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Exploring the structure and influence factors of trade competitive advantage network along the Belt and Road

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ABSTRACT

The comparative advantage among countries determines their trade relations pattern and even regional governance mode, which has profound significance for understanding the Belt and Road (B&R) initiative. B&R has been gaining attention internationally since its proposal. This paper aims to investigate the structure and influence factors of trade competitive advantage networks of the countries along the B&R (BR-TCANs). Different from the existing literature, this paper constructs the directed trade comparative advantage index (DTCA), and establishes BR-TCANs by using the bilateral trade data in 1993–2018 collected from the United Nations Commodity Trade Statistics Database (UNCOMTRADE). Subsequently, based on complex network approach, we analyze the structure and its evolution characteristics of BR-TCANs, and then discuss the factors that influence the formation of BR-TCANs' structure by using exponential random graph models (ERGMs). The results show that there are obvious small-world and reciprocity characteristics on BR-TCANs. Both Turkey and Russia have the largest scope of trade competitive advantages, and China has the strongest intermediation ability in BR-TCANs. BR-TCANs form three communities, including the West, the North and the South. The formation of BR-TCANs is greatly influenced by popularity, clustering, reciprocity and self-reinforcing mechanism, and is manifested in the heterogeneity of GDP and FDI and in the homogeneity of population and trade openness. Countries with higher GDP, spoken language and currency advantages are more likely to establish trade competitive advantages with others. Accordingly, the BR-TCANs are embedded in the networks of common language, currency, geographic boundary and free trade agreements.

1. Introduction

China's president Jinping Xi put forward the Belt and Road (B&R) initiative in 2013, which refers to the overland Silk Road Economic Belt (The Belt) and the 21st-Century Maritime Silk Road (the Road), aims to promote the connectivity of Asian, European and African continents and their adjacent seas, establish and strengthen cooperation partnerships among the countries along the B&R, set up all-dimensional, multilayered and composite connectivity networks, and achieve the objective of diversified, independent, balanced and sustainable development in these countries. Since then, related countries have made breakthroughs in infrastructure construction, outward direct investment, production capacity cooperation and trade development. The countries along the B&R have rich energy resources, huge market potential, rapid

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economic development, and are increasingly becoming an important part of the global economic progression (Jin, 2015; Zhang, 2016) [1,2]. Recently, trading activities among the countries along the B&R, including import and export trading have increased rapidly. According to UNCOMTRADE, the total trade volume of countries along the B&R in 2017 was 13.35 trillion US dollars, accounting for about 40% of the total global trade volume, which made B&R countries a vital part of the global trade market. However, as the geographic location of countries along the B&R spread across Asia, Europe and Africa, huge differences exist among resource endowments, technology and economic development levels of these countries (Xu et al. 2015; Li & Liu, 2016; Fang & Zhao, 2018) [3–5], thereby countries along the B&R have varied trade competitive advantages in other countries' markets.

Actually, the strength of a country's trade competitive advantage is a key factor that determines whether a country can act as the "bridgehead" in international trade cooperation, which has always been the focus of academic attention. Balassa (1965) [6] was the first to propose the Revealed Comparative Advantage Index (RCA) that can be used to measure the international competitive advantage of a country's export products, and Vollratlh (1988) [7] introduced the Competitive Advantage Index (CA) to calculate the international competitive advantage of a country's export products. Other similar indicators include the trade competitiveness index (TC), market share (MR), Lafay index and the revised RCA indexes. With the improvement on the competitive advantage index system, many scholars have measured and analyzed the trade competitive advantage between countries. Peterson (1988), Hoekman et al. (1992) and Seyoum & Belay (2007) [8–10] and other researchers measured and compared the competitive advantages of different countries in terms of trade based on RCA, MR and other indicators. Du (2015) [11] analyzed the structure of merchandise being traded between China and India, and the results indicate that China has competitive advantages on labor-intensive light industrial products, machinery and transportation equipment, while India has competitive advantages on agricultural products, mineral resources, pharmaceuticals, chemicals and light industrial products. Wang & Xiao (2016) [12] analyzed China's export trade competitiveness in comparison with other countries along the B&R and found that the competitiveness of China's primary sector products in the markets of countries along the B&R has weakened or even diminished completely, while the competitiveness of secondary sector products, especially industrial products, was relatively strong. Zhao & Sang (2016) [13] studied the international competitiveness of China and the countries along the B&R in 10 sectors, and found that China's manufacturing industry has strong international competitiveness, while West Asia and CIS region have strong international competitiveness in resource intensive products. Chen et al. (2017) [14] investigated the trade competitiveness between China and the countries along the B&R. Their results indicate that although China's competitive advantage still mainly focuses on labor-intensive products, its trade competitiveness is decreasing. On the contrary, China's trade competitiveness in capital and technology-intensive products is increasing recently.

However, previous research only focused on the overall trade competitive advantages of a specific country or a group of selected countries or specific products of them. Systematic discussion on the development and evolution pattern of directed trade competitive advantage between countries from the whole and strategic levels through a scientific method is lacked. Furthermore, complex networks as a systematic scientific research method, have been widely used in the field of international trade. Snyder & Kick (1979) [15] and Smith & White (1992) [16] were the first to apply the complex network method in investigating the global structure of international trade. They believe that the international trade system has a Core–periphery structure, which established a new perspective in terms of studying the international trade pattern by applying complex network methods. Since then, numerous scholars such as Mahutga (2006) [17], Kali & Reyes (2007) [18], Garlaschelli & Loffredo (2005) [19], Serrano et al. (2007) [20], Fagiolo et al. (2008) [21], Fagiolo et al. (2009) [22], Chen (2011) [23], Dai (2012) [24], Ma et al. (2016) [25], Li et al. (2017) [26], Andrade & Rêgo (2018) [27] and Jiang et al. (2018) [28] have analyzed the overall and local structural characteristics of the international trade network. In spite of this, there are still few discussions on the competitive advantage pattern of trade between countries based on the complex network method. The trade competitive advantage relationship in the post-crisis era is no longer a simple binary relationship, but a systemic problem at the economic network level (Schweitzer et al. 2009; Battiston et al. 2010; Askari et al. 2018) [29–31], so it is necessary to systematically analyze it using complex network methods. At present, although many scholars such as Li et al. (2017) [26], Chong & Qin (2017) [32], Zhan (2018) [33] and Long et al. (2019) [34] have used the complex network method to examine the trade competition and complementary relationships between countries, they have not further analyzed the trade competitive advantage relationship between countries. Moreover, previous research applied network structure indicators to analyze its network structure and dynamic characteristics, but lack of using the effective models to empirically investigate the formation mechanism of trade competitive advantage pattern among countries.

In order to fill the gap in the literature, this paper analyzes the trade competitive advantages of countries along the B&R based on the complex network theory, and discusses the structural characteristics and the factors influencing the formation of trade competitive advantage networks of the countries along the B&R (BR-TCANs) through the network structure indicators and the application of the ERGM model. The main contributions of this paper are as follows. Firstly, we proposed the directed trade comparative advantage index (DTCA) and employed it to measure the DTCA between 62 countries along the B&R from 1993 to 2018. Secondly, based on the complex network theory, we constructed the BR-TCANs in 1993–2018, and systematically analyzed their characteristics and the role each country played in the network from the macro-countrywide, medium-community and micro-individual. Thirdly, we employed a more advanced model of ERGM to reveal the formation mechanism of BR-TCANs from the network pure structural effects, countries' attribute effects and network embedding effects.

