rolling stock products in detail: rail locomotives and self-propelled coaches and vans (RLSCV) (Section 5.2.1) and part products (Section 5.2.2), which have close links within the industry line, to mainly reflect the position of the international production fragmentation of the BRI countries and their competitiveness. The RLSCV drives and carries passengers and cargo and is more high-tech and sophisticated than other categories of products. In the production of the RLSCV, producers need to assemble and further process many parts. Hence, through the comparison of trade patterns of RLSCV and parts products, we figured out the position of the international production fragmentation of the BRI countries in the RSMI. Figures of other categories of products are attached in the Appendix A as Figures A1–A3.

Table 5. Network-level indices of five categories of products in the BRI region (means of 3 phases).

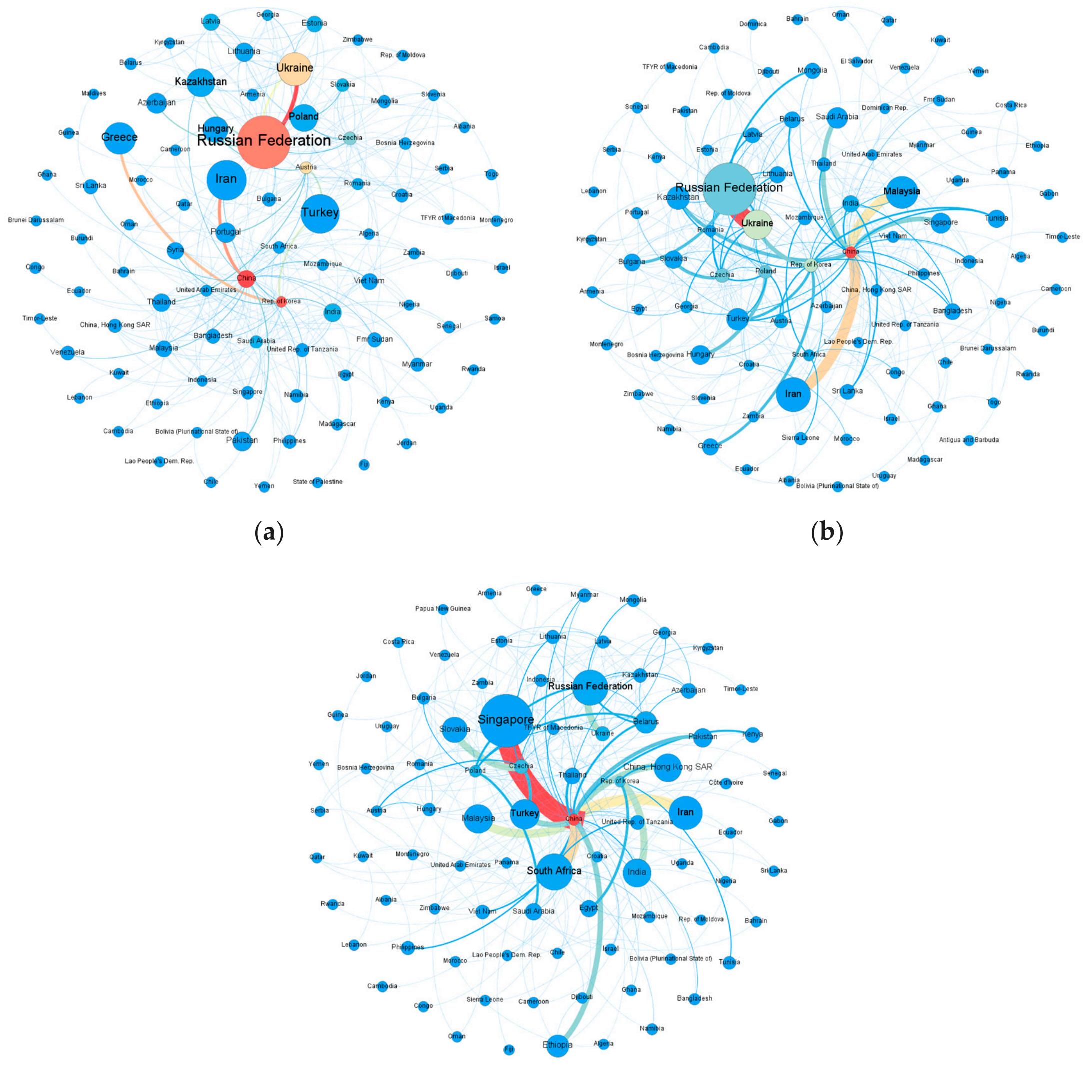
Products	Nodes	Edges	Network Density	Modularity Degree	Clustering Coefficient	Average Path Length
Rail Locomotives and Self-propelled Coaches and Vans	92.33	331.33	0.04	0.57	0.28	2.95
Maintenance or Service Vehicles	77.67	201.00	0.03	0.24	0.21	3.58
Not Self-propelled Coaches and Vans	97.00	377.00	0.04	0.46	0.30	3.01
Parts	109.00	1061.33	0.09	0.41	0.53	2.27
Track Fittings, Signaling, and Traffic Control Auxiliary Equipment	104.67	619.00	0.06	0.48	0.50	2.38

5.2.1. Rail Locomotives and Self-propelled Coaches and Vans

RLSCV is one of the most important components of the rail system. A relatively large and stable number of countries were involved in the production of RLSCV products. Their trade network structure is relatively clear and their community partitions distinct. In the three phases, an average of 57 countries were involved in the export of RLSCV products, and the average network degree was 3.59. The modularity degree of RLSCV products was 0.57, which was the highest among the five categories of rolling stock products (Table 5).

