

Manufacturing Diffusion Trends from the Perspective of Trade Network: the Belt vs. the Road

Citation for published version (APA):

Yu, S., Niu, D., Liao, F., & Jiang, Y. (2022). Manufacturing Diffusion Trends from the Perspective of Trade Network: the Belt vs. the Road. *Maritime Policy and Management*, 49(5), 716-736.
<https://doi.org/10.1080/03088839.2022.2087238>

Document license:

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DOI:

[10.1080/03088839.2022.2087238](https://doi.org/10.1080/03088839.2022.2087238)

Document status and date:

Published: 01/01/2022

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

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To cite this article: Shunan Yu, Dongyue Niu, Feixiong Liao & Yonglei Jiang (2022) Manufacturing diffusion trends from the perspective of trade network: the belt vs. the road, *Maritime Policy & Management*, 49:5, 716-736, DOI: [10.1080/03088839.2022.2087238](https://doi.org/10.1080/03088839.2022.2087238)

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Manufacturing diffusion trends from the perspective of trade network: the belt vs. the road

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ABSTRACT

With the deepening of the 'Belt and Road (B&R)' initiative (BRI), the trends of manufacturing relocation and diffusion along the B&R has accelerated. This paper first collects bilateral trade data of 16 categories of major commodities among 55 countries along the B&R for 2017. Second, according to current and future transportation accessibility, this paper constructs two types of topological networks among countries along the B&R from the perspectives of both competitive and complementary trade. Percolation theory is adopted to analyze the manufacturing diffusion trends and bottleneck links among the two types of topological trade networks, which provides a new perspective through which to study manufacturing relocation and diffusion patterns. The results show that (1) based on current transportation accessibility, main industries percolate and agglomerate among countries with rapid economic development along the 21st Century Maritime Silk Road and that (2) the improvement in the China-Europe Railway Express (CR Express) postpones diffusion trends and improves the relocation potential of Silk Road Economic Belt regions.

KEYWORDS

'Belt and road' initiative; manufacturing relocation; competitive trade network; complementary trade network; percolation theory

1. Introduction

China proposed the 'Belt and Road (B&R)' initiative (BRI), which aims to promote regional cooperation to allow for free and orderly flows of economic production factors, the efficient allocation of resources, and the deep integration of markets, in 2013 (Shao et al. 2018; Wen et al. 2019; Jiang, Liao, and Jin 2021). Since the implementation of the BRI, the trade scale of the countries and regions along the route has continued to expand. In 2016, the total foreign trade of 64 countries along the B&R reached US\$7,188.55 billion, accounting for 21.7% of total global trade, which shows strong economic development potential. With the continuous advancement of the BRI and the continuous improvement of transportation and other infrastructure in the countries and regions along the route, the entire region forms a setting in which the industrial layout and foreign trade form an interactive cycle involving land and the Maritime Silk Road as an important transportation link. On the one hand, the improvement in transportation infrastructure promotes industry relocation and upgrade layout adjustment in the entire region, which leads to changes in the intraregional trade pattern (Tang and Cui 2020). On the other hand, changes in the trade pattern trigger new demand for transportation services and lead to the further adjustment of industrial development and layout. Therefore, analyzing the percolation and diffusion characteristics of major

manufacturing industries among countries along the route on the basis of clarifying the bilateral trade characteristics of major commodities and comprehensive transportation accessibility among B&R countries is an important foundation on which to accelerate economic and trade cooperation among these countries.

At present, analyses on the trend of industrial relocation are based mainly on gradient and fly-in theory. The former suggests that manufacturing firms relocate from an optimal location to less developed neighboring regions. The latter suggests that manufacturing firms relocate from the best developed regions to the least developed regions directly. From the perspective of competitive and complementary network theory in international trade (Liu, Xu, and Zhang 2020), two assumptions concerning industrial relocation can be further extended and formed. First, the stronger the competitiveness of the commodity trade between two countries in a certain industry is, the more likely the industry to relocate between the two countries. Second, the stronger the complementarity of the commodity trade between two countries in a certain industry is, the more likely the industry to relocate between the two countries. Based on these two assumptions, this research analyzes the diffusion trends and bottleneck links of manufacturing with percolation theory regarding the competitive and complementary trade networks of major import and export commodities among B&R countries.

The remainder of this paper is structured as follows. [Section 2](#) reviews the relevant literature. [Section 3](#) discusses the concepts of competitive and complementary trade, the formulation of multimodal transport costs (TCs), and percolation theory. [Section 4](#) describes the study area and data collection process and presents the empirical analysis results. Finally, a discussion and conclusions are presented in [Section 5](#).

2. Literature review

With the continuous advancement of the BRI, the industrial layout of and international trade among B&R countries has been further improved and promoted. Therefore, the following section reviews the existing research from two aspects: (1) industrial (re)location and (2) international trade.

The first aspect concerns industrial (re)location. Industry transfer is a macro reflection of the location and relocation of individual factories at the micro level (Chen and Yang 2019). Regarding the related theoretical frameworks, the existing research includes flying geese pattern theory (Akamatsu 1962), product lifecycle theory (Vernon 1966), marginal industry expansion theory (Kojima 1973) and labor-intensive industrial relocation theory (Lewis 1984), which explain the reasons for industrial relocation between advanced and nonadvanced countries. In addition, theories, such as new economic geography theory (Krugman 1991), focus on explaining the changing mechanism of spatial layout for industries in different regions. Regarding empirical study, the existing research has focused mainly on the identification of (re)location factors (Van Dijk and Pellenbarg 2000) and the impact of these factors (Sleutjes and Beckers 2013). The current modeling approaches involve mainly logit models (e.g., Kronenberg 2013), the network design models (e.g., Chen and Yang 2018) and other statistical methods (e.g., Bocci and Rocco 2016). Overall, the extant research has focused mainly on the reasons for the (re)location decisions of industries while seldom analyzing the related spatial patterns and diffusion trends.

The second aspect focuses on international trade. According to Liu, Xu, and Zhang (2020), the existing research has concentrated mainly on three topics: the evolution of trade demand or supply (Rana 2016), trade network structure (Liu, Wang, and Zhang 2018; Zhao et al. 2020; Feng et al. 2020) and the determinants of trade activities (Alderighi 2018). Unexpectedly, such studies have seldom analyzed the trade patterns of competitiveness and complementarity, which are defined as rivalry and collaboration, respectively, in terms of benefits from trade economic activity (Anna and Agnieszka 2016) and are essential for investigating trading activities (Thissen, Graaff, and Oort 2016). Regarding competitiveness and complementarity analysis, strategic resources for national development, such as

liquefied natural gas (Chen et al. 2016), iron ore (Yang et al. 2020) and agricultural products (Simo, Mura, and Buleca 2016), are mainly considered. Regarding the research approach, several useful indicators for identifying intercountry competitiveness and complementarity, such as the revealed comparative advantage (RCA) index (Liesner 1958), the export similarity index (ESI) (Glick, Rose, and Rose 1999), and the trade complementarity index (TCI) (Kojima 1964), have been adopted in many studies, which concentrate mainly on the analysis of competition and seldom focus on the complementary relationships among countries. Liu, Xu, and Zhang (2020) analyzed the competitiveness and complementarity of agricultural trade among B&R countries with the indicators ESI and TCI, which provided an in-depth reference for the present study; however, the impact of transportation accessibility was not considered in the abovementioned study.

In this study, we focus on the competitiveness and complementarity of manufacturing trade among B&R countries and analyze the spatial patterns and diffusion trends of the manufacturing industry in these countries based on percolation theory, in which the weight of the link is calculated according to the competitiveness, complementarity and transportation accessibility among these countries. In addition, the critical value for the occurrence of the percolation transition and the corresponding bottlenecks are discussed.

3. Methodology

To analyze the diffusion trends and bottlenecks of manufacturing industries, we propose an evaluation method. First, with the comprehensive consideration of trade competitiveness, trade complementarity and transportation accessibility, a dynamic trade topology network of B&R countries is constructed, in which trade competitiveness and complementarity are described by the ESI and TCI, respectively, and transportation accessibility is obtained by the TC calculated based on multimodal supernetwork representation. Second, the industrial relocation mode of the dynamic network is analyzed through percolation theory. Finally, the percolation transition and bottlenecks of the manufacturing industries of B&R countries are identified and discussed. The variables and their corresponding explanations are shown in Table 1.

Table 1. Variable notation list.