The remainder of the paper is organized as follows. Section 2 introduces the data source and methodology of the research, including the DTCA, the construction of BR-TCANs and the corresponding indicators of the network structure. The analysis results of the structural characteristics and the evolutionary trends on BR-TCANs are discussed in Section 3. Section 4 explores the formation of BR-TCANs using the ERGMs. Conclusions and policy implications are drawn in Section 5.

2. Methodology

2.1. Directed trade competitive advantage index and BR-TCANs construction

2.1.1. Directed trade competitive advantage index (DTCA)

The Revealed Comparative Advantage Index (RCA) proposed by Balassa (1965) [6] is the most commonly used indicator for studying trade competitive advantage. This indicator is free from the constraints of various theoretical assumptions and can eliminate the influence of total amount of national trade and the fluctuation of total world trade. Therefore, it can better reflect the relative comparative advantage of a country's trade exports. Accordingly, RCA has strong practicality and is widely applied in studying trade competitiveness (Qu, 2012; Guo & Zhao, 2016) [35,36]. However, RCA can only reflect the competitive advantage of individual countries' trade in comparison with the world's average but cannot reflect the directed trade competitive advantage between countries. In order to investigate the directed trade competitive advantage between countries, the RCA is expanded into DTCA (Directed Trade Competitive Advantage Index). The calculation formula of DTCA is as follows:

$$DTCA_{ij} = \frac{X_{ij}}{\sum_i X_{ij}} \Bigg/ \frac{\sum_j X_{ij}}{\sum_i \sum_j X_{ij}} \tag{1}$$

where X_{ij} denotes the export value from country i to j, $\sum_i X_{ij}$ denotes the total exports of countries from all over the world to country j, $\sum_j X_{ij}$ denotes the total export value of country i, $\sum_i \sum_j X_{ij}$ denotes total world trade. Therefore, $DTCA_{ij}$ is in fact the ratio of the market share of export of country i in the market of country j to the market share of the total export volume of country i within the global trade market. The range of DTCA is $[0, +\infty)$, and the larger the value, the greater a country possesses trade competitive advantage in another country. The DTCA index is divided into two levels according to the practice of Balassa (1965). When $DTCA < 1.25$, the trade competitive advantage of one country in another country is weak. When $1.25 \leq DTCA$, the trade competitive advantage of one country in another country is strong.

2.1.2. BR-TCANs construction

We construct the BR-TCANs of 62 countries (see Appendix Table A.1) along the B&R[1] using the data collected from the UNCOMTRADE in 1993–2018. First, we construct the trade matrix $\mathbf{M}_t = [m_{ij}]_t (i \in \mathbf{V}_i, j \in \mathbf{V}_j, i \neq j)$ by making the vector $\mathbf{V}_i$ as exporters, the vector $\mathbf{V}_j$ as importers and m_{ij} represent the trade volume from country $\mathbf{V}_i$ to $\mathbf{V}_j$. Then according to Eq. (1), the DTCA between countries along the B&R is calculated and the matrix $\mathbf{W}_t = [w_{ij}]_t (i \in N, j \in N, i \neq j)$ is obtained. Following the complex network theory, the BR-TCANs are constructed by making the exporting country as the starting node represented by the vector $\mathbf{V}_i = (v_1, v_2, \ldots, v_n)$, making the trade importing country as the destination node represented by vector $\mathbf{V}_j = (v_1, v_2, \ldots, v_n)$ and using the weight matrix $\mathbf{W}_t = [w_{ij}]_t (i \in N, j \in N, i \neq j)$ to represent the weighted edge between $\mathbf{V}_i$ and $\mathbf{V}_j$, and the w_{ij} is the DTCA from country $\mathbf{V}_i$ to country $\mathbf{V}_j$. Thus, $\mathbf{V}_i$, $\mathbf{V}_j$ and $\mathbf{W}$ constitute the directed-weighted BR-TCANs. When $w_{ij} > 1.25$, the number of edges in the BR-TCANs only retains 20% of the total the number of edges, but these edges make up 85% of the total trade competitive advantage weight, which plays an important role in the network. Consequently, the threshold $w_{ij} > 1.25$ is set for the weighted edges of the BR-TCANs. In the remainder of this paper, the BR-TCANs of $w_{ij} > 1.25$ is used to investigate the network structure during 1993–2018, and the BR-TCAN in 2018 is shown in Fig. A.1 of Appendix.

2.2. Corresponding indicators of network structure

The BR-TCANs clearly show different structures over time, which can be described by the following indexes.

2.2.1. Density

The density indicates the tightness of the connection between the countries in the BR-TCANs. The higher the number of edges between countries, the greater the density is. It is defined as follows:

$$Density = \frac{M}{N(N-1)} \tag{2}$$

where M represents the number of edges and N denotes the number of countries in the BR-TCANs.

[1] These are 65 countries along the B&R, but because of the territorial disputes and missing data of Montenegro, Serbia and Palestine, they were excluded, leaving only 62 other countries as the research object in this paper.

2.2.2. Average path length and diameter

The average path length (*APL*) is defined as the average number of steps of the shortest paths for all possible pairs of countries in the BR-TCANs. The maximum path length for all pairs of nodes is the diameter of network. Thus, the average path length and diameter are defined as follows:

$$APL = \frac{1}{N(N-1)} \sum_{i \geq j} d_{ij}, Diameter = \max_{i,j} d_{ij} \tag{3}$$

where N denotes the number of countries in BR-TCANs, and d_{ij} denotes the shortest geodesic distance between country i and j.

2.2.3. Average clustering coefficient

The average clustering coefficient ($\overline{C}$) is the mean of the clustering coefficients of all the countries in the sample. The larger the value, the stronger the agglomeration effect is in network. The average clustering coefficient is defined as follows:

$$\overline{C} = \frac{1}{N} \sum_{i=1}^{N} C_i \tag{4}$$

where $C_i = \frac{E_i}{k_i(k_i-1)}$ represents the clustering coefficient of country i, the k_i denotes the degree of country i, and the E_i indicates the number of competitive advantage relationships between neighboring of country i in the network.

2.2.4. Reciprocity

Reciprocity is applied to measure the tendency of node-pairs to form mutual connections with each other. The reciprocity is measured by the reciprocity coefficient. The larger the value, the more reciprocal relationships are in the BR-TCANs. It is defined as follows:

$$reciprocity = \frac{\sum_{i \neq j}(w_{ij} - w)(w_{ji} - w)}{\sum_{i \neq j}(w_{ij} - w)^2} \tag{5}$$

where w_{ij} denotes the weighted-edges from country i to j. $w = \frac{\sum_{i \neq j} w_{ij}}{M(M-1)}$ denotes the mean of edges w_{ij} in all directed edges, and M is the number of edges in network.

2.2.5. Normalized mutual information

Normalized mutual information (NMI) is used to measure the stability of the community structure within the network of over time by comparing members within the community in different years. The larger the value, the more stable the community structure of the network is. It is defined as follows:

$$NMI_{(t,t+1)} = \frac{\sum_{h=1}^{k^t} \sum_{l=1}^{k^{t+1}} n_{h,l} \log(\frac{n.n_{h,l}}{n_h^t n_l^{t+1}})}{\sqrt{\left(\sum_{h=1}^{k^t} n_h^t \log \frac{n_h^t}{n}\right)\left(\sum_{l=1}^{k^{t+1}} n_l^{t+1} \log \frac{n_l^{t+1}}{n}\right)}} \tag{6}$$

Here n_h^t indicates the number of countries in community h at time t, n_l^{t+1} indicates the number of countries in the community l at time $t+1$, $n_{h,l}$ denotes the number of countries that are in community h at time t and move to community l at time $t+1$, n denotes the number of countries in the network at time t.