In phase 1, the average annual total of intraregional exports was US$ 0.547 billion. However, as shown in Figure 7a, exports were mainly concentrated among several large exporters, including China, South Korea, Russia, Ukraine, and Austria. The total share of intraregional exports of these countries was 78%. China, which was in the center of the trade network, was also the country with the largest out-degree centrality and out-strength centrality. China imported RLSCV products from technologically advanced countries such as South Korea and Austria and exported mainly to countries in South Asia, Southeast Asia, Central Asia, and Africa, such as Iran, Pakistan, Malaysia, Vietnam, Kazakhstan, and Sudan. South Korea was still in the center of the trade network and exported a large amount of RLSCV products to Greece, Turkey, Iran, and many other countries. Russia and Ukraine were each other's most important trade partners and mutually exported large volumes. Russia accounted for 74% of both Ukraine's imports and exports. Ukraine accounted for 91% of Russia's imports, while Russia's export dependence on Ukraine was less (only 31%). Both Ukraine and Russia exported mainly to countries in Central Asia, West Asia, and Central and Eastern Europe, such as Kazakhstan, Azerbaijan, and Hungary. Hence, they were on the periphery of the network as compared with other large exporters. Austria exported mainly to Turkey, Portugal, Thailand, and China.

Then, in phase 2, the overall extent of intraregional trade expanded further. However, the gaps in export volumes among exporters became wider. The average annual total of intraregional exports increased to US$ 1.62 billion, which was almost three times that of phase 1. The top five exporters changed to China, Ukraine, South Korea, Russia, and Czechia (Figure 7b), and their total share of intraregional exports increased to 80.21%. China's status as the largest exporter within the BRI region was further consolidated, and it gradually became an export power. China's export value increased to 5.54 times that of phase 1. In phase 1, its export value was only 1.07 times that of the second-largest exporter, but in this phase, its exports attained 2.57 times that of the second-largest exporter, making its dominant position increasingly evident. China actively expanded its exports to Asian countries. For Iran, which is its largest export destination, China's export value increased 2.24 times and exceeded US$ 0.1 billion. The values of exports to India, Malaysia, Turkey, and Thailand also increased 6.56 times, 13.03 times, 37.04 times, and 83.65 times, respectively. China also began to export large quantities to countries such as Saudi Arabia, Singapore, and Belarus. Meanwhile, China's import value and the number of its import sources substantially decreased. Ukraine's export value also substantially increased to 3.54 times that of its phase 1 value, making it the second-largest exporter. However, it was still highly dependent on Russia as an export market, which accounted for 75% of Ukraine's exports. Nonetheless, Ukraine decreased its import dependence on Russia and began to import many products from South Korea and Czechia. South Korea fell to the position of third-largest exporter, but its exports also increased to 2.16 times that of the former phase. South Korea expanded large amounts of exports to Ukraine, Tanzania, and Kazakhstan, and its imports from Austria also substantially increased. As the fourth-largest exporter, Russia mainly exported to Mongolia and Bulgaria. However, it still maintained high import dependence on Ukraine, which accounted for 90% of Russia's imports. The total export value of Czechia also increased to 4.67 times that of the former phase. The value of its exports to Slovakia, Latvia, Lithuania, and Russia also increased substantially.



(**a**) (**b**)

(**c**)

Figure 7. Trade networks of rail locomotives and self-propelled coaches and vans products in the BRI region: (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), and (**c**) phase 3 (2014–2017). The size of the node indicates the in-strength centrality, and the color is given by the out-strength centrality. The diameter and color of edges represent the volume of the trade flow. Red represents a high value and blue represents a low value.

In phase 3, the extent of growth in intraregional trade slowed down; however, the gaps in export value among the BRI countries became wider. The average annual total of intraregional exports increased to US$ 1.84 billion, which increased by only 13.6%. The top five exporters were China, South Korea, Czechia, Poland, and Ukraine (Figure 7c). Their total export share substantially increased to 88.3%. China was located in the center of the network, and its leading status as the largest exporter and as an export power was further strengthened. Although China's import value continuously decreased, its export value further increased to 6.74 times that of the second-largest exporter, making the gap more evident. China kept close trade links with Southeast Asian countries. Singapore became China's most important export destination instead of Iran in this phase, and its average annual import value from China exceeded US$ 0.25 billion. While maintaining large amounts of exports to Singapore, Thailand, and Malaysia, China also substantially increased its exports to the Philippines, whose import value from China increased to 127 times that of the former phase. China also actively enhanced its trade links with African countries. South Africa became China's second-largest export destination, whose average annual import value from China was 39.7 times that of phase 2 and exceeded US$ 0.1 billion. China's imports to Ethiopia and Kenya also increased by more than US$ 20 million separately. Moreover, China also took the place of South Korea and became the most important import source for Turkey and Pakistan. After the outbreak of the Ukraine crisis, Ukraine's imports and exports declined to 80.1% and 61.3%, respectively, and its imports from South Korea were also interrupted. Ukraine's exports to the BRI countries decreased by different degrees. However, Russia was still its largest export destination, accounting for 72% of its exports. Russia's imports and exports also decreased by 43% and 68.4%, respectively. Impacted by the drop in Ukraine's exports, Russia's imports from Belarus and Poland substantially increased. However, its exports to the main destinations greatly decreased, and those of Bulgaria, its most important export destination in phase 2, were also interrupted. South Korea, Czechia, and Poland exceeded Ukraine and Russia and became the second-largest, third-largest, and fourth-largest exporters, respectively. South Korea vigorously expanded its market to countries such as Egypt and India. The trade partners of Czechia and Poland were still concentrated in a small range within Western Asia and Central and Eastern Europe.