Variables	Variable description
K	Product category
ESI_{ij}	Trade competitiveness index of countries i and j
TCI_{ij}	Trade complementarity index of countries i and j
$RRCA_i$	Export RCA of country i
$RRTA_j$	Import RCA of country j
X_i^k	Export volume of product k of country i
X_j^k	Export volume of product k of country j
M_i^k	Import volume of product k of country i
X_i^t	Total export volume of all products of country i
X_j^t	Total export volume of all products of country j
M_i^t	Total import volume of all products of country i
X_w^k	Export volume of product k of all B&R countries
X_w^t	Total export volume of all products of all B&R countries
M_w^k	Import volume of product k of all B&R countries
M_w^t	Total import volume of all products of B&R countries
θ^k	Export share of product k in the market

3.1. Trade competitiveness and complementarity

3.1.1. ESI

The ESI reflects the level of structural similarity of the export products of two countries. The larger the ESI value is, the more similar the export product structure and the higher the degree of competitiveness between the two countries. According to Liu, Xu, and Zhang (2020), the formula for calculating ESI is as follows:

$$ESI_{ij} = \left\{ \sum_k \left[\frac{(X_i^k/X_i^t) + (X_j^k/X_j^t)}{2} \times \left[1 - \left| \frac{(X_i^k/X_i^t) - (X_j^k/X_j^t)}{(X_i^k/X_i^t) + (X_j^k/X_j^t)} \right| \right] \right] \right\} \times 100 \quad (1)$$

The ESI value varies from 0 to 100, and this paper takes $ESI > 50$ as the standard, as it means that the export structures of the two countries are similar and that there is a high degree of competitiveness between these countries. The larger the value of ESI is, the higher the degree of competitiveness between countries i and j .

3.1.2. TCI

The TCI is an index for the complementarity of manufacturing product trade between two countries, reflecting the corresponding level of homogeneity between a country's export supply and import demand. The larger the TCI value is, the more similar the import and export structures of commodities between two countries, and the larger the complementarity between them. The formulas for calculating TCI are as follows:

$$RRCA = \frac{X_i^k/X_i^t}{X_w^k/X_w^t} \quad (2)$$

$$RRTA = \frac{M_i^k/M_i^t}{M_w^k/M_w^t} \quad (3)$$

$$\theta^k = \frac{X_w^k}{X_w^t} \quad (4)$$

$$TCI_{ij} = \sum_k \theta^k \times RRCA_i \times RRTA_j \quad (5)$$

We define 1 as the threshold TCI value when the relative comparative advantages of the product in the two countries are the same ($TCI = 1$). If $TCI > 1$, then it indicates that there is a high degree of complementarity between the two countries. The larger the value of TCI is, the higher the degree of complementarity between country i and j .

3.2. TC calculation

In this study, transportation accessibility is represented by the multimodal freight TCs among countries. To obtain the TCs, an approach based on the concept of supernetworks is adopted (Zhang et al. 2011), the specific steps of which are presented below.

First, a multimodal supernetwork is constructed, where the nodes represent the intersections of countries or transportation infrastructure, the solid links denote transportation of the same mode, and the dummy links are used to connect different transport modes. In this study, a supernetwork includes road, railway, and sea transportation, a simple example of which is shown in Figure 1.

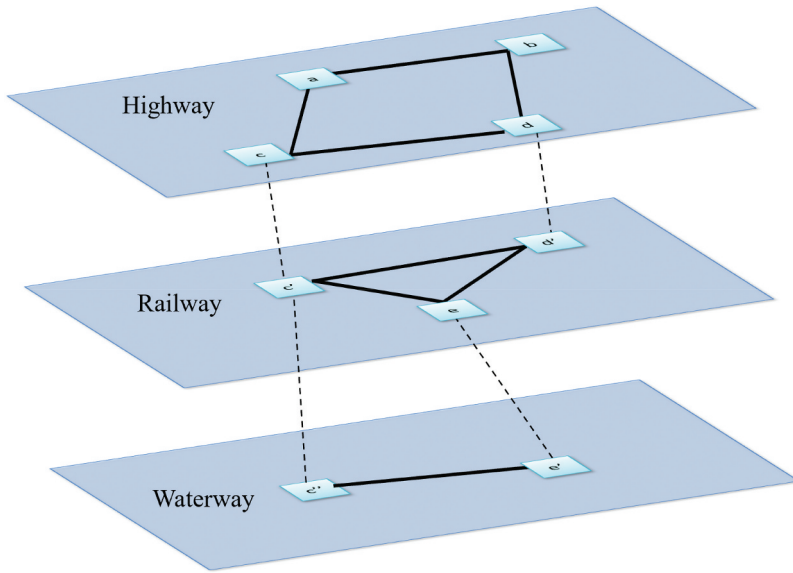


Figure 1. Multimodal supernetwork.

Table 2. Generalized TCs in a multimodal supernetwork.

Type		Monetary costs	Time cost
Transport	Highway	Length×unit cost ¹	Length/speed×time value
	Railway	Length×unit cost	(length/speed+timestamps ²)×time value
	Waterway	Length×unit cost	(Length/speed+timestamps)×time value
Intermodal transfer	Highway-railway	Unit cost ³	Transfer time×time value
	Highway-waterway	Unit cost	Transfer time×time value
	Railway-waterway	Unit cost	Transfer time×time value

There are three unimodal transport networks, among which the road and railway networks are interconnected at nodes c and d, and the sea and the railway networks are interconnected at nodes c and e, and the transport modes can be changed.

The generalized multimodal freight TCs involve monetary costs and time expenses at the links (including solid and dummy links) and nodes. The specifications of link costs in our analysis are listed in Table 2 (Jiang, Liao, and Jin 2021).

Then, the multimodal supernetwork is taken as a static network in which the TC of each link is used to denote its length. Furthermore, the minimum generalized TC between any two nodes can be calculated with standard shortest-path algorithms.

3.3. Percolation theory

Percolation theory is used to study the clustering phenomenon in random environments, as it is capable of exploring the emergence of clusters and the dynamic changes in cluster sizes in topological networks in the fields of physics, chemistry, and material science. Therefore, we aim to analyze the diffusion trends of manufacturing firms using this theory to provide a new perspective for manufacturing industry diffusion.

Suppose that there is a network, $G(V, E)$, with V nodes and E links, as shown in Figure 2(a), and that each link, e_{ij} , is associated with an independent and fixed weight, p_{ij} . Given q ($0 < q < 1$), when $p_{ij} \geq q$, e_{ij} appears, which can be denoted as the following function:

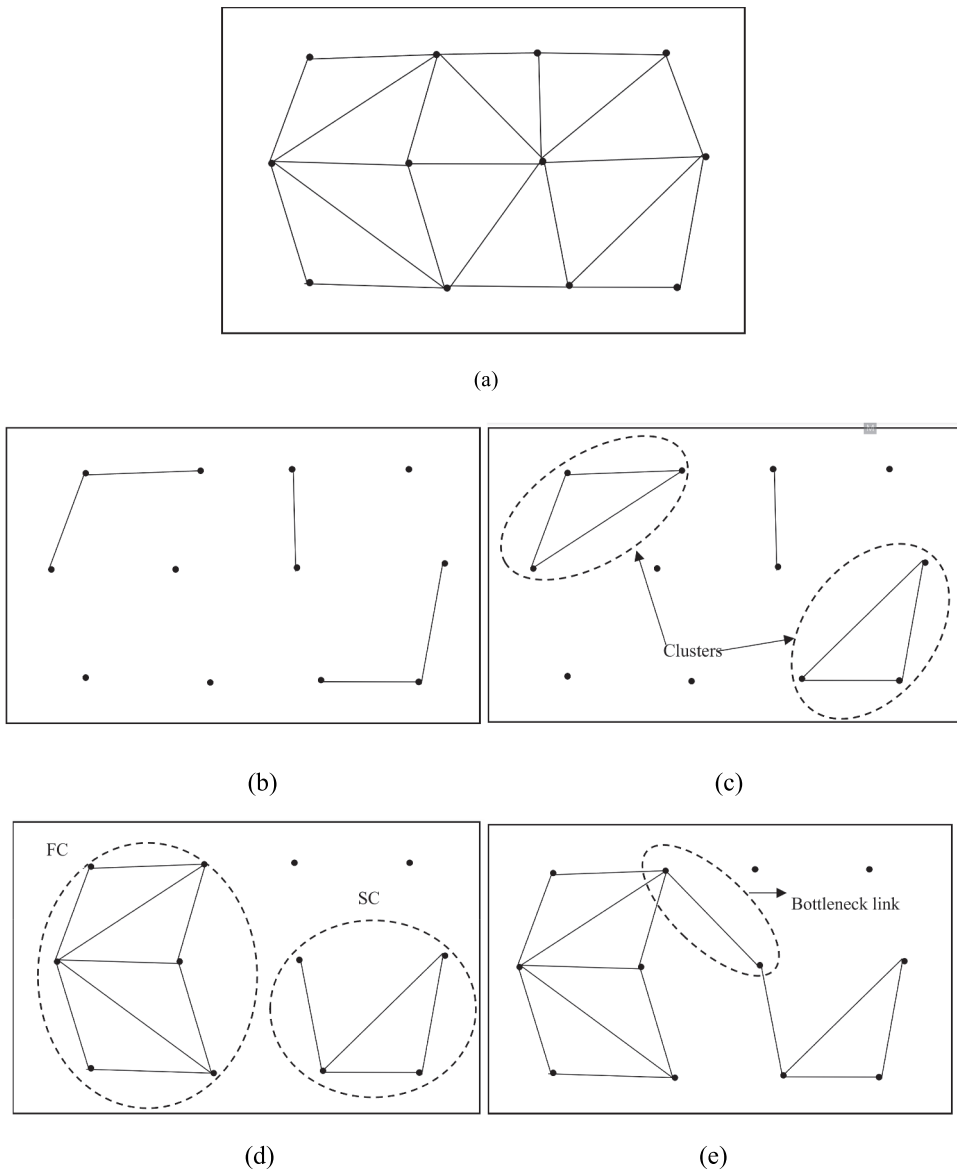


Figure 2. Process of percolation theory based on graph theory.