2.2.6. Degree centrality

Degree centrality is the most direct indicator for describing the importance of each node in a network, which is used to describe the scope of direct contact of a country with others. The degree centrality can be divided into out-degree centrality and in-degree centrality in the directed network. The higher the out-degree or in-degree centrality of a country, the greater the scope of export or import competitive advantage in BR-TCANs is. Degree centrality is defined as follows:

$$D_i^{out} = \frac{\sum_{j=1}^{N} a_{ij}^{out}}{N-1}, \; D_i^{in} = \frac{\sum_{j=1}^{N} a_{ji}^{in}}{N-1} \tag{7}$$

where N denotes the number of countries in BR-TCANs, a_{ij} is the adjacency matrix corresponding to BR-TCANs. $a_{ij} = 1$ if there is an edge between country i and j, $a_{ij} = 0$ otherwise.

2.2.7. Betweenness centrality

Betweenness centrality measures the extent that a country is located in the middle of other country-pairs in BR-TCANs, which reflects a country's ability of controlling other country-pairs. Thus, the higher the value of a country, the greater that country is able to control and coordinate the trading of other country-pairs in BR-TCANs. It is defined as follow:

$$B_i = \sum_{j,l} \frac{N_{jl}(i)}{N_{jl}}, j \neq l \neq i \tag{8}$$

where N_{jl} is the shortest path length between country j and l, $N_{jl}(i)$ represents the shortest path length between country j and l through the country i.

3. Structure characteristics of BR-TCANs

3.1. Overall network structure

The number of countries and edges, density, average clustering coefficient, average path length, diameter and reciprocity coefficient of the network can be used to depict features of the overall network structure. Table 1 presents the results from 1993 to 2018. We get the following conclusions by analyzing the result presented in Table 1.

Firstly, Table 1 shows that when the number of countries is fixed, the number of edges and density of the BR-TCANs are approximately 620 and 0.165, respectively. More, they show the characteristics of the overall stability and partial fluctuations with a narrow range are shown in Table 1 as well. These indicate that the size of the BR-TCANs is relatively small, but there is huge potential of trade cooperation between countries in the future. Simultaneously, the size of the BR-TCANs has little variation during 1993–2018, but it shows certain fluctuation adjustment over the years, especially in 2008 and 2011 due to the impact of the financial crisis in 2008 and the European debt crisis in 2011. Therefore, countries along the B&R should further strengthen cooperation to stimulate huge potential of trade and cope with the impact of global economic fluctuations.

Secondly, the average path length and diameter are approximately 3 and 5 respectively, which implies that the average number of steps is 3 and the maximum number of steps is 5 for each country-pair that has established trade competitive advantages relations. In other words, any two countries are capable of establishing trade competitive advantages relationship if there are two "bridge" countries between them in BR-TCANs, and indirect competitive advantage trade relations between countries require up to 4 "bridge" countries at most. Therefore, the distance between any two countries is small in BR-TCAs. In addition, the average clustering coefficient is approximately 0.46 and has an upward trend, which indicates that BR-TCANs exhibits the characteristics of clustering and the competitive advantages trade relationships between trading countries has become increasingly close. Generally, if a network is highly clustered and has a small average path length, it is called a small-world network. Regarding the results, the BR-TCANs display the obvious features of a small-world network.

Thirdly, the reciprocity coefficient of BR-TCANs during the period 1993–2018 is calculated. It shows that the average value of reciprocal coefficient of BR-TCANs is 0.425, and it fluctuates around 0.45 in 1993–2010. Affected by the European debt crisis in 2011, the reciprocity coefficient shows a sharp decline in 2011, but the value is still above 0.341. This indicates that there is reciprocity in trade competitive advantage relationships in the BR-TCANs. The products of one country have comparative advantages in the market of another country, and the products of another country are also likely to be competitive in the market of that country.

3.2. Community structure

In a network, different communities will be formed due to the different strength and tightness of trade competitive advantage relations. Exploring the relationships in the intra-community and inter-community can intuitively reflect the faction in network (Xu & Sun, 2015) [3] and can help discover the topology of some hidden functions (Barigozzi et al. 2011) [37]. The community detection is a good method for exploring the aggregation of nodes in network. It helps reveal and portray the composition and structure of communities, and analyze the relationships in the intra-community and inter-community. This paper uses the Spinglass community detection algorithm to divide BR-TCANs in 1993–2018 (Reichardt & Bornholdt, 2006) [38]. Due to the length limitation of this paper, we only report the results in 1993, 2005 and 2018 (Fig. 1).

First, the results show that the community structure of BR-TCANs exposes the phenomenon of geographic area assembly. We find that BR-TCANs gradually form three communities over the years: The West, the North and the South. The connections in intra-community are closer, and in inter-community are relatively sparse. Specifically, the West community contains Czech, Romania and other European countries, the North community contains Russian, Ukraine and other central and north Asian countries, and the South community is consisted of China, United Arab Emirates and other Southeast and West Asia countries. Second, we calculate NMI and further analyze the stability of BR-TCANs community structure over the years (Fig. 2). The result shows that BR-TCANs community structure changes over time, and the evolution of community structure experiences four stages. The first stage is 1993–1997, during which the three communities of BR-TCANs are basically formed after the separation, reorganization and adjustment of the community

Table 1
Descriptive statistics regarding the BR-TCANs in 1993–2018.

Year	Nodes	Edges	Density	Diameter	APL	$\overline{C}$	Reciprocity
1993	62	547	0.145	5	2.244	0.334	0.428
1994	62	611	0.162	4	2.256	0.386	0.469
1995	62	655	0.173	5	2.205	0.393	0.472
1996	62	626	0.166	4	2.214	0.441	0.449
1997	62	634	0.168	5	2.208	0.434	0.418
1998	62	660	0.175	5	2.182	0.467	0.413
1999	62	655	0.173	5	2.223	0.483	0.459
2000	62	675	0.178	5	2.240	0.502	0.424
2001	62	654	0.173	4	2.225	0.486	0.397
2002	62	664	0.176	5	2.225	0.494	0.447
2003	62	650	0.172	5	2.240	0.489	0.451
2004	62	664	0.176	4	2.200	0.498	0.419
2005	62	641	0.169	4	2.245	0.490	0.409
2006	62	635	0.168	5	2.245	0.483	0.440
2007	62	636	0.168	4	2.239	0.470	0.445
2008	62	602	0.159	4	2.307	0.468	0.423
2009	62	628	0.166	5	2.269	0.474	0.457
2010	62	648	0.171	4	2.206	0.481	0.459
2011	62	609	0.161	4	2.192	0.448	0.341
2012	62	627	0.166	5	2.206	0.472	0.363
2013	62	607	0.160	5	2.242	0.464	0.364
2014	62	613	0.162	4	2.218	0.461	0.365
2015	62	569	0.150	5	2.267	0.467	0.408
2016	62	553	0.146	4	2.277	0.462	0.433
2017	62	556	0.147	5	2.241	0.477	0.455
2018	62	512	0.135	5	2.303	0.466	0.438

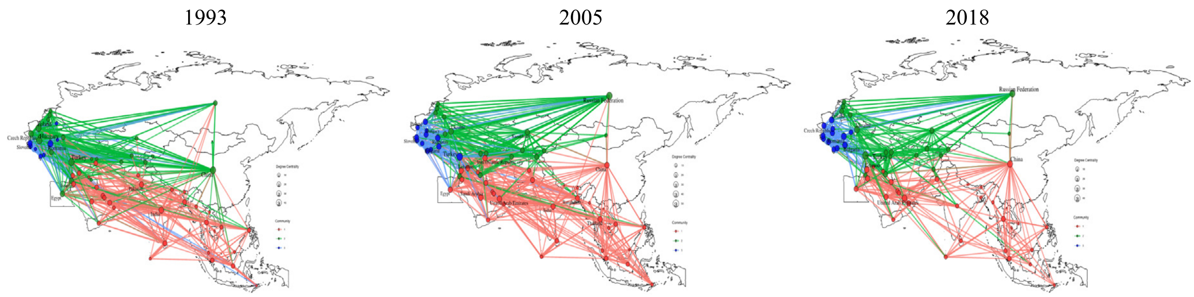


Fig. 1. Community Structure of BR-TCANs in 1993–2018. *Note*: The size of the nodes is proportional to degree centrality and the width of the edges is proportional to DTCA.