5.2.2. Parts

Parts products include the essential components of the final products of rolling stock and are widely applied in the production of the body and joints of various kinds of rolling stock. Some of the parts included in this category are relatively sophisticated and complex, and production has a high technology requirement. Compared with other categories of rolling stock products (Table 5), the largest number of countries were involved in the production of parts products and had frequent trade interactions with each other. The structure of the trade networks of parts products was complex, and the community partitions were relatively indistinct. From the mean value of the three phases (Table 5), approximately 89 countries were involved in the export of parts products. The average clustering coefficient was 0.53. However, the modularity degree was relatively low at only 0.41.

In phase 1, BRI countries were widely involved in the intraregional production and export of parts products. A total of 108 of 110 traders had export records. The mean annual total of intraregional exports was as high as US$ 1.32 billion. However, the gaps in export values among BRI countries were still wide. The top five exporters were Ukraine, Czechia, Russia, Austria, and China (Figure 8a). Ukraine was the largest exporter of parts products, but it was on the periphery of the network and highly dependent on Russia for imports and exports. Russia accounted for 61% of Ukraine's imports and 81% of its exports. Ukraine also accounted for 86% of Russia's imports and 81% of its exports. However, Ukraine and Russia's export destinations were still mainly concentrated in a small range of Central and Eastern European and Central Asian countries. Czechia was an important exporter of parts products that had large-value trade links with other large exporters, especially Austria and Slovakia. China's competitiveness for parts products was relatively low compared with that for RLSCV products. From the perspective of export links, China was the largest exporter, with an out-degree of 72. However, the value of its export products was relatively low. From the perspective of export value, China only ranked fifth. It still needed to import large amounts of parts products from other technologically advanced countries, such as Austria, Russia, and South Korea. Austria even accounted for 62% of China's imports in this category.

Then, in phase 2 the exports of parts products became concentrated. The number of exporters decreased to 84, while their average annual total of intraregional exports increased to US$ 2.12 billion. Ukraine, Czechia, and Russia were still the top three exporters (Figure 8b), with slightly increasing import and export values. The range and structural characteristics of Ukraine's exports were similar to those of phase 1. Ukraine's exports further increased its market dependence on Russia, which accounted for 69% of Ukraine's exports, but Ukraine's imports decreased its source dependence on Russia, falling to 68%, and Ukraine increased imports from Central European countries—such as Czechia, Poland, and Austria—and East Asian countries, such as China and South Korea. Russia also decreased its trade dependence on Ukraine, which accounted for 74% and 54% of Russia's imports and exports, respectively, but increased its imports from China. China and South Korea substantially increased their average annual intraregional export value to three times and 4.5 times that of the previous phase and became the fourth-largest and fifth-largest exporters, respectively. China's out-degree increased to 82, and it not only maintained large-value exports to India, Iran, and South Korea but also increased its exports to South Africa, Russia, Kazakhstan, and Ukraine to 9.1 times, 15.4 times, 52 times, and 76.3 times that of phase 1, respectively. Its exports to Indonesia and Turkey also increased substantially. However, China's import value also increased to 2.19 times that of the previous phase. Among those, the imports from Hungary and Czechia substantially increased. South Korea also actively expanded its export to other BRI countries, especially Turkey, Iran, Indonesia, the Philippines, and Thailand.