$$e_{ij} = \begin{cases} 1, & p_{ij} \geq q \\ 0, & p_{ij} < q \end{cases} \quad (6)$$

When the value of q is large, few links appear in the network, as shown in [Figure 2\(b\)](#). As the value of q decreases, an increasing number of links appear in the network, and the link clusters have different sizes, as shown in [Figure 2\(c\)](#). When q continues to decrease, the sizes of the first- and second-largest clusters (FC and SC, respectively) may increase accordingly, as shown in [Figure 2\(d\)](#). Once the FC is integrated with the SC, percolation transition occurs; the link connecting the FC to the SC is called the bottleneck link, as shown in [Figure 2\(e\)](#), and the corresponding value q^* is called the critical value.

The variable p_{ij} can be broken down into p_{ij}^{ESI} and p_{ij}^{TCI} , the calculation step of which is as follows. First, based on the comprehensive transportation network system along the B&R, the minimum TC between countries i and j , TC_{ij} , can be obtained (Zhang et al. 2011; Possamai et al., 2015). After normalization, the TC is multiplied by the ESI and TCI, respectively, and then normalized to obtain the location factors, k_{ij}^{ESI} and k_{ij}^{TCI} , which can be denoted as in Eq. (7) and (8), respectively. Second, location factors are ranked from smallest to largest, the 95th percentile of k_{ij}^{ESI} and k_{ij}^{TCI} is taken, and then, they are recorded as $95\%max\{k_{ij}^{ESI}\}$ and $95\%max\{k_{ij}^{TCI}\}$, respectively. Finally, p_{ij}^{ESI} and p_{ij}^{TCI} can be calculated by Eq. (9) and (10):

$$k_{ij}^{ESI} = sst(ESI_{ij}) \times st\left(\frac{1}{TC_{ij}}\right) \quad (7)$$

$$k_{ij}^{TCI} = sst(TCI_{ij}) \times st\left(\frac{1}{TC_{ij}}\right) \quad (8)$$

$$p_{ij}^{ESI} = \frac{k_{ij}^{ESI}}{95\%max\{k_{ij}^{ESI}\}} \quad (9)$$

$$p_{ij}^{TCI} = \frac{k_{ij}^{TCI}}{95\%max\{k_{ij}^{TCI}\}} \quad (10)$$

4. Case study

4.1. Study area

To analyze the industrial diffusion trend of B&R countries, we take 66 countries, including China, as the study area, as shown in Figure 3. Although some data of low-traffic countries are missing, it does not affect the overall results.

4.2. Data collection

To calculate the ESI and TCI values of trade along the B&R, we collect bilateral trade data, including those on the import and export volume of 16 categories of major commodities among 66 countries, for 2017 from World Integrated Trade Solutions (WITS). Due to the lack of statistical data in 2017 for 11 countries (i.e., Laos, Cambodia, Iraq, Syria, Palestine, Yemen, Bangladesh, Afghanistan, Bhutan, Turkmenistan, and Tajikistan), we exclude them from the calculation, in other words, 55 countries compose the study area.

To calculate the TCs in this study, we use the unit cost data collected by Jiang, Liao, and Jin (2021), as shown in Table 3. Moreover, link lengths and travel times are computed by geographic information system (GIS) software based on the supernetwork. Based on the data in Table 3, the lowest TCs between each pair of countries can be calculated with the multimodal supernetwork method (Zhang et al. 2011).

To analyze the impact of transportation accessibility on the dynamic changes in the trade network, this work calculates the minimum TC between countries for two different scenarios (current and future scenarios) for comparison. The cost in the current scenario is calculated based on the current China-Europe Railway Express (CR Express) data, which are the same as those in Table 3, while the cost in the future scenario is calculated based on the future planned CR

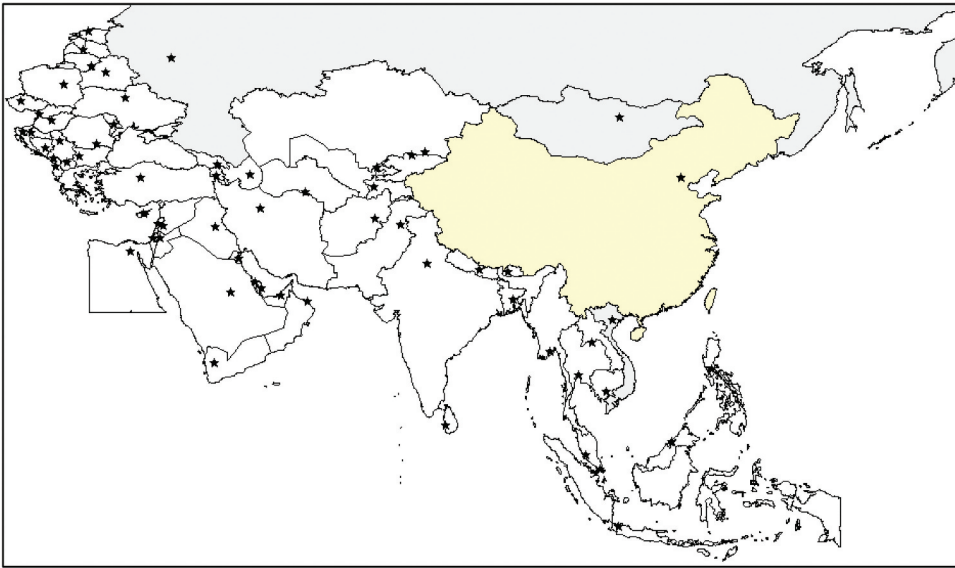


Figure 3. Geographical information of the study area.

Table 3. Unit costs in the multimodal supernetwork.

Type		Monetary cost	Time cost
Transport	Highway	6 USD/FEU ·km	8 USD/h (speed = 100 km/h)
	Railway	0.72 USD/FEU ·km	8 USD/h (speed = 29.2 km/h)
	Waterway	0.15 USD/FEU ·km ⁵	8 USD/h (speed = 27.5 km/h)
Transfer	Highway-railway	1,000 RMB/FEU	8 USD/h (transfer time = 1.5 h)
	Highway-waterway	1,000 RMB/FEU	8 USD/h (transfer time = 7 days)
	Railway-waterway	1,000 RMB/FEU	8 USD/hr (transfer time = 7 days)

Table 4. Study scenarios.

	Competitive network	Complementary network
Scenario 1	Without transportation accessibility	Without transportation accessibility
Scenario 2	Current transportation accessibility	Current transportation accessibility
Scenario 3	Future transportation accessibility	Future transportation accessibility

Express data; specifically, the unit cost is reduced to 0.5 USD/FEU·km, the speed is increased to 54 km/h, and the frequency is increased to 7 trains/week. Thus, three scenarios are set based on the competitive and complementary trade networks, as shown in [Table 4](#).

4.3. Results and analysis

4.3.1. Analysis of competitive trade network

4.3.1.1. Competitive trade network construction. According to Eq. (1), the ESI among the 55 countries is obtained, as shown in [Table 5](#). The maximum value of ESI between the 1,485 country pairs is 90.50, which is for the country pair of Brunei in Southeast Asia and Qatar in the Middle East, while the minimum value is 1.62, which is for the country pair of Brunei in Southeast Asia and Maldives in East Africa. The mean value of ESI is 47.43, which indicates that the trade competitiveness level of country pairs in the B&R region is close to significant. The number of country pairs with obvious competitiveness ($ESI \geq 50$) is 713, accounting for 48.0% of all country pairs. Nearly half of B&R countries have obvious competitive relationships in terms of major import and export

Table 5. Descriptive statistics of the competitive trade index.