structure and 1997 Asian financial crisis. The second stage is 1997–2007, during which countries further consolidate the trade competitive advantage relationship in countries along BR after 1997 Asian financial crisis. While with the development of economic globalization, countries have actively expanded their trade competitive advantage markets, and its pattern shows certain fluctuations and adjustments. The third stage is 2007–2013. Affected by the global financial crisis in 2008, the community structure of BR-TCANs underwent a round of reshuffle on 2008 and its community pattern unstable in subsequent years. The fourth stage is 2013–2018. Since the BR initiative was put forward in 2013, BR-TCANs pattern has been basically stable. The community patterns only slightly adjusted in 2017 and 2018 due to the Belt & Road forum for international cooperation.

3.3. Node centrality

This paper calculates the degree centrality and betweenness centrality of the BR-TCANs according to Eqs. (7) and (8). The results are presented in Table 2. Turkey and Russia are constantly ranked within the top three in terms of out-degree centrality and in-degree centrality in BR-TCANs. This indicates that Turkey and Russia are at the core in the BR-TCANs, and they have the largest number of export trade competitive advantage markets along the B&R as well as the competitive advantage market of the most countries along the B&R export. Moreover, China's out-degree centrality and in-degree centrality are significantly smaller than those of Turkey and Russia, and the rankings of China's out-degree and in-degree centrality in the BR-TACNs vary significantly. The results imply that China's scope of trade competitive advantage is smaller in comparison with Turkey or Russia. There is greater instability in the trade competitive advantage relationships with countries along the B&R.

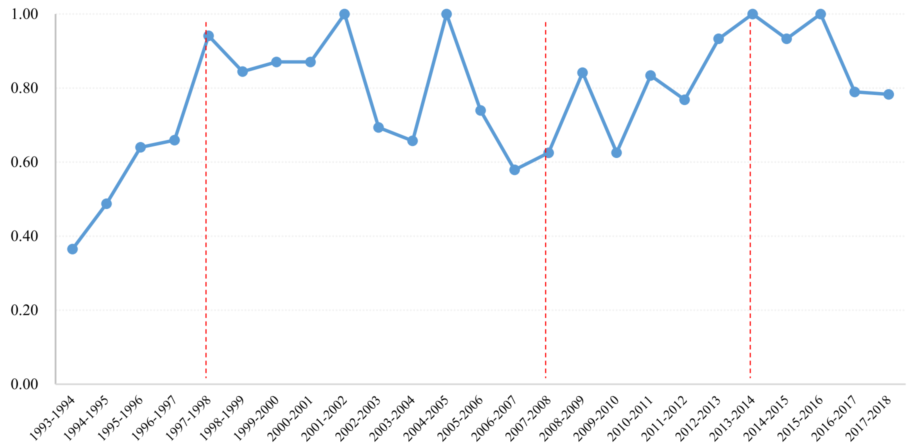


Fig. 2. NMI and community stability of BR-TCAN in 1993–2018.

Table 2
The top 3 countries of node centrality in BR-TCANs in 1993–2018.

	1993	2000	2005	2010	2014	2018
Out-degree centrality						
1	HUN,TUR (0.443)	TUR (0.459)	TUR (0.508)	TUR (0.475)	TUR (0.475)	TUR (0.443)
2	CHN (0.393)	RUS (0.393)	RUS (0.410)	RUS (0.377)	RUS (0.361)	CHN, ARE, UKR (0.344)
3	POL (0.377)	CHN, UKR (0.361)	UKR (0.344)	BGR,ROM,UKR,EGY (0.295)	UKR (0.328)	RUS (0.328)
In-degree centrality						
1	HUN,TUR (0.361)	RUS (0.361)	RUS (0.361)	RUS (0.393)	RUS (0.393)	TUR (0.295)
2	POL (0.344)	TUR (0.328)	TUR (0.328)	TUR (0.377)	TUR (0.328)	BGR, ROM, RUS (0.262)
3	CHN,ROM (0.328)	THA, EGY (0.295)	ROM,THA (0.279)	IND (0.360)	BGR (0.311)	CHN, POL (0.230)
Betweenness centrality						
1	CHN (0.224)	CHN (0.202)	CHN (0.226)	CHN (0.231)	CHN (0.255)	CHN (0.280)
2	HUN (0.108)	TUR (0.143)	THA (0.129)	IND (0.101)	IND (0.115)	TUR (0.147)
3	IND (0.094)	THA (0.107)	TUR (0.127)	TUR (0.097)	RUS (0.104)	RUS (0.119)

Note: The number in brackets is the nodes centricity score.

In terms of betweenness centrality, China, Thailand, and Turkey are ranked as the top three during the sample period, and China is always ranked top 1 in the BR-TACNs. This reflects that China has an obvious intermediary advantage of acting as "bridge" in the BR-TACNs, and has the power to exert a huge influence on increasing other countries participation in the development of trading along the B&R and plays an important role in promoting economic and trade relations and governing international economics of all countries along the B&R.

4. The analysis of factors affecting formation of the BR-TCANs

4.1. ERGM conceptualization

Different from the traditional econometric model which is based on the attribute data and independence of individuals, the ERGM is a statistical inference model that analyzes the formation of network based on the relational data, local network structure and relational interdependence (Cranmer et al. 2012; Cranmer et al. 2017; Silk et al. 2017) [39–41], and is considered as one of the effective tools for empirical analysis of relevant theories of network science (Contractor et al. 2006) [42].

For each country-pair i and j of a set N of 62 countries, Y_{ij} is a network edge variable with $Y_{ij} = 1$ if there is an edge from country i to j, and $Y_{ij} = 0$ otherwise. We specify y_{ij} as the observed value of Y_{ij}, $\boldsymbol{Y}$ as the matrix of all Y_{ij} and $\boldsymbol{y}$ as the matrix of all observed y_{ij}, and $\boldsymbol{y}$ is the subset of the set $\boldsymbol{Y}$. The principle of ERGM model is to predict the probability of occurring $\boldsymbol{y}$ in $\boldsymbol{Y}$ with the given θ, whose mathematical expression is $\Pr(\mathbf{Y} = \mathbf{y}|\theta)$. According to Robins et al. (2007) [43], the general form of the ERGM is as follows:

$$pr(\mathbf{Y} = y|\theta) = (\frac{1}{\kappa})\exp(\sum_{H}\theta_H^T g_H(y)) \tag{9}$$

where κ is the normalizing quantity to ensure that Eq. (9) is a proper probability distribution. H stands for all factors that may affect the formation of a network, generally including the endogenous types factor α (Robins et al. 2007) [43], the countries' attributes types factor β (Wang et al. 2016) [44], and other external network types factor γ (Snijders, 2002) [45], and $\alpha, \beta, \gamma \in H$. Therefore, the ERGM can be further refined to:

$$\Pr(Y = y|\theta) = \frac{1}{\kappa(\theta)} \exp\{\theta_\alpha^T g_\alpha(y) + \theta_\beta^T g_\beta(y, X) + \theta_\gamma^T g_\gamma(y, Z)\} \tag{10}$$