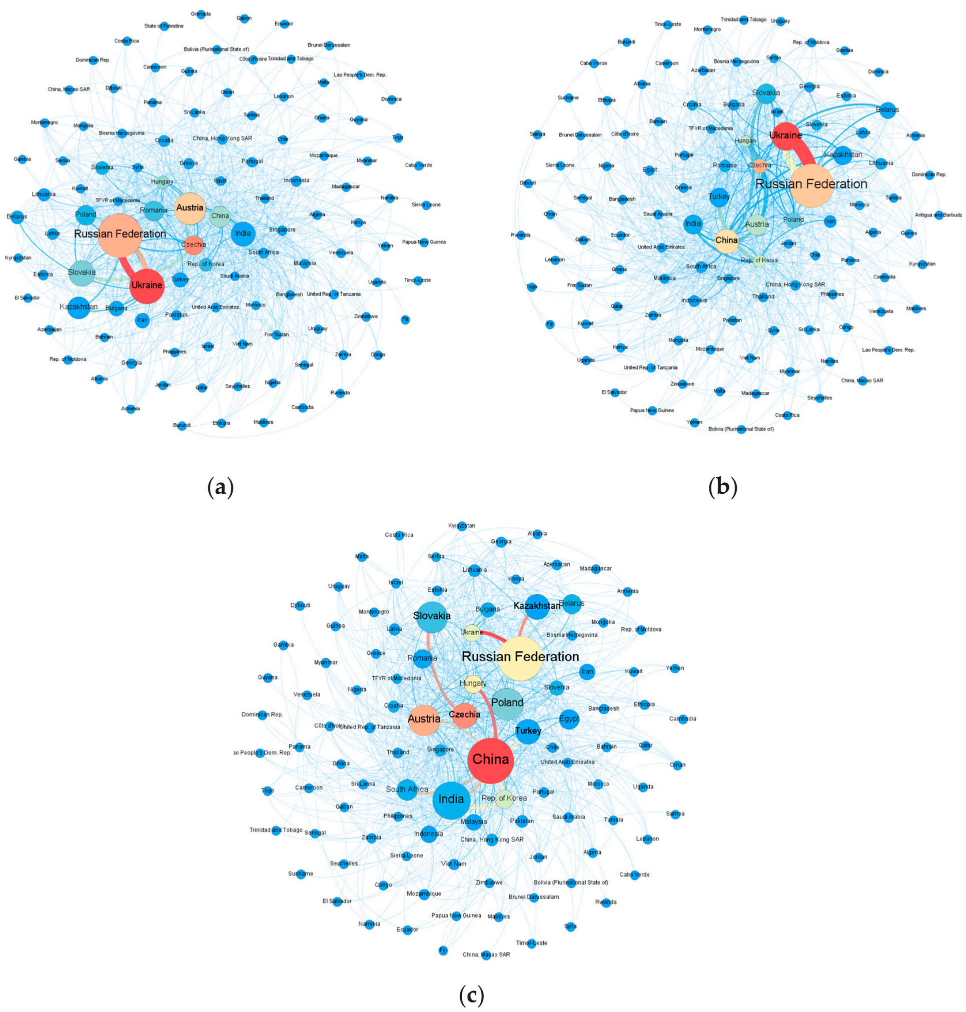


Figure 8. Trade networks of parts products in the BRI region. (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014–2017). The settings are the same as in Figure 7.

In phase 3, the exports of parts products were further concentrated and the number of exporters was reduced to 75 (Figure 8c). However, the average annual export value decreased to US$ 1.69 billion. China's average annual intraregional export value increased to 1.64 times that of the previous phase, and its out-degree also increased to 90, which made China the largest exporter of parts products from the perspectives of both export links and export values. China exported mainly to India, South Africa, South Korea, and Iran, but it still sustained a large amount of imports from traditional technologically advanced countries, such as Hungary, Austria, and Czechia, and strengthened trade links with Chinese Hong Kong. Chinese Hong Kong became the fourth-largest import source of China. The export values of Czechia, Austria, and Hungary only slightly changed, and these countries still became the second-largest, third-largest, and fourth-largest exporters, respectively. However, their export ranges and structures were still stable. Ukraine and Russia's export values substantially decreased. Ukraine's export and import dependence on Russia dropped slightly but was still higher than 60%. However, Russia's trade dependence on Ukraine decreased considerably.

6. Discussion

6.1. Evolution of Trade Links and Community Structure

To record the changes in the overall trade pattern of the rolling stock products in the BRI, we compared the characteristics and community structures of the first kind of the rolling stock trade networks in the three phases and generalized the evolution of the trade links and community structure.

In general, from 2003 to 2017 the rolling stocks trade's connectivity among the BRI countries continuously grew. However, limited by the regional development level, the growth was fast at first and then eventually decelerated. Countries involved in trade were increasingly clustered. The small-world effect was also developing.

Under the effect of globalization and regionalization, the intraregional trade's community structure frequently changed but was still locally stable in some subregions. Large exporters such as China, Russia, and Austria were always the centers of their communities and had a strong influence therein. The communities of countries at the center of their spheres of influence were relatively stable. China's changes in trade links were most active in the BRI region. Following the development of economic globalization, China continuously broke the bonds of geographical distance. It not only cooperated with other technologically advanced countries but also incorporated some Latin American and African countries into the same community and increased trade influence on other African and Southeast Asian countries. Although the members of the China-centered community changed frequently, it was always the largest community in the trade network. Ukraine and Russia maintained a strong influence on some Eastern European and Central Asian countries, which were mainly from the former Soviet bloc. Czechia and Austria mainly developed trade links with countries in Central and Southern Europe, North Africa, and the centers of other communities.

The communities that countries in other subregions belonged to also changed frequently. Countries in Central Asia, Western Asia, and North Africa were in the overlapping margins of the spheres of influence, and hence they experienced a stronger impact of globalization. However, they lacked internal links, and the impact of regionalization was weak. Thus, the community distribution in these regions was fragmented and changed frequently. The Sub-Saharan African and Southeast Asian countries experienced the strong effect of both regionalization and globalization and gathered into closely interconnected subregions, within which communities changed frequently but relatively synchronously.

6.2. Intraregional Export Competitiveness of BRI Countries and the Evolutions

In order to explore the evolution of the intraregional export competitiveness within the BRI region, we compared the trade patterns of the two typical categories of rolling stocks in three phases. We then generalized the competitiveness, considering the export volume and range and technological power comprehensively.