ESI	Country pairs	Maximum value	Minimum value	Mean value
All pairs	1,485	90.50	1.62	47.43
ESI \geq 50	713	90.50	50.02	61.91

commodity trade. Country pairs with obvious trade competition are taken as links, and the capitals of the corresponding two countries are taken as nodes. Then, the competitive topological trade network is constructed, as shown in Figure 4.

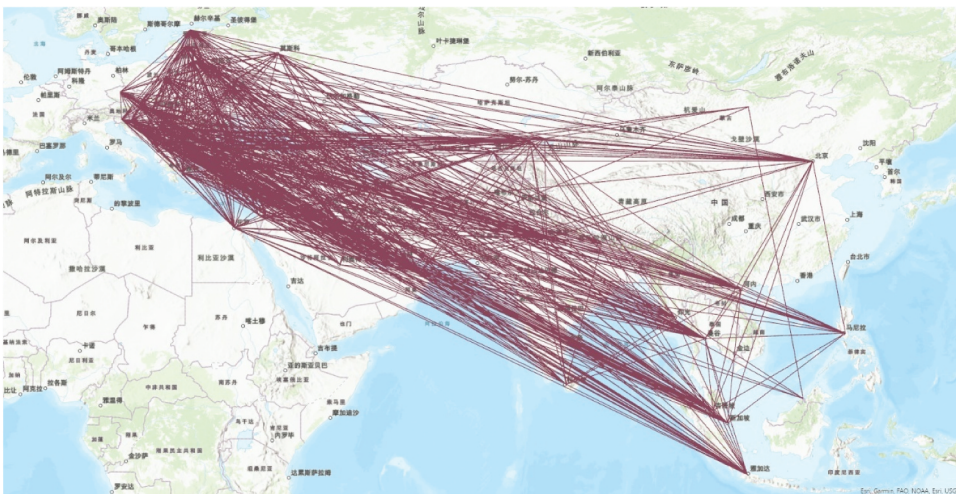
4.3.1.2. Results of scenario 1. (1) Percolation transition process and diffusion trends

The percolation transition process of scenario 1 is shown in Figure 5. When $q < 0.72$, the scale of the FC increases as q decreases, while the scale of the SC is constant at 3 (the calculation method for FC and SC is the count number of links). When $q = 0.72$, percolation transition occurs, and the two largest clusters become integrated.

The diffusion trend of scenario 1 is shown in Figure 6 (the FC is in red, the SC is in blue, the third-largest cluster is in yellow, the fourth-largest cluster is in purple, and the bottleneck link is in green). When $q = 1$, the FC is located in Eastern Europe and Southeast Asia, while the SC is located in Southeast and South Asia (Figure 6(a)). As q decreases, the FC gradually spreads to West and South Asia, as shown in Figure 6(b,c), respectively. When $q = 0.72$, percolation transition occurs with the bottleneck link between Russia and Qatar (Figure 6(d)).

(2) Diffusion characteristics

According to the percolation transition process and diffusion trends, the main industries gradually percolate from the island countries to the coast countries, with the bottleneck link between Russia along the Silk Road Economic and Qatar along the 21st Century Maritime Silk Road. Moreover, Eastern Europe and Southeast, South and West Asia are at the top of the list of relocation regions, which reveals that when the transportation accessibility is not taken into consideration, the main industries are agglomerating among both the countries along the Silk Road Economic and the countries along the 21st Century Maritime Silk Road. In addition, most of these countries have strong trade competitiveness, possibly because countries with strong competitiveness have similar resource endowments, geographical locations, and industrial structures, thus verifying the first hypothesis.

**Figure 4.** Topological competitive trade network structure.

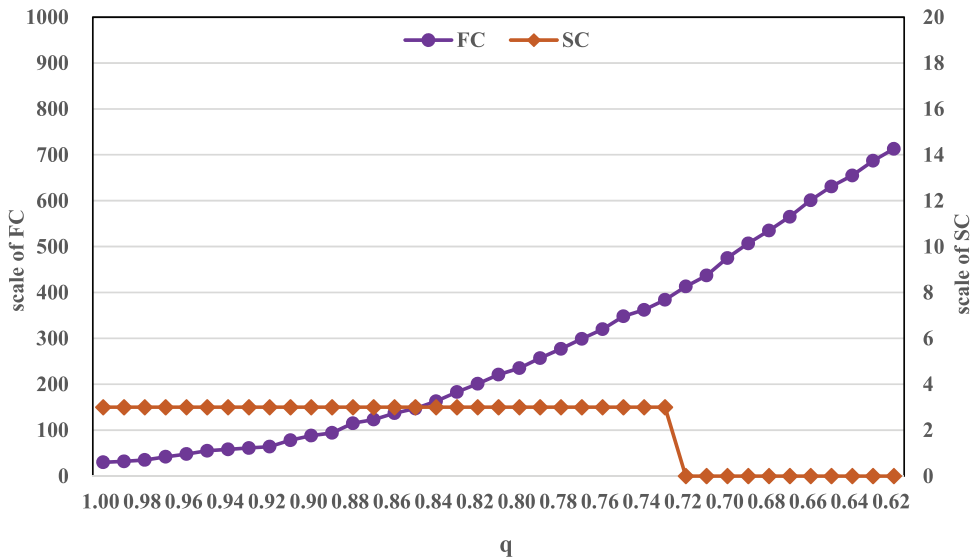


Figure 5. Percolation process of scenario 1.

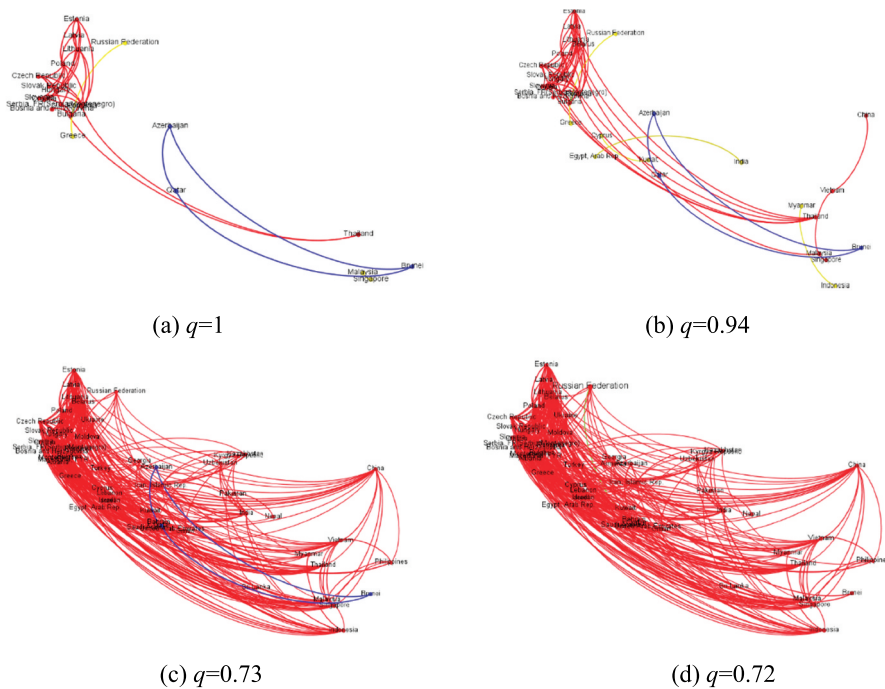


Figure 6. Spatial patterns of diffusion clusters under different values of q . (a) $q = 1$ (b), $q = 0.94$, (c) $q = 0.73$, (d) $q = 0.72$.

4.3.1.3. Results of scenario 2. In scenario 2, the influence of transportation accessibility on the results is considered.