In Eq. (10), the items represent the three types of network structure statistics that affect network generation. $g_\alpha(y)$ is the network statistic corresponding to endogenous network structural configurations including the number of ties and the number of triangles and so on, which captures the pure structural effects of network formation; $g_\beta(y, X)$ is the network statistic corresponding to the country attributes X, which tests the country attribute effects of network formation; $g_\gamma(y, Z)$ is the network statistic corresponding to the other network Z, examining the network embedding effects of a network formation. The θ_α^T, θ_β^T and θ_γ^T represent the estimated parameter vectors of the three network structure statistics, respectively. These parameters passed the significance test, indicating that the network structure statistics have a significant impact on the formation of network. The estimated value of the parameter is positive, which indicates that the probability of this structure in the network is greater than the random expectation under other conditions. At present, the Markov Chain Monte Carlo Maximum Likelihood Estimation (MCMC MLE) is used to estimate and test the parameters of the model. In addition, the most fit and parsimonious model can be selected through the application of the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), and the model with smaller AIC and BIC is the best ERGM. The goodness-of-fit (GOF) of the ERGM is used to evaluate the fitting ERGM. The ***statnet*** package in R is used to estimate the ERGM in this paper.

4.2. Variables and network effects

4.2.1. Pure structural effects

In some situations, network relationships can spontaneously promote the formation of other relationships, and gradually form an ordered network structure through accumulation. This effect is known as the pure structure effect (Robins, 2007) [43]. For BR-TCANs, the results obtained in Section 3.1 indicate that the BR-TCANs have the characteristics of reciprocity and small-world. Thus, the reciprocity, popularity, diffusivity and clustering are examined for the formation of BR-TCANs, and the items of mutual, gwidegree, gwodegree, gwesp and gwdsp are included in ERGM. Among them, gwidegree, gwodegree, gwesp and gwdsp are geometrically weighted in-degree, geometrically weighted out-degree, geometrically weighted edgewise shared partner distribution and geometrically weighted dyadwise shared partner distribution, respectively.

4.2.2. Country attribute effects

A country's attributions such as resource endowments and advantages will affect its behavior and formation of a network (Andrade & Rêgo, 2018) [27]. This effect is called the country attribute effect (Kilduff & Krackhardt, 2008) [46]. For the formation of BR-TCANs, the country attribute effects mainly are homophily and Matthew effect. Homophily is that countries with the same characteristics are likely to establish relationships (Lazarsfeld & Merton, 1954) [47], and the Matthew effect refers to the phenomenon that the strong get stronger and the weak get weaker (Boeren, 2009) [48].

The homophily of countries' attributes play a key role in the formation of BR-TCANs. Studies by Garlaschelli & Loffredo (2004, 2005) [49,50] and Wu (2014) [51] show that countries' population and GDP determines the topological structure of the international trade relations network, and countries with similar population and GDP are likely to form trade competitive advantage relation as the similar demand for goods. Furthermore, trade openness can accelerate the development of domestic technological progress, improve productivity and enhance a country's competitiveness in the international market (Romer, 1986; Zhuang et al. 2005) [52,53]. In addition, foreign direct investment has technology spillover effects, which has an important impact on the development of trade and its international competitiveness. Due to the symmetrical market and welfare, countries with similar level of trade openness and foreign direct investment are more likely to build trade competitive advantage relations.

What is more, a country with a stronger attribute tends to establish trade competitive advantage relations with others. Generally speaking, countries with higher GDP have higher productivity and lower goods price. These advantages are conducive to their expansion into the international market, so that they occupy a stronger competitive advantage in the market of more countries. In addition, a country with a higher centrality in networks such as language, free trade agreements, country borders and common currency is mostly at the core of the network and has external trade advantages. This makes it easier for the country to establish a competitive advantage in more countries' markets. More importantly, countries with higher centrality in BR-TCANs tend to form competitive advantage relations with others because of self-reinforcing mechanism.

In order to test homophily of population, economic development, degree of openness and FDI on the formation of BR-TCANs, we use the number of population (POP), GDP, trade openness index (TO) and net inflow of foreign direct investment (FDI) to represent population, economic development, degree of openness and FDI respectively, which come from World bank database (see Appendix Table A.2), and the terms of Homophily (POP), Homophily (GDP), Homophily (TO) and Homophily (FDI) are included in ERGM. What is more, for the Matthew effect of economic development and external trade advantages, the terms of Nodecov (GDP), Nodecov (dCOL), Nodecov (dCSL), Nodecov (dFTA), Nodecov (dCGB), Nodecov (dCCN), Nodecov (dBR-TCAN) are contained in ERGM. Among them, dCOL, dCSL, dFTA, dCGB, dCCN and dBR-TCAN are the degree centrality (d) of common official language (COL), common spoken language (CSL), free trade agreement network (FTA), common geographic boundary network (CGB), common currency network (CCN) and BR-TCANs.

4.2.3. Network embedding effects

In addition to the influence of pure structural effect and country attribute effect, the formation of BR-TCANs is also affected by external binary relations, i.e., common cultural relations and free trade agreement relations. It is called external network embedding effect (Granovetter, 1984; Park, 2015) [54,55] as this external binary relationships show the associated characteristics of BR-TCANs. Spatial proximity between countries is an important factor affecting trade relations (Anderson & Wincoop, 2003; Chaney, 2014) [56,57]. Generally speaking, if the country-pair is neighbors geographically, the transportation cost of trade between the two countries is lower, and the market information is more accessible, the possibility of establishing a competitive trade relationship between the two countries is higher.

The free trade agreement has become a major issue that cannot be omitted and has high priority in terms of international economic and trade relations in the 21st century (Anderson & Yotov, 2016) [58]. Signing a formal free trade agreement can enable a country to greatly reduce the tariff of transnational trade, and lead to the reduction of price of goods in the destination market. This is helpful for exporters to further improve their competitiveness in destination market and build trade competitive advantage relations. What is more, sovereign monies are important national barriers to trade (Rose & Wincoop, 2001) [59]. A country sharing a common currency can boost its trade, and then affect its trade competitiveness in different countries. Thus, a pair of countries using a common currency is more likely to build a trade competitive advantage relationships.

Besides geospatial factor, free trade agreement and currency, cultural similarity is also an important factor affecting trade relations between countries (Lewer & Berg, 2007) [60]. Generally speaking, the greater the cultural similarity between two countries, the greater the possibility of building competitive trade relationships as the reducing of hidden transaction cost, moral hazard and uncertainties. Specifically, language, as a core component of culture and a concrete manifestation of cultural connotation, can directly affect the trade relations in the way of communication. Thus, we use common official language (COL) and common spoken language (CSL) as a proxy for culture to examine the influence of culture on the formation of BR-TCANs.

In order to test the network embedding effects of geospatial factor, free trade agreement, currency and culture on the formation of BR-TCANs, we use common geographic boundary network (CGB), free trade agreement network (FTA), common currency network (CCN), common official language (COL) and common spoken language (CSL) to describe dyad geographic relations, free trade agreements, currency, and culture between countries, which come from CEPII, and the Edgecov (CGB), Edgecov (FTA), Edgecov (CGB), Edgecov (COL) and Edgecov (CSL) are included in ERGM. The ERGM structure statistic variables are presented in Table 3.