The BRI countries were extensively involved in the intraregional export of rolling stock products. However, only a few countries, such as China, Ukraine, Russia, Czechia, Austria, and South Korea, could maintain large amounts of annual exports from 2003 through to 2017 and had strong competitiveness compared with other BRI countries.

As a large emerging exporter in this industry, China continuously enhanced its export strength and technological competitiveness. It was always the largest RLSCV products' exporter, and hence its dominant position was gradually strengthened. It gradually decreased its high RLSCV and parts products' import dependence on technologically advanced countries, continuously enlarged its dominant position in the export of RLSCV products, and gradually became the largest exporter of parts products.

Russia and Ukraine were relatively less competitive and less influential compared with other large exporters. Their trades were highly mutually dependent, and both focused on countries in a small range which were mainly former Soviet countries. Ukraine always had a trade surplus of rolling stock products with Russia. However, the trade surplus in high-tech products, such as parts and RLSCV products, was relatively small. After the Ukraine crisis, the turmoil of the regional geopolitical environment and the deterioration of the relationship between Ukraine and Russia increased the risk in their trade link. Thus, Russia actively enriched its import sources and export destinations, which effectively reduced its trade dependence on Ukraine.

Czechia and Austria retained a high level of export volume and technological competitiveness but lacked expansive vitality in the rolling stock products market. These countries accumulated a robust technology and production capacity of rolling stock products during the European integration in previous years. They were also important import sources of parts and RLSCV products for many large exporters in the BRI region. However, although they still had stable export volumes and export markets, compared with China these countries lacked export vitality.

South Korea had mastered the advanced production technology of rolling stock products decades ago and was active in market expansion. It was always one of the leading countries in the markets of high-tech products such as parts and RLSCV. It is most likely to vigorously compete with China in the export of rolling stock products within the BRI region. In addition to being closely connected with several large exporters, such as China and Ukraine, South Korea also exported large amounts of products to countries such as Turkey, Iran, Greece, Egypt, and India. However, its export destinations were relatively dispersed and did not form a contiguous regional market.

6.3. Vulnerability of Rolling Stocks Trade Networks

In complex systems, vulnerability measures the susceptibility to incidents that can result in considerable reductions of components [73]. The rolling stock trade networks' vulnerability is related to the trade system's functionality and ability to sustain steady trades. Previous studies show that attacks on nodes whose degree or betweenness degree are high are fatal to complex networks, and suggest that these node-level indices can be measures of network vulnerability [46,69]. Hence, focusing on the stability of product supplements and basic structure, we briefly analyzed the vulnerability of the overall rolling stock trade networks in the BRI from the perspective of the risks of important countries, which have a high betweenness degree centrality and out-degree centrality (Figure 9), being attacked.

The rolling stock products' trade network in the BRI region is relatively stable and secure, considering the overall domestic and international conditions of the important nodes. In all of the three phases, most BRI countries with a high normalized betweenness centrality, such as China, South Africa, India, Turkey, and Austria, are also large exporters with a high out-degree centrality (Figure 9). These countries have stable domestic political and economic environments, enough natural and human resources, and a relatively higher level of technical competitiveness throughout the entire BRI region, which could guarantee the steady production, export, and intermediary export of rolling stock products within this region.

The stability of the rolling stock trade network could also be tested by the impact of Ukraine's significant falloff in exports on the overall trade pattern. As shown in Section 5.1.1, Ukraine was the second-largest rolling stock exporter (from the perspective of export volume) in the BRI region. Its export volume significantly decreased since the Ukraine crisis in 2013. However, the basic structure of the trade network remained stable—the number of trade flows was hardly affected in phase 3.

The gap in export volume left by Ukraine's decrease in export was also filled by other large exporters which could steadily supply rolling stock products. Russia, which was Ukraine's most important export destination, also turned to other exporters, such as Poland, Austria, and Belarus.