(1) Percolation transition process and diffusion trends

The percolation transition process of scenario 2 is shown in Figure 7. When $q < 0.64$, the scales of the FC and SC increase as q decreases. When $q = 0.64$, percolation transition occurs, and the two largest clusters become integrated. Compared with scenario 1, in scenario 2, the critical value is

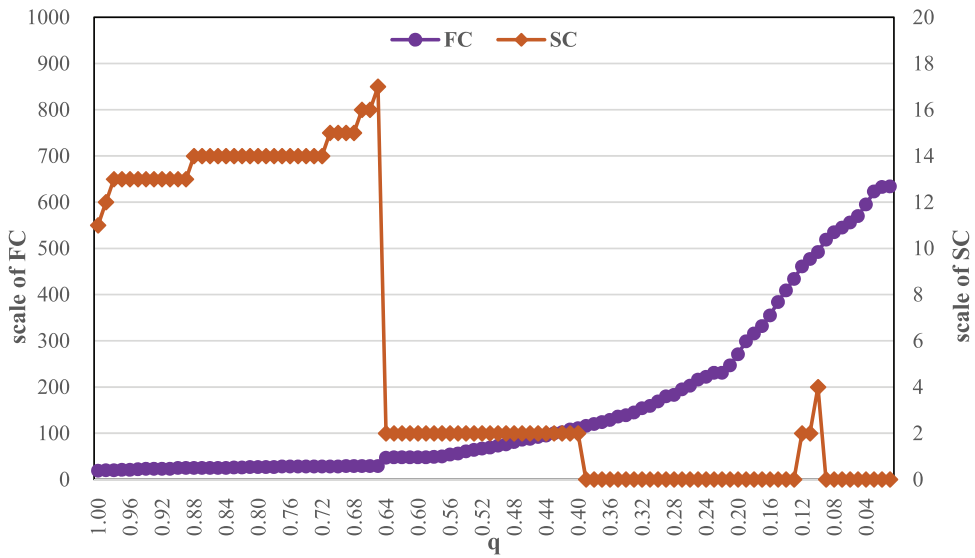


Figure 7. Percolation process of scenario 2.

decreased, which means that percolation transition occurs later than in scenario 1. This finding indicates that when taking current transportation accessibility into account, percolation transition is postponed.

The diffusion trend of scenario 2 is shown in Figure 8 (the notes are the same as those in Figure 6). When $q = 1$, the FC is located in Southern Europe and Western Asia, and the SC is located in South and Southeast Asia (Figure 8(a)). As q decreases, the FC is still located in Southern Europe and West Asia, while the SC spreads to West Asian countries (Figure 8(b,c)). When $q = 0.64$, percolation transition occurs, with the bottleneck link between Singapore and Israel (Figure 8(d)).

(2) Diffusion characteristics

According to the percolation transition process and diffusion trends, the FC is always located in Southern Europe and West Asia, and the SC is always located in Southeast Asia. Compared with scenario 1, the regions for industrial percolating are more inclined along the 21st Century Maritime Silk Road. However, most inland regions, such as Central Asia, are not at the top of the list for industrial relocation, revealing that for the current competitive trade pattern and corresponding comprehensive transportation system, the main industries are still agglomerating among those B&R countries with rapidly developing coastal economies. In addition, transportation accessibility along the 21st Century Maritime Silk Road is greater than that along the Silk Road Economic Belt and has impacts on industrial relocation trends in the competitive trade network. The bottleneck link is between Singapore and Israel, both of which are along the 21st Century Maritime Silk Road. The reason for this may be that the Middle East is an export-oriented region for petroleum and its chemical products owing to its rich oil and natural gas resources, while Singapore is an economically developed country in the Asia-Pacific region with the advantage of the petrochemical industry in terms of transshipment. Therefore, for the two regions, the main competitive advantage exists only in the most developed countries, and the competitive relationship between other countries is not obvious. In addition, although the transportation location conditions in the Middle East are superior, the cost of other production locations is relatively high due to the high economic level of resource-exporting countries. Therefore, the Middle East becomes the bottleneck area of this percolation transition.

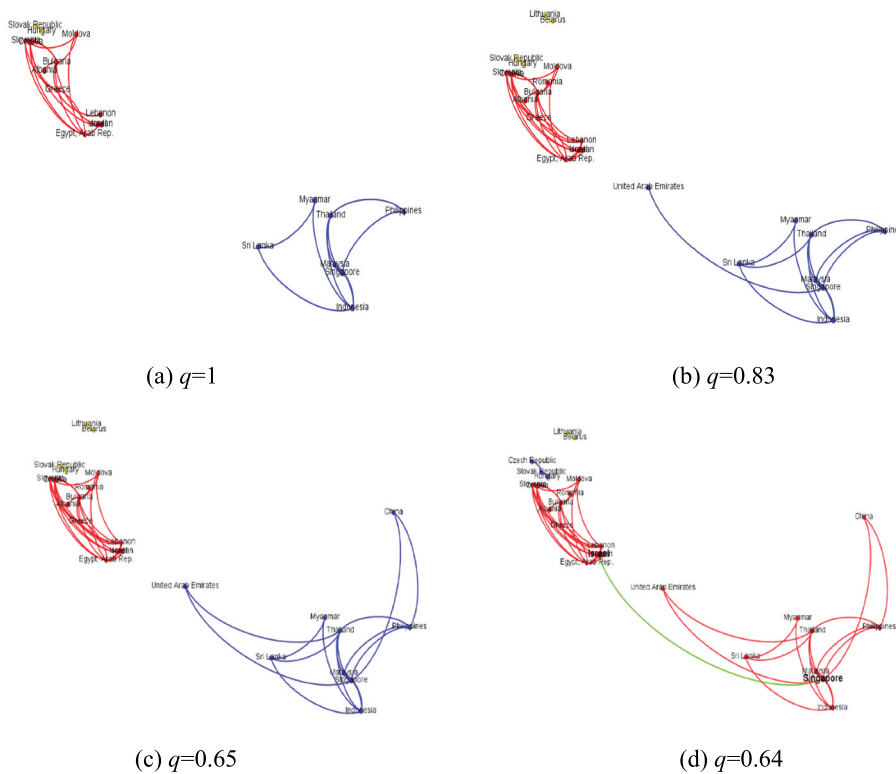


Figure 8. Spatial patterns of diffusion clusters under different q values. (a) $q = 1$, (b) $q = 0.83$, (c) $q = 0.65$, (d) $q = 0.64$.

4.3.1.4. Results of scenario 3. In scenario 3, it is assumed that the rail system is improved in the future, and the influence of future transportation accessibility on the results is considered.

(1) Percolation transition process and diffusion trends

The percolation transition process of scenario 3 is shown in Figure 9. When $q < 0.46$, the scales of the FC and SC increase as q decreases. When $q = 0.46$, percolation transition occurs, and the two largest clusters become integrated. Compared with scenarios 1 and 2, the critical value of q is the lowest, which means that percolation transition is further postponed. Comparing the above three scenarios, it can be seen that the better the transportation accessibility is, the later the percolation transition occurs. The reason for this may be that the improvement in transportation accessibility promotes cooperation and competition in regional trade and lead manufacturing through agglomerating regionally instead of through percolating throughout the entire network. In addition, of the three scenarios, it can be seen that the diffusion trends of the competitive trade network exhibit a dual-core cluster mode.

The diffusion trend of scenario 3 is shown in Figure 10 (the notes are the same as those in Figure 6). When $q = 1$, the FC is located in Europe and West Asia, and the SC is located in Southeast Asia (Figure 10(a)). As q decreases, the FC spreads to Europe and West and Central Asia, and the SC spreads to eastern West Asia (Figure 10(b,c)). When $q = 0.46$, percolation transition occurs, and the bottleneck link is still between Singapore and Israel (Figure 10(d)).

(2) Diffusion characteristics

According to the percolation transition process and diffusion trends, the FC further spreads to Eastern Europe, western Russia and Central Asia, while the SC is still located in Southeast Asia. Compared with scenario 2, in scenario 3, less industries percolating regions are located along the 21st Century Maritime Silk Road. The reason may be that the transportation accessibility in Eastern

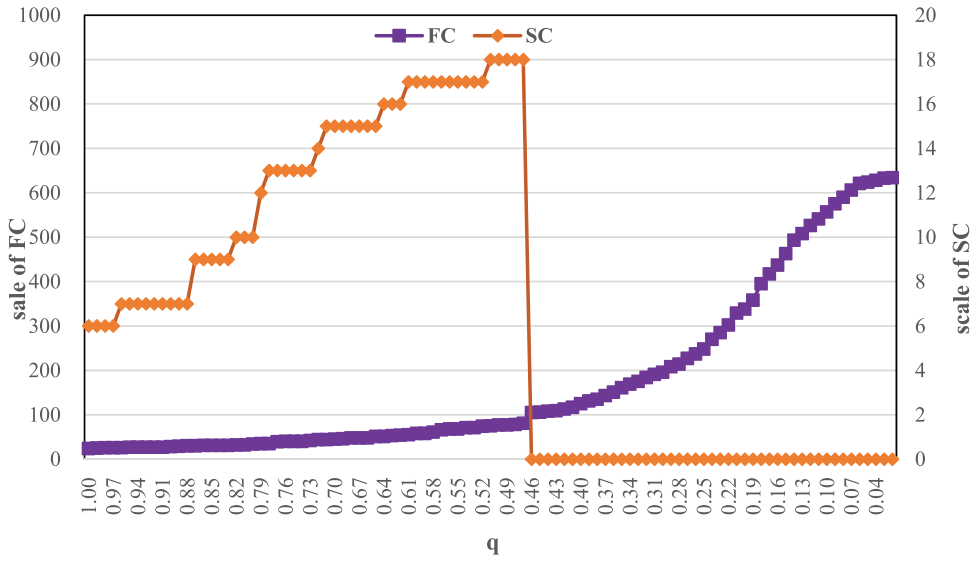


Figure 9. Percolation process of scenario 3.