4.3. ERGM results

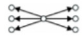
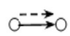
Table 4 reports the results of ERGM for cross-sectional BR-TCAN in 2018. In Model 1-Model 4, we add statistics of network embedding effects, homophily, Matthew effect and pure structural effects to the ERGM step by step. Comparing the results of Model 1 to Model 4, we find that the coefficients of Model 4 are significant with the smallest AIC and BIC. In order to further test the ability of Model 4 to explain the formation of BR-TCANs, we assess the goodness-of-fit of Model 4 by comparing the network structure statistics of model-based simulations network with observed BR-TCAN. As shown in Fig. 3, the statistics of Edge-wise shared partners, in degree, out degree and triad census are plotted, and the distribution of these statistics is close between the observed network and the simulated network. This means that Model 4 can capture the key mechanism of the formation of BR-TCANs. Thus, we select the model 4 as the most optimal and parsimonious ERGM to model the formation of BR-TCANs.

In order to further test the dynamic influence effect of the network structure, we calculate the ERGM estimated results of cross-sectional BR-TCANs in 1993, 2000, 2005, 2010 and 2018 using Model 4 as the baseline, and the results are presented in Table 5. Firstly, in terms of endogenous structural effects, the coefficients of gwidegree, gwesp and mutual are significantly positive at the level of 0.1% over the years, and the results are robust. This indicates that the popularity, clustering and reciprocity play important roles in the evolution of BR-TCANs. Compared with gwidegree, gwesp and mutual, the coefficients of gwdsp are significantly negative and gwdsp is not robust, reflecting the diffusivity is weak in the formation of BR-TCANs.

Secondly, there are country attribute effects in the formation and evolution of BR-TCANs. For the homophily, the coefficient of Homophily (POP) is significantly positive at the level of 0.1%, indicating that the formation of BR-TCANs shows homophily in population. That is to say, country-pair with similar population is easier to form trade competitive advantage relationship. The coefficients of Homophily (GDP) and Homophily (FDI) are significantly negative at the level of 0.1% in most year, reflecting that the formation of BR-TCANs shows heterophily in GDP and FDI. The possible reason is that the greater difference in GDP and FDI, the stronger the complementarity of their trade and economic development. Thus there is higher possibility to form trade competitive advantage relationships. Moreover, the coefficient of Homophily (TO) is significantly negative first before 2010 and then becomes significantly positive after 2010, indicating that there is trade openness heterophily in formation of BR-TCANs first and then gradually manifested as the homophily after 2010. The possible explanation is that due to the impact of the financial crisis, trade protectionism is on the rise, which makes it easier for countries with a similar trade openness are more likely to build trade competitive advantage relationships as the symmetrical market and welfare.

For the Matthew effect, the coefficient of Nodecov (GDP) is positive and statistically significant at the level of 1% in most years, which indicates that there is economic Matthew effect in the formation of BR-TCANs, countries with higher GDP

Table 3
ERGM structure statistic variables.

Classify	Variable symbol	Variable name	Configuration	Statistics	Terms in *statnet*
Constant term	edges	edges		$\sum y_{ij}$	edges
Pure Structural Effect	mutual	Reciprocity		$\sum_{i,j} y_{ij} y_{ji}$	mutual
	GW indegree	Geometrically weighted in-degree		$\sum_{k=2}^{N-1} (-1)^k \frac{S_k^i(y)}{\lambda^{k-2}}$	gwidegree
	GW outdegree	Geometrically weighted out-degree		$\sum_{k=2}^{N-1} (-1)^k \frac{S_k^o(y)}{\lambda^{k-2}}$	gwodegree
	Gwesp	Geometrically weighted edgewise shared partner distribution		$\sum_{i,j,k} y_{ij} y_{jk} y_{ik}$	gwesp
	Gwdsp	Geometrically weighted dyadwise shared partner distribution		$\sum_{i,j,k} y_{ij} y_{jk}$	gwdsp
Country Attribute Effect	Homophily(x)	Homophily effect		$\sum_{i,j} y_{ij} x_i x_j$	Homophily(POP) Homophily(GDP) Homophily(TO) Homophily(FDI)
	Nodecov(x)	Matthew effect		$\sum_{i,j} x_i y_{ij}$	Nodecov(GDP) Nodecov(dCOL) Nodecov(dCSL) Nodecov(dFTA) Nodecov(dCGB) Nodecov(dCCN) Nodecov(dBR-TCAN)
Network Embedding Effect	Edgecov(g)	Embedding effect		$\sum_{i,j} y_{ij} g_{ij}$	Edgecov(CGB) Edgecov(FTA) Edgecov(CCN) Edgecov(COL) Edgecov(CSL)

have stronger driver to form trade competitive advantage in others because of their huge capacity and market demand. The coefficient of Nodecov (GDP) is small and the effect on the formation of BR-TCANs is relatively not obvious. In terms of external trade advantages, only the coefficients of Nodecov (dCSL) and Nodecov (dCCN) are significantly positive, and the coefficients of Nodecov (dCOL), Nodecov (dFTA) and Nodecov (dCGB) are negative. The results show that countries with spoken language and currency advantages are more likely to establish trade competitive advantages with other countries along the Belt and Road. The advantages of having more FTA partners and neighbors do not promote the establishment of competitive advantage relations between countries. In addition, the Nodecov (dBR-TCAN) has a significantly positive coefficient, which indicates that there is an obvious self-reinforcing mechanism in the formation of BR-TCANs.

Finally, for the network embedding effects, the coefficients of Edgecov (COL), Edgecov (CSL), Edgecov (FTA), Edgecov (CGB) and Edgecov (CCN) are significantly positive at the level of 0.1% except for individual years, indicating that BR-TCAN is embedded in the network of language, free trade agreements, geospatial proximity and common currency. In other words, there is higher possibility to form a trade competitive advantage relationship between two countries when they use a common language and currency, sign a free trade agreement and are geographically close. For the magnitude of these coefficients over the years, the coefficient of Edgecov (COL) decreases and the gap with the coefficient of Edgecov (COL) is shrinking. The possible explanation is that having a common official language has a strong promotion on the establishment of trade competitive advantage relationships. However, due to the exchange and dissemination of culture and the increasing opportunities for people to communicate face to face, people pay more attention to the commonality and intimacy of oral communication, so that a widely used common spoken language can significantly promote trade competitive advantage in other country markets. In addition, the coefficient of Edgecov (FTA) and Edgecov (CCN) shows a downward trend, and the coefficient of Edgecov (CGB) increases first then decreases in 1993–2018. Comparing the coefficients, it shows that the BR-TCANs is the strongest embedded in the network of CGB and FTA, followed by CCN, COL and CSL.

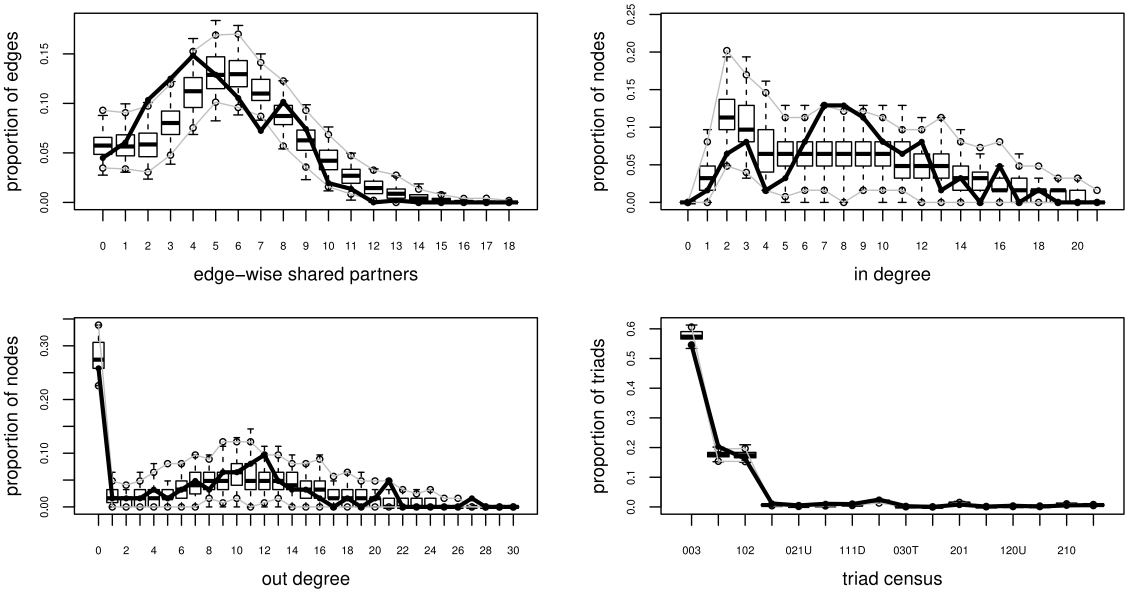


Fig. 3. The goodness-of-fit assessment of ERGM for BR-TCAN in 2018.