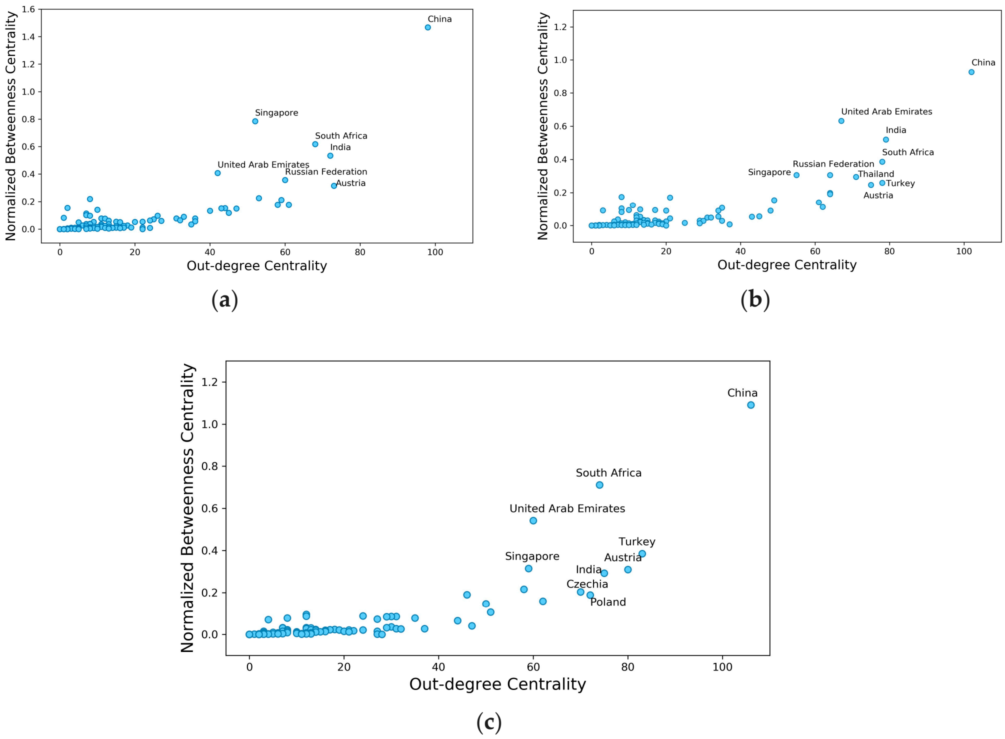


Figure 9. Out-degree centrality versus normalized betweenness centrality. (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014–2017). Only several countries high in normalized betweenness centrality and out-degree centrality are labeled.

6.4. Implications of This Study

Some studies on the development of the RSMI have been conducted in individual countries [9,23–26]. However, few scholars have paid attention to the transnational cooperation during the production process of the rolling stock products and the undergoing changes in the BRI region. There lacks an overall analysis of the patterns and the productive links of a group of countries within the BRI region or any other regions in the RSMI. The SNA method is a mature tool that can be used to analyze the trade relations and the structure of trade systems [32–36]. Studies on global [49–52] or regional trade network analysis are abundant [58–60], but the products analyzed are mainly concentrated on resources [53–55,61,62] or agricultural products [56,63]. A trade network analysis has not been conducted on high-tech industrial products, which call for different analysis perspectives because of their complex structure [74,75], differentiated technical contents of components, and transnational division of labor in the production process.

In this study, we analyzed the rolling stock products' trade network within the BRI region from 2003 through to 2017 to reflect the pattern of the RSMI. A sequential clustering method was used to divide the period from 2003 through to 2017 into three phases. We then built two kinds of trade networks in each phase and carried out the SNA. The implications are highlighted as follows:

(1) The pattern of the RSMI and the trade relations of the rolling stock products within the BRI region are revealed in this study. The changes in the overall pattern and trade links among the BRI countries were also captured.

(2) The method of analyzing the spatiotemporal patterns of high-end manufacturing industries was enriched. Rolling stock products were reclassified into several categories according to their

features, and a trade network analysis was conducted separately. Combined with the position of those products within the production chain and the export volume, the competitiveness of the main exporters was evaluated.

(3) A sequential clustering method was introduced into the phase division of the spatiotemporal pattern analysis. Compared with equal internal division, which was widely used in previous studies, the phase division method utilized in this paper can prevent the interruption of the real evolution process and the blurring of the phase features.

(4) The exclusiveness of the range of the recognized BRI countries was broken compared with former studies. Besides countries spatially located along the "Belt and Road", other countries that signed a BRI agreement with China were also incorporated in this study, which showed the openness of the BRI.

7. Conclusions

In the new wave of rail transit construction and the proposal of the BRI, there are dynamic changes in the patterns of the RSMI and the trade of rolling stocks in the BRI region which are becoming increasingly complex. In this study, we explored the characteristics and evolution of the rolling stock products' trade patterns in the BRI region, especially focusing on the trade links, community structure, and intraregional competitiveness of the BRI countries based on export volume, export range, and international production fragmentation to reflect the regional RSMI patterns. Based on the result, combined with differences among the product features and the patterns of international production fragmentation, we obtained the following findings:

(1) From 2003 to 2017, the connectivity and clustering degree of the rolling stock trade among countries in this region increased significantly. In the BRI region, four to five main communities could be detected. These communities' members and scales continuously changed, but they were always centered on large exporters such as China, Ukraine, Russia, Austria, Czechia, and South Korea. These countries had their separate spheres of influence within their communities. The communities of the countries far from any such spheres of influence changed frequently.

(2) The BRI countries were extensively involved in the intraregional export of rolling stock. However, their competitiveness gaps were huge. China was always the largest exporter and continuously enhanced its export strength and technological competitiveness. Russia and Ukraine were also large exporters in the BRI region, but they were relatively less competitive and influential and mutually dependent. After the Ukraine crisis, the exports of both countries were hit hard. Czechia and Austria retained large export volumes and strong technological competitiveness but lacked expansive vitality. South Korea was competitive in their export volumes and production technology. As it was also active in market expansion like China in the BRI region, China and South Korea are likely to vigorously compete in the export of rolling stocks in the future. The competitiveness of other BRI countries was far weaker than the above-named countries.

In this study, we identified the opportunity of the RSMI in the BRI region and the active changes taking place in complex patterns. We explored the patterns of the RSMI through the analysis of trade patterns. In follow-up studies, we shall focus on the following points to further explore the rolling stock trade within the BRI region:

(1) Further define the classification of rolling stock products. We shall focus on the conditions, such as technology and labor, needed in the production process of a certain category of products and their position in the industry chain to compare the advantages and disadvantages of the BRI countries.