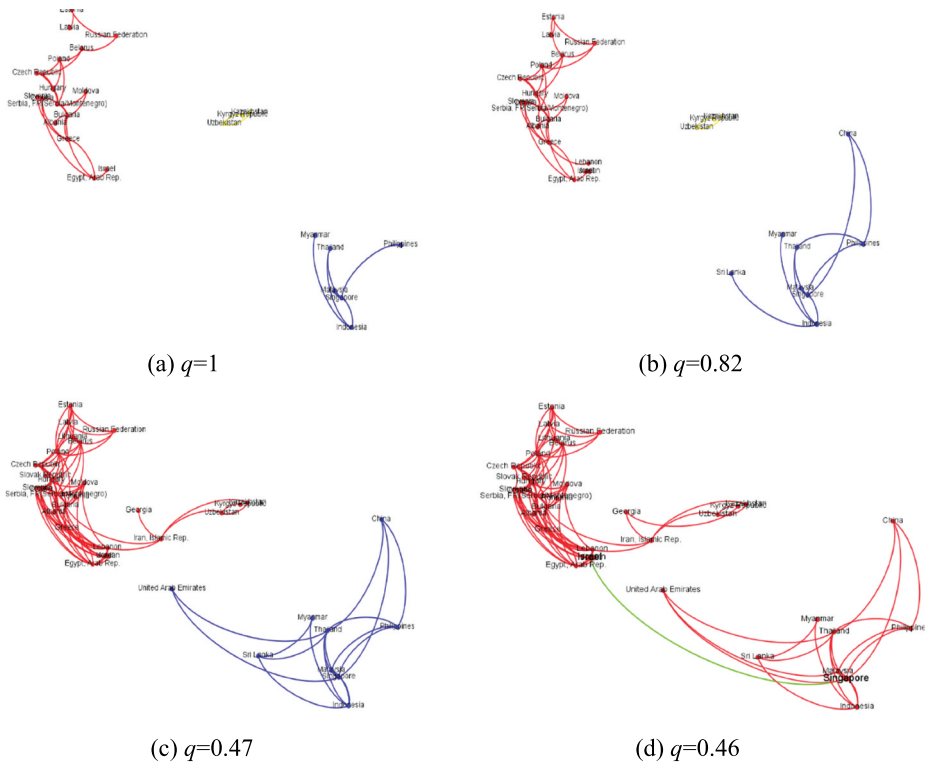


Figure 10. Spatial patterns of diffusion clusters under different q values. (a) $q = 1$, (b) $q = 0.82$, (c) $q = 0.47$, (d) $q = 0.46$.

Europe (particularly Russia) and Central Asia has been improved due to the improvement in the Asia-Europe railway. Moreover, the improvement in the CR Express promotes industries percolating to the regions of the Silk Road Economic Belt from the 21st Century Maritime Silk Road and makes some inland countries become target regions for industrial relocation. Singapore and Israel are still bottleneck countries, which indicates that the improvement in the railway system cannot change the location of bottleneck countries, the coast countries still have important impacts on the industry relocation and diffusion trend.

4.3.2. Analysis of complementary trade network

4.3.2.1. Complementary trade network construction. According to Eq. (2)-(5), the TCI among the 55 countries is obtained. As shown in Table 6, the maximum TCI value between the 1,485 country pairs is 3.02, which is for the country pair of Iraq in the Middle East and Maldives in East Africa, while the minimum value is 0.26, which is for the country pair between Pakistan in South Asia and Maldives in East Africa. The mean TCI value is 1.13, which is larger than 1, indicating that the import and export trade between B&R countries is mainly complementary. Moreover, the number of country pairs of obvious trade complementarity is 1,132, accounting for 76.2% of all country pairs, which further reflects the close economic and trade cooperation between these countries. The country pairs with obvious trade complementarity are taken as links, and the capitals of the corresponding two countries are taken as nodes. Then, the complementary topological trade network is constructed, as shown in Figure 11.

4.3.2.2. Results of scenario 1.

(1) Percolation diffusion process

As shown in Figure 12, the scale of the FC increases as q decreases, while the SC does not exist (i.e., the scale is 0). It can be seen that no percolation transition occurs in scenario 1.

Table 6. Descriptive statistics of the complementary trade index.

TCI value	Country pairs	Maximum value	Minimum value	Mean value
All pairs	1,485	3.02	0.26	1.13
$TCI \geq 1$	1,132	3.02	1	1.18

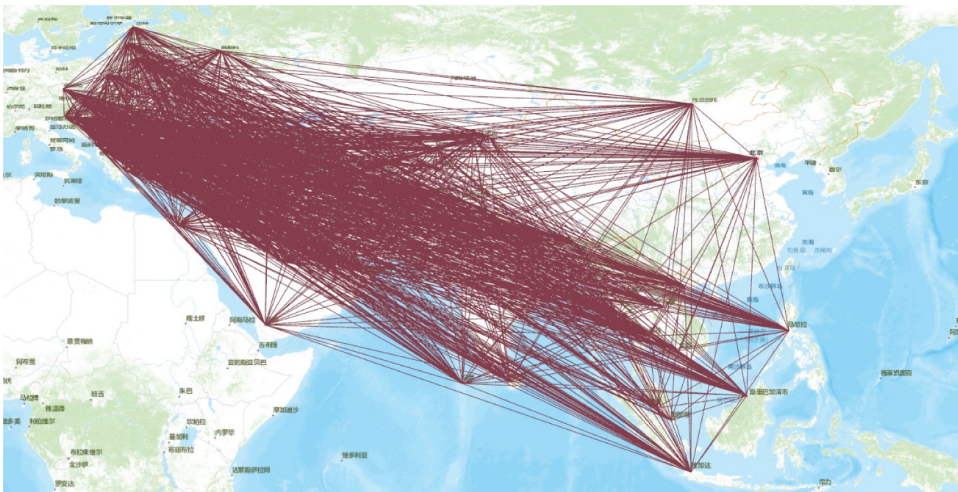


Figure 11. Topological complementary trade network structure.

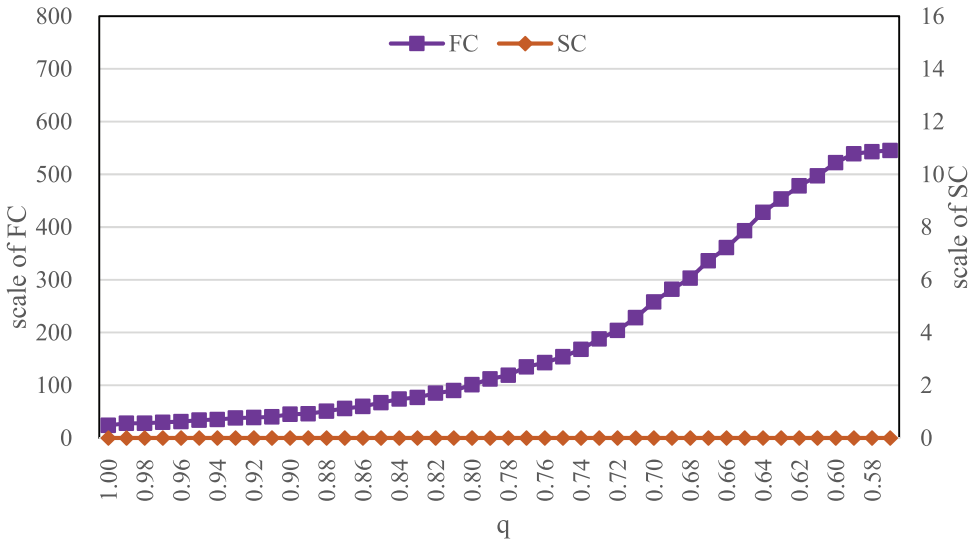


Figure 12. Percolation process of scenario 1.