Table 4
ERGM estimated results for BR-TCAN in 2018.

	Model 1	Model 2	Model 3	Model 4
Pure structural effect				
edges	−2.770(0.076)***	−2.770(0.098)***	−4.574(0.287)***	−2.544(0.030)***
gwidegree				5.825(0.004)***
gwodegree				−3.977(0.040)***
gwesp				0.347(0.008)***
gwdsp				−0.279(0.001)***
mutual				1.952(0.015)***
Country attribute effect				
Homophily (POP)		−0.051(0.120)	0.048(0.131)	0.065(0.011)***
Homophily (GDP)		0.131(0.128)	−0.051(0.148)	−0.078(0.012)***
Homophily (FDI)		−0.183(0.127)	−0.124(0.144)	−0.175(0.012)***
Homophily (OPEN)		0.084(0.116)	0.123(0.127)	0.083(0.011)***
Nodecov (GDP)			0.0000003(0.000)	0.0000001(0.000)***
Nodecov (dCOL)			−0.077(0.026)**	−0.026(0.000)***
Nodecov (dCSL)			0.023(0.019)	0.017(0.000)***
Nodecov (dFTA)			−0.051(0.008)***	−0.036(0.000)***
Nodecov (dCGB)			−0.108(0.026)***	−0.058(0.002)***
Nodecov (dCCN)			0.025(0.100)	0.157(0.008)***
Nodecov (dBR-TCAN)			0.101(0.006)***	0.049(0.000)***
Network embedding effect				
Edgecov (CCN)	−0.056(0.750)	−0.064(0.748)	0.518(0.811)	−0.287(0.007)***
Edgecov (COL)	0.560(0.327)	0.523(0.329)	1.210(0.410)**	0.331(0.042)***
Edgecov (CSL)	0.245(0.285)	0.265(0.286)	0.683(0.339)*	0.234(0.035)***
Edgecov (FTA)	1.842(0.116)***	1.862(0.118)***	2.055(0.154)***	0.851(0.015)***
Edgecov (CGB)	2.169(0.170)***	2.149(0.172)***	2.270(0.209)***	1.940 (0.030)***
AIC	2344	2349	1930	1688
BIC	2381	2411	2036	1825

Note:
*Significant at 5%.
**Significant at 1%.
***Significant at 0.1%.

Table 5
ERGM estimated results for the BR-TCANs in 1993, 2000, 2005, 2010 and 2018.

	1993	2000	2005	2010	2018
Pure structural effect					
edges	−4.381(0.009)***	−2.559(0.028)***	−4.189(0.023)***	−4.335(0.033)***	−2.544(0.030)***
gwidegree	4.192(0.038)***	6.840(0.132)***	7.050(0.000)***	10.850(0.002)***	5.825(0.004)***
gwodegree	1.489(0.021)***	2.008(0.074)***	5.358(0.006)***	3.703(0.002)***	−3.977(0.040)***
gwesp	0.322(0.003)***	0.073(0.008)***	0.933(0.008)***	0.615(0.013)***	0.347(0.008)***
gwdsp	−0.125(0.000)***	−0.237(0.002)***	−0.194(0.001)***	−0.229(0.003)***	−0.279(0.001)***
mutual	2.010(0.005)***	1.575(0.009)***	1.200(0.009)***	1.458(0.008)***	1.952(0.015)***
Country attribute effect					
Homophily (POP)	0.113(0.004)***	−0.046(0.009)***	0.104(0.008)***	0.041(0.008)***	0.065(0.011)***
Homophily (GDP)	−0.551(0.004)***	−0.033(0.009)***	−0.101(0.008)***	0.054(0.009)***	−0.078(0.012)***
Homophily (FDI)	−0.049(0.004)***	0.029(0.008)***	−0.052(0.008)***	−0.329(0.009)***	−0.175(0.012)***
Homophily (OPEN)	−0.040(0.003)***	−0.127(0.008)***	−0.013(0.008)	0.039 (0.008)***	0.083(0.011)***
Nodecov (GDP)	0.0000008(0.000)*	0.0000006(0.000)**	0.0000003(0.000)***	−0.0000001(0.000)**	0.0000001(0.000)***
Nodecov (dCOL)	−0.025(0.000)***	−0.023(0.002)***	−0.032(0.002)***	−0.022(0.002)***	−0.026(0.000)***
Nodecov (dCSL)	0.008(0.000)***	−0.004(0.001)**	0.005(0.001)***	−0.002(0.001)	0.017(0.000)***
Nodecov (dFTA)	−0.011(0.000)***	−0.023(0.000)***	−0.024(0.000)***	−0.033(0.000)***	−0.036(0.000)***
Nodecov (dCGB)	−0.042(0.000)***	−0.083(0.001)***	−0.079(0.002)***	−0.069(0.002)***	−0.058(0.002)***
Nodecov (dCCN)	−0.078(0.004)***	0.035(0.009)***	0.052(0.008)***	0.217(0.008)***	0.157(0.008)***
Nodecov (dBR-TCAN)	0.058(0.001)***	0.045(0.000)***	0.050(0.000)***	0.079(0.000)***	0.049(0.000)***
Network embedding effect					
Edgecov (COL)	1.379(0.013)***	0.783(0.033)***	0.928(0.030)***	0.478(0.030)***	0.331(0.042)***
Edgecov (CSL)	−0.313(0.011)***	0.076(0.026)**	0.256(0.023)***	0.137(0.025)***	0.234(0.035)***
Edgecov (FTA)	1.807(0.018)***	1.178(0.017)***	0.828(0.012)***	0.773(0.013)***	0.851(0.015)***
Edgecov (CGB)	1.159(0.077)***	2.309(0.032)***	1.810(0.021)***	1.323(0.024)***	1.940(0.030)***
Edgecov (CCN)	1.295(0.051)***	0.718(0.104)***	0.972(0.119)***	0.033(0.095)	−0.287(0.007)***
AIC	2179	2445	2206	2413	1688
BIC	2317	2583	2343	2550	1825

Note:
*Significant at 5%.
**Significant at 1%.
***Significant at 0.1%.