(2) Strengthen the analysis of countries at the initial stage of development. In the BRI network, facility connectivity and unimpeded trade support the infrastructure construction and development of the local manufacturing industry for some less developed countries. Analyzing changes in the development of the manufacturing industry in these countries can comprehensively reflect the influence of the BRI from the perspective of multiple agents.

(3) Explore the physical and social factors that influence the pattern. In this study, we examined the evolution of trade patterns and focused on the descriptive analysis of the community structure, trade links, and competitiveness of the BRI countries to indicate the development of the RSMI. The natural and physical factors of the patterns and evolutions will be explored in follow-up studies. Proposals for the advantages and disadvantages of the BRI countries based on these factors will be stated to further enhance these countries' export competitiveness.

Author Contributions: Conceptualization, Yuanhui Wang and Changqing Song; methodology, Yuanhui Wang; Software, Yuanhui Wang and Xiaoqiang Chen; validation, Yuanhui Wang and Changqing Song; formal analysis, Yuanhui Wang; resources, Changqing Song; data curation, Yuanhui Wang; writing—original draft preparation, Yuanhui Wang; writing—review and editing, Changqing Song, Gary Sigley, and Lihua Yuan; supervision, Changqing Song; project administration, Changqing Song; funding acquisition, Changqing Song. All authors have read and agreed to the published version of the manuscript.

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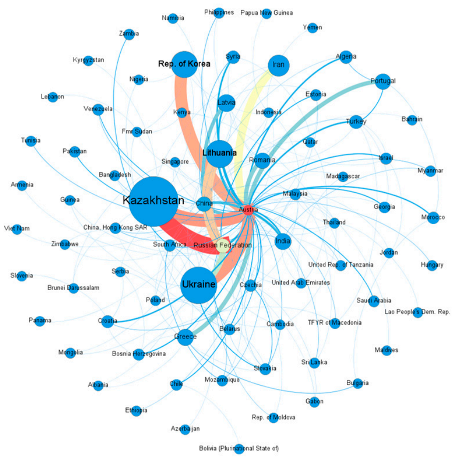
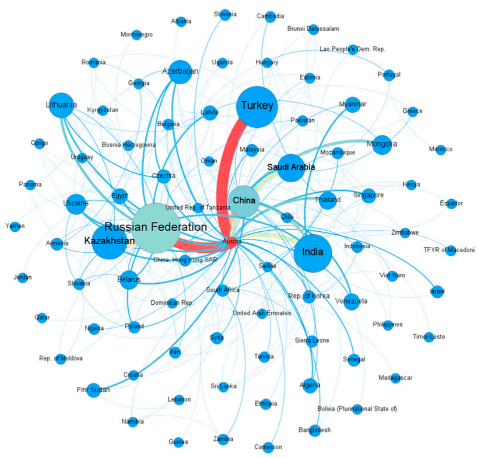
Conflicts of Interest: The authors declare no conflict of interest.

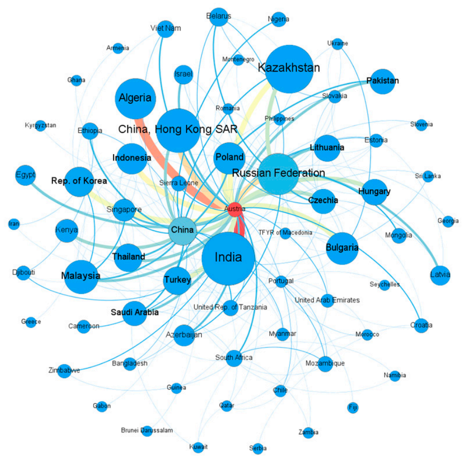
Appendix A



(**a**)



(**b**)



(**c**)

Figure A1. Trade networks of maintenance or service vehicles products in the BRI region. (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014-2017). The settings are the same as in Figure 7.