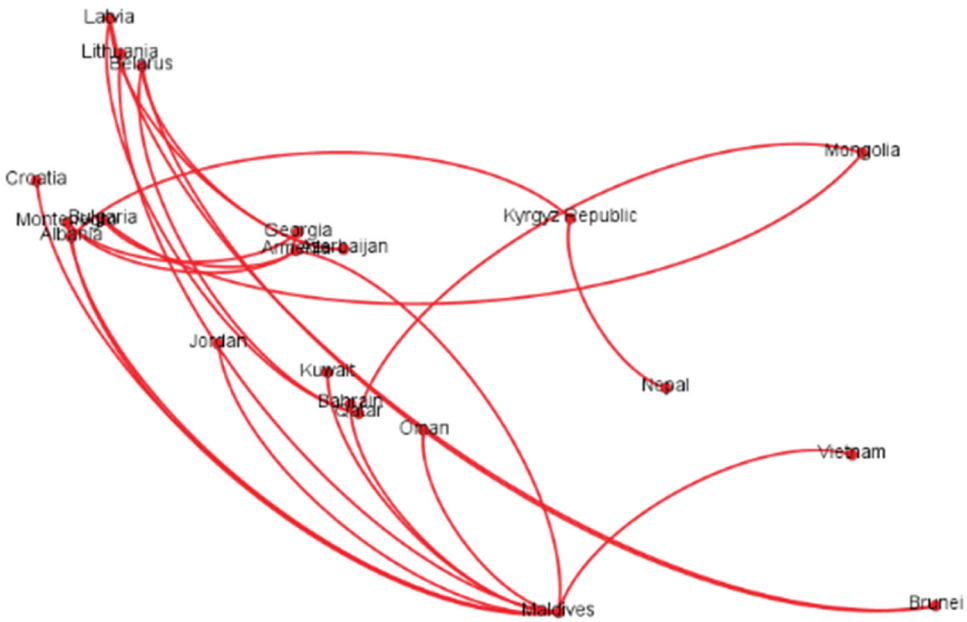


Figure 13. Spatial pattern of the diffusion cluster when $q = 1$.

The diffusion pattern of scenario 1 when $q = 1$ is shown in Figure 13 (the FC is in red); the FC is located in Eastern Europe (mainly in Latvia), Southern Europe and Asia (mainly in Maldives).

(2) Diffusion characteristics

According to the diffusion pattern, Eastern Europe, Southern Europe and Asia are at the top of the list of relocation regions, which contains both countries along the 21st Century Maritime Silk Road and countries along the Silk Road Economic. As these countries have strong trade

complementarity, it is possibly because countries with strong complementarity have large endowment gaps and distant geographical locations, which is consistent with *fly-in theory* and verifies the second hypothesis.

4.3.2.3. Results of scenario 2. Similar to the competitive network, in scenario 2, the influence of transportation accessibility on the results is considered.

(1) Percolation transition process and diffusion trends

The percolation transition process of scenario 2 is shown in Figure 14. When $q < 0.56$, the scale of the FC increases as q decreases, while the scale of the SC is still too small (≤ 3). When $q = 0.56$, percolation transition occurs, and the two largest clusters become integrated. Compared with scenario 1, in scenario 2, the critical value is decreased, which indicates that percolation transition is postponed when taking current transportation accessibility into account. In addition, when considering current transportation accessibility, the percolation transition process occurs, but it is not obvious, due to the small scale of the SC.

The diffusion trend of scenario 2 is shown in Figure 15 (the notes are the same as those in Figure 6). When $q = 1$, the FC is located in Southern Europe, and the SC is located in West and Southeast Asia. (Figure 15(a)). As q decreases, the FC spreads to West and Southeast Asia, while the SC is located in Southeast and East Asia (Figure 15(b,c)). When $q = 0.56$, percolation transition occurs, with the bottleneck link being that between Israel and Thailand (Figure 15(d)).

(2) Diffusion characteristics

According to the percolation transition process and diffusion trends, in the complementary trade network, the main industries in the regions along the route are concentrated in 25 countries, led by Greece, Israel, the United Arab Emirates and Singapore in Eastern Europe, the Middle East and Southeast Asia (the FC), respectively, and 3 countries in the Asia-Pacific region, led by China (the SC). Most of these countries are along the 21st Century Maritime Silk Road, which reveals that the coast countries have important impacts on the industry relocation and diffusion trend under current transportation accessibility of the complementary network. Moreover, trade complementarity among B&R countries is significantly higher than is competitiveness, with the largest subnetwork being formed in the Eastern Europe-Mediterranean-South Asia-Southeast Asia area before the occurrence of percolation transition, which is similar to the spatial layout of the 21st Century Maritime Silk Road. It also reveals that in the complementary trade network and current

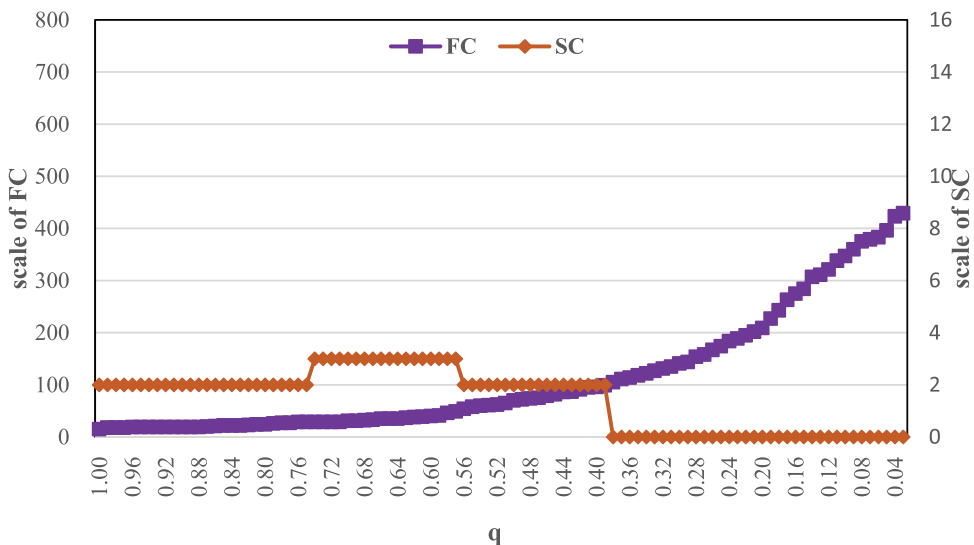


Figure 14. Percolation process of scenario 2.

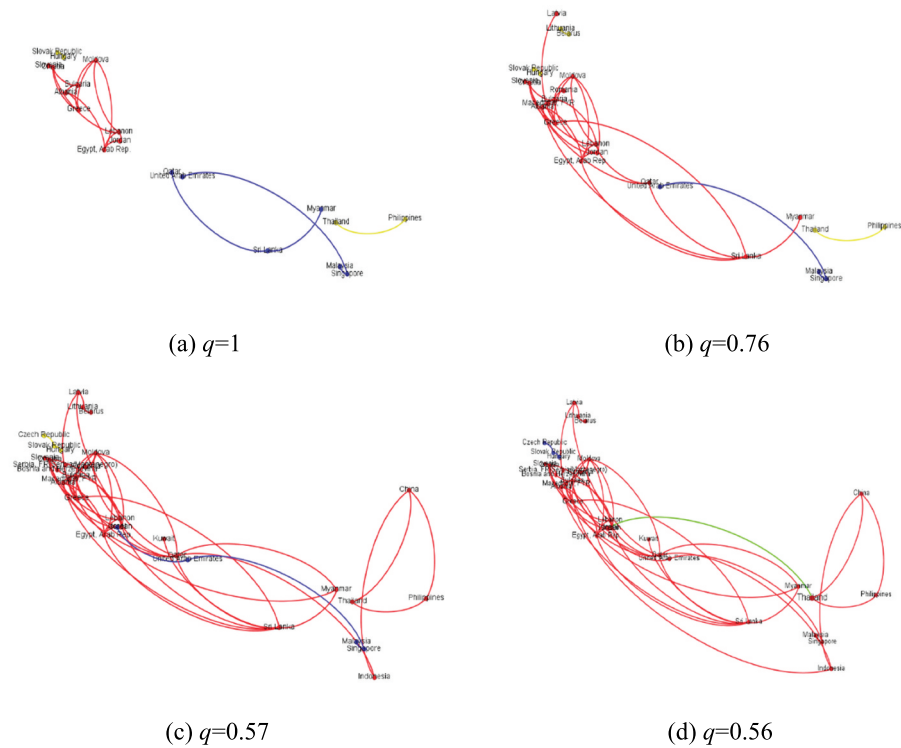


Figure 15. Spatial patterns of diffusion clusters under different q values. (a) $q = 1$, (b) $q = 0.76$, (c) $q = 0.57$, (d) $q = 0.56$.

comprehensive transportation system, the main industries are still percolating and agglomerating among those countries with rapidly developing coastal economies. In addition, similar to the percolation transition in the competitive trade network, the bottleneck link in complementary trade networks is still that between the Middle East (Israel) and Asia-Pacific (Thailand), both of which are along the 21st Century Maritime Silk Road. It is revealed that the industrial structure characteristics (export oriented for petroleum and its chemical products) and special location conditions (located between Asia-Pacific and Eastern Europe) of the Middle East region make it an important bottleneck for communication between the regions of Asia-Pacific and Eastern Europe in the complementary trade network. However, as the trade complementarity among B&R countries is significantly higher than competitiveness, the diffusion and percolation of major commodities can occur relatively easily.