5. Conclusions and policy implications

Based on the complex network theory, the BR-TCANs are constructed using the bilateral trade data onto 62 countries along the B&R from the UNCOMTRADE database in 1993–2018. Then, the structural features and evolution are analyzed and the factors influencing the structure formation of the BR-TCANs are discussed by using the ERGM. We got some important findings and proposed several policy implications:

(1) The scale of BR-TCANs is relatively small, and there is great potential for trade development among countries along the B&R in the future. In addition, the BR-TCANs displays an obvious feature of a small-world network, and the reciprocal characteristic of trade competitive advantage relationships between countries in the BR-TCANs is obvious. (2) Turkey and Russia are high-ranked in terms of degree centrality among countries in the BR-TCANs during the sample period, indicating that Turkey and Russia are at the core of BR-TCANs. They not only have the largest number of export trade competitive advantage markets along the B&R, but also are the competitive advantage market of most countries along the B&R export. China is always ranked top1 in betweenness centrality over the years, indicating that China has the advantage in coordinating the development of the B&R. (3) The community structure of BR-TCANs exposes the phenomenon of geographic area assembly. BR-TCANs gradually form three communities over the years: the West, the North and the South, and there are adjustments and changes in the patterns of BR-TCANs due to certain economic fluctuations around the world. (4) The formation of BR-TCANs is greatly influenced by popularity, clustering, reciprocity and self-reinforcing mechanism. The formation of trade competitive advantage relationships causes heterophily in GDP and FDI and homophily in population and trade openness. What is more, countries with higher GDP, common spoken language and common currency advantages are more likely to establish trade competitive advantage relations with others. In addition, the formation of the BR-TCANs has the obvious network embedding effect. Two countries using common language, currency and geographic boundary and signing free trade agreement are more likely to form trade competitive advantage relationships.

According to the above conclusions, the following suggestions are put forward for promoting a country trade competitive advantage on the market of other countries and the overall development of BR-TCANs: firstly, leading powers need to play more roles in the development of BR-TCANs. BR-TCANs show obvious self-reinforcing mechanism. In addition, Turkey and Russia have the largest number of export and import trade competitive advantage markets and China has intermediary advantage of acting as “bridge” in BR-TACNs. Therefore, these countries can take the network advantage

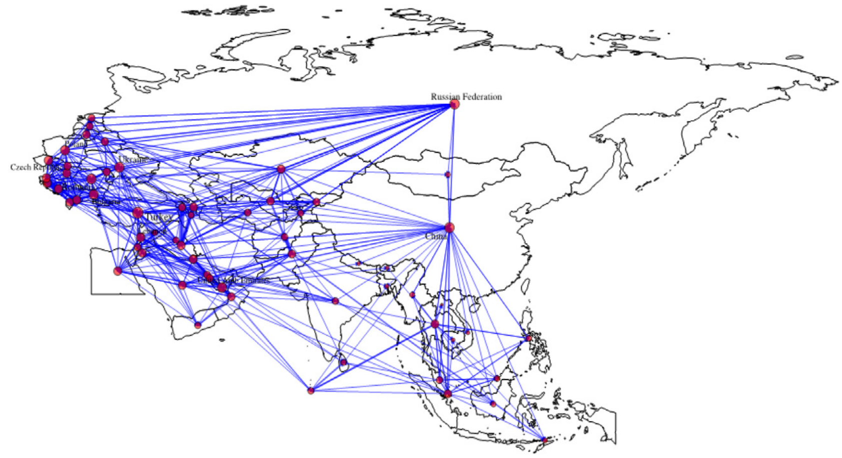


Fig. A.1. The BR-TCAN in 2018. *Note*: The size of the nodes is proportional to degree centrality and the width of the edges is proportional to DTCA.

to improve the cooperation with others along B&R and expansion of the overall scale of trade competitive advantage relationships. Secondly, further enhance regional cooperation and industrial complementarity among countries along B&R. BR-TCANs show the community structure of geographic area assembly, which is susceptible to the fluctuations of the global economy. What is more, the phenomenon of industrial convergence between countries is increasingly serious, which may even lead to cutthroat competition between each other. Therefore, countries along B&R should strengthen regional cooperation to cope with the impact of global economic fluctuations. Simultaneously, each country should make full use of their advantages and continue to optimize the industrial policies based on its own resource endowments and realistic industrial structure to further enhance industrial complementarity among countries along B&R, and promote the cluster and reciprocity of trade. Thirdly, we suggest strengthening the construction of facilities connectivity, policy coordination, financial integration and people-to-people bonds between countries along B&R. The results show that the formation of BR-TCANs has homophily in trade openness. What is more, country-pair sharing common language, currency and geographic boundary, and signing free trade agreement can promote forming trade competitive advantage relationship. Thus, each country should pay more attention to the construction of complex infrastructure networks, financial cooperation networks, free trade agreement network and the exchange of culture to reduce the barrier in physics, policy and culture.

CRediT authorship contribution statement

Lianyue Feng: Data curation, Methodology, Software, Writing - original draft. **Helian Xu:** Data curation, Methodology, Investigation, Writing - reviewing & editing. **Gang Wu:** Conceptualization, Visualization, Investigation, Writing - reviewing & editing. **Yuan Zhao:** Writing - reviewing & editing. **Jialin Xu:** Writing - reviewing & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

See Fig. A.1 and Tables A.1 and A.2.

Table A.1
List of countries along the B&R involved in this paper.

No.	Code	Country's name	No.	Code	Country's name
1	AFG	Afghanistan	32	LKA	Sri Lanka
2	ALB	Albania	33	LTU	Lithuania
3	ARE	United Arab Emirates	34	LVA	Latvia
4	ARM	Armenia	35	MDA	Republic of Moldova
5	AZE	Azerbaijan	36	MDV	Maldives
6	LAO	Lao People's Democratic Republic	37	MKD	The former Yugoslav Republic of Macedonia
7	BGR	Bulgaria	38	MMR	Myanmar (Burma)
8	BHR	Bahrain	39	MNG	Mongolia
9	BIH	Bosnia and Herzegovina	40	MYS	Malaysia
10	BLR	Belarus	41	NPL	Nepal
11	BRN	Brunei Darussalam	42	OMN	Oman
12	BTN	Bhutan	43	PAK	Pakistan
13	CHN	China	44	PHL	Philippines
14	CZE	Czech Republic	45	POL	Poland
15	EGY	Egypt	46	QAT	Qatar
16	EST	Estonia	47	ROM	Romania
17	GEO	Georgia	48	RUS	Russian Federation
18	HRV	Croatia	49	SAU	Saudi Arabia
19	HUN	Hungary	50	SGP	Singapore
20	IDN	Indonesia	51	SVK	Slovakia
21	IND	India	52	SVN	Slovenia
22	IRN	Iran	53	SYR	Syrian Arab Republic
23	IRQ	Iraq	54	THA	Thailand
24	ISR	Israel	55	TJK	Tajikistan
25	JOR	Jordan	56	TKM	Turkmenistan
26	KAZ	Kazakhstan	57	TMP	Timor-Leste (East Timor)
27	KGZ	Kyrgyzstan	58	TUR	Turkey
28	KHM	Cambodia	59	UKR	Ukraine
29	KWT	Kuwait	60	UZB	Uzbekistan
30	BGD	Bangladesh	61	VNM	Viet Nam
31	LBN	Lebanon	62	YEM	Yemen

Table A.2
Variable description of country attributes and external networks.

Symbol	Meaning	Data sources
GDP	GDP of each country	World Bank
POP	Population of each country	World Bank
Area	Area of each country	World Bank
FDI	Net inflows of direct investment of each country	World Bank
TO	Trade openness of each country	World Bank
COL	The common official language network, the two countries use a common official language with a value of 1, otherwise 0.	CEPII
CSL	The common spoken language network, the two countries use a common spoken language with a value of 1, otherwise 0.	CEPII
FTA	The free trade agreement network, the two countries sign a free trade agreement or CU with the value of 1, otherwise 0.	WTO
CGB	The common geographic boundary network, the two countries have a common geographic boundary with a value of 1, otherwise 0.	CEPII
CCN	The common currency network, the two countries use the same currency with a value of 1, otherwise.	CEPII

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