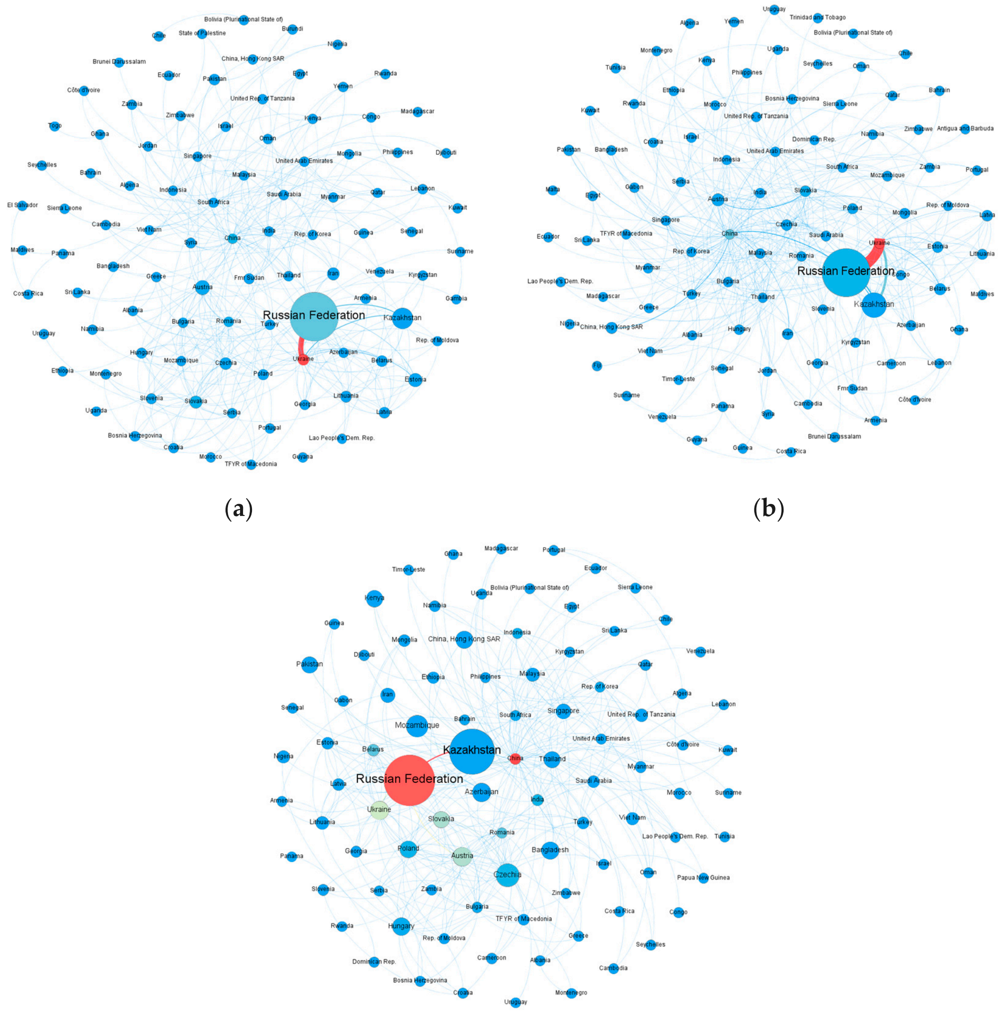
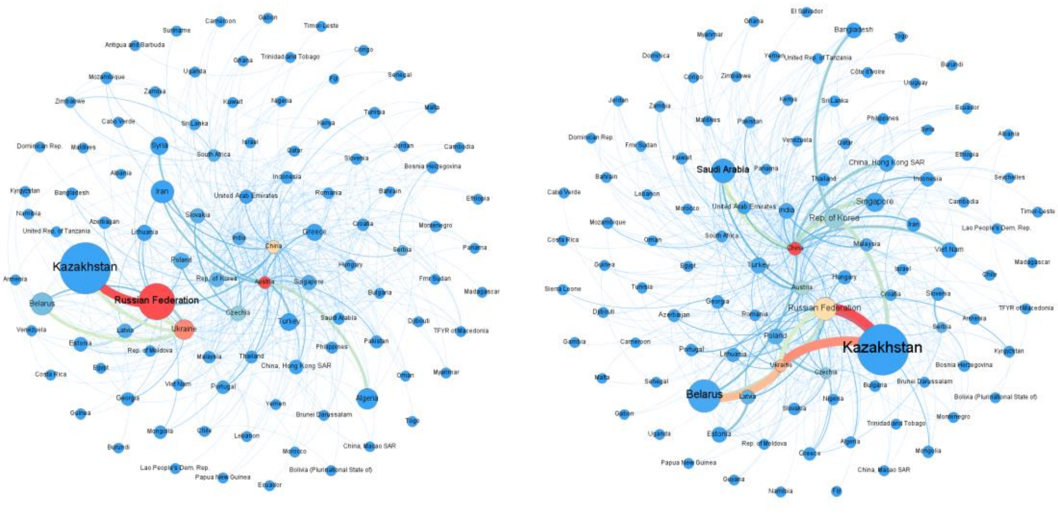
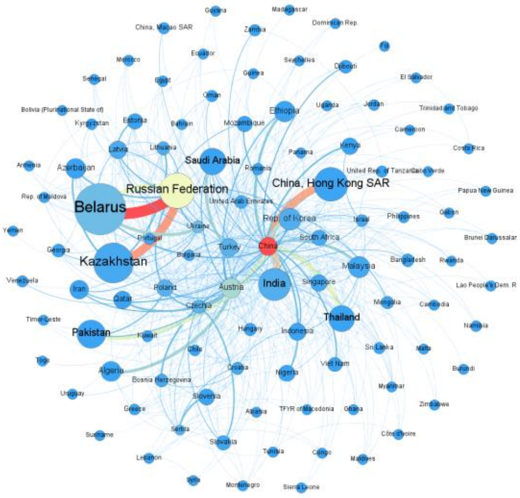


Figure A2. Trade networks of not self-propelled coaches and vans products in the BRI region. (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014–2017). The settings are the same as in Figure 7.



(**a**) (**b**)

Figure A3. *Cont*.



(c)

Figure A3. Trade networks of track fitting, signaling, and auxiliary traffic control equipment products in the BRI region. (**a**) phase 1 (2003–2008), (**b**) phase 2 (2009–2013), (**c**) phase 3 (2014–2017). The settings are the same as in Figure 7.

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