4.3.2.4. Results of scenario 3. Similar to the competitive network, in scenario 3, it is assumed that the rail system will be improved in the future, and thus, the influence of future transportation accessibility on the results is considered.

(1) Percolation transition process and diffusion trends

The percolation transition process of scenario 3 is shown in [Figure 16](#). When $q < 0.38$, the scale of the FC increases as q decreases, while the scale of the SC is still too small (≤ 5). When $q = 0.38$, percolation transition occurs, and the two largest clusters become integrated. Compared with scenarios 1 and 2, the critical value of q is the lowest, which means that percolation transition is further postponed. Comparing the above three scenarios, it can be seen that the better the transportation accessibility is, the later the percolation transition occurs, which is the same situation as that in the competitive trade network. In addition, from the three scenarios, it can be seen that the diffusion trends of the complementary trade network show a single polar cluster mode.

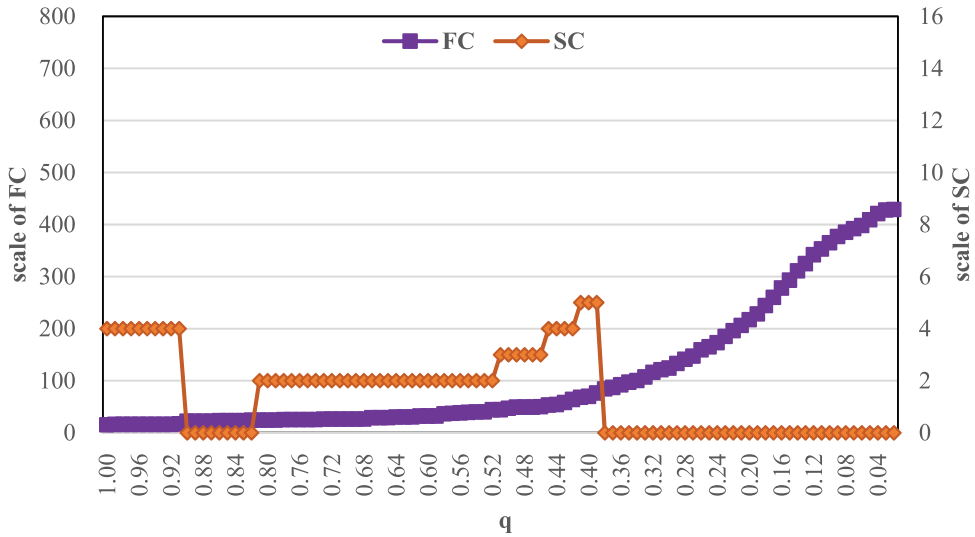


Figure 16. Percolation process of scenario 3.

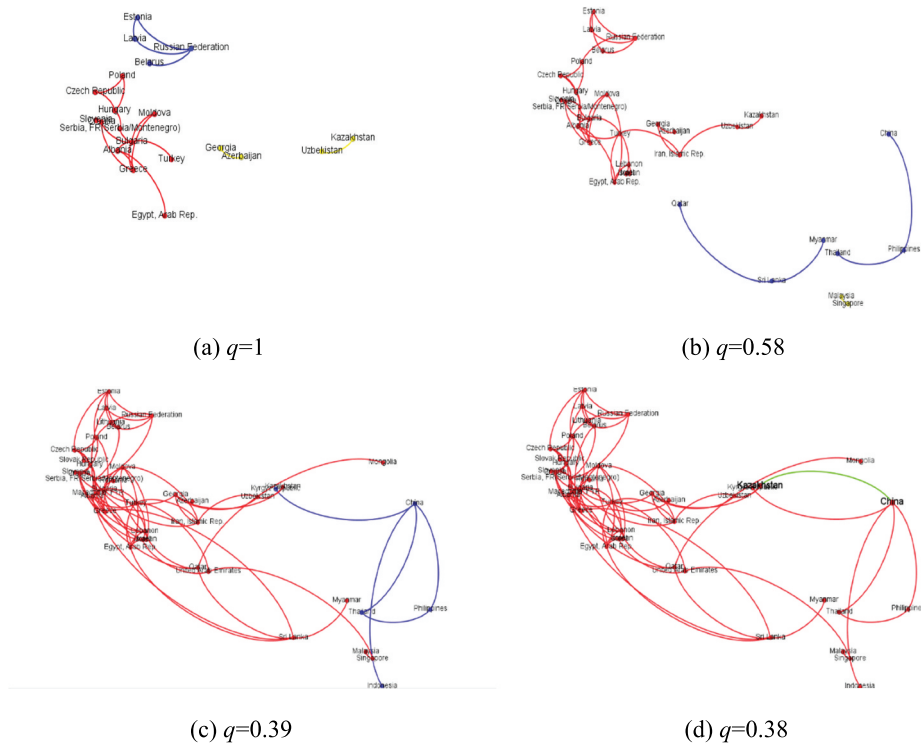


Figure 17. Spatial patterns of diffusion clusters under different q values. (a) $q = 1$, (b) $q = 0.58$, (c) $q = 0.39$, (d) $q = 0.38$.

The diffusion trend of scenario 3 is shown in Figure 17 (the notes are the same as those in Figure 6). When $q = 1$, the FC is located in Southern Europe, and the SC is located in Eastern Europe (Figure 17(a)). As q decreases, the FC expands gradually and grows to include Europe and West,

South, and East Asia, while the SC is located in East and Southeast Asia (Figure 17(b,c)). When $q = 0.38$, percolation transition occurs, and the bottleneck link is that between China and Kazakhstan (Figure 17(d)).

(2) Diffusion characteristics

According to the percolation transition process and diffusion trends, the agglomeration expands to both Middle Eastern Europe and Central Asia. Compared with scenario 2, less industries percolating regions are located along the 21st Century Maritime Silk Road. The reason may be that the transportation accessibility in these regions has been improved due to the improvement of the Asia-Europe railway. Similar to the competitive trade network, the improvement in the CR Express promotes the industries percolating from the 21st Century Maritime Silk Road to the regions of the Silk Road Economic Belt. The bottleneck countries are China and Kazakhstan, which indicates that China plays an important role in industrial relocation and diffusion and should accelerate its industrial relocation upgrading and structural adjustment.

5. Discussion and conclusions

With the continuous advancement of industrial relocation, the diffusion trends along the B&R have accelerated. Based on percolation theory, this study constructs two types of topological trade network from the perspective of the ESI and TCI to analyze the diffusion trends and bottleneck links among the B&R countries. The following interesting results are obtained. First, percolation transition occurs during the diffusion of the manufacturing relocation process from both two perspectives, which proves the feasibility of percolation theory for studying industrial relocation. Second, the stronger the competitiveness and complementarity of the commodity trade between two countries in a certain industry are, the more likely the industry to relocate between the two countries. Third, based on the current comprehensive transportation system, the main industries are percolating and agglomerating among the countries with rapid economic development along the 21st Century Maritime Silk Road. Fourth, the improvement in the CR Express postpones the diffusion trends while improving the relocation potential of Eastern Europe and Middle Eastern and Central Asia and promotes industries percolating from the 21st Century Maritime Silk Road to the regions of the Silk Road Economic Belt.

Therefore, to promote orderly and reasonable industrial relocation, several recommendations are made. First, in the current, countries along the B&R route should focus on improving the connectivity infrastructure and transportation accessibility of the 21st Century Maritime Silk Road to promote the industrial relocation of coast countries. Second, in the future, B&R countries should focus on improving the connectivity infrastructure and transportation accessibility of the Silk Road Economic Belt to make inland countries and regions the target regions for industrial relocation. Third, China will play an important role in industrial relocation and diffusion in the future, and thus, it is important for China to accelerate its industrial relocation upgrading and structural adjustment.

Notes

1. This is the TC of a forty-foot equivalent unit (FEU) of cargo per kilometer (RMB/TEU·KM).
2. The timestamps denote the waiting time for transport vehicles.
3. This is the handling fee of each FEU at the station (RMB/TEU).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Fundamental Research Funds for the Central University (2020RC010), National Natural Science Foundation of China [grant number:71621001, 91746201].

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