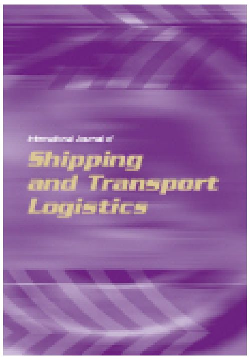


International Journal of Shipping and Transport Logistics

ISSN online: 1756-6525 - ISSN print: 1756-6517
https://www.inderscience.com/ijstl

An empirical study of Sino-European trade geographic regional competition under the belt and road and Arctic routes based on transportation cost equilibrium line model

Manling Zhang, Tianming Ding, Chaojun Ding

DOI: 10.1504/IJSTL.2024.10064765

Article History:

Received:	03 October 2023
Last revised:	21 January 2024
Accepted:	24 March 2024
Published online:	15 July 2025

An empirical study of Sino-European trade geographic regional competition under the belt and road and Arctic routes based on transportation cost equilibrium line model

Manling Zhang, Tianming Ding and Chaojun Ding*

School of Naval Architecture and Maritime,
Zhejiang Ocean University,
Changzhi Island Sea Road 1#,
Zhoushan, Zhejiang, 316022, China
Email: manningna@163.com
Email: dtmdtm@sina.com
Email: dingchaojun@zjou.edu.cn
*Corresponding author

Abstract: With the advancement of globalisation and the growth in trade activities, the demand for goods transportation between China and Europe has been continuously increasing. Faced with the ever-growing demand for cargo transportation, the commercial application of Arctic routes has presented new opportunities. In the new landscape of the traditional Suez Canal route (SCR), China-Europe freight trains, and Arctic routes, starting from China-Europe trade, utilising China's railway freight rates and maritime data, incorporating the time value cost of goods into freight calculations, and constructing a transportation cost equilibrium analysis model, we aim to explore the competitive advantages of Arctic routes, the SCR, and China-Europe freight trains in different regions. The results show that it is most economical to transport containerised goods from the northern and eastern regions of China through Arctic routes.

Keywords: Arctic routes; Suez Canal route; China-Europe Railway Express; time value cost of goods; advantageous competitive region partition.

Reference to this paper should be made as follows: Zhang, M., Ding, T. and Ding, C. (2025) 'An empirical study of Sino-European trade geographic regional competition under the belt and road and Arctic routes based on transportation cost equilibrium line model', *Int. J. Shipping and Transport Logistics*, Vol. 20, No. 3, pp.381–405.

Biographical notes: Manling Zhang is a Master's student at Zhejiang Ocean University. Her research interest is transportation planning and management.

Tianming Ding is a Professor at Zhejiang Ocean University. His research interest is marine education research.

Chaojun Ding is a Lecturer at Zhejiang Ocean University. His research interests include Arctic shipping routes, shipping networks and transportation systems.

1 Introduction

Global warming has made Arctic routes a promising transportation corridor for international trade. Among the Arctic routes, the Northeast Passage is the shortest route connecting Asia and Europe, and it is about 40% shorter than the Suez Canal route (SCR) in Asia-Europe trade (Laulajainen, 2009). Furthermore, the Arctic's abundant energy resources have also made it a new hot spot. Once the SCR is blocked due to natural disasters, piracy and war, the Arctic routes will play a greater role in world shipping. Therefore, the Arctic routes has the potential to become an alternative route for cargo shipping routes and railway routes between Asia and Europe, and will have a significant impact on the future transportation layout of the Eurasian continent.

In addition, the Chinese Government put forward the Belt and Road (B&R) Initiative in 2013, confirming the importance of China Railway Express for constructing an international land cargo route under the B&R Initiative policy (Cheng et al., 2022). Under the background of the B&R Initiative, China-Europe freight trains have developed rapidly. According to China Railway data, from January to November 2023, a total of 1.749 million 20-foot equivalent units (TEU) of goods were transported via China-Europe freight trains, up 19% from the same period a year ago (CGTN, 2023).

Moreover, the traditional SCR still dominates the cargo transport between China and Europe (Du et al., 2019). Therefore, the future cargo transport between China and Europe will form a competitive situation consisting of the traditional SCR, the China-Europe freight train, and the Arctic routes. Exploring the competitive advantages of the Arctic routes and the traditional B&R Initiative in different regions is crucial for formulating a high-quality development strategy for Arctic routes. Such exploration will help Arctic routes develop competitive strategies that meet market demand, enable China to better utilise Arctic routes as alternative shipping routes between China and Europe, and grasp the dynamic changes in the future maritime landscape.

The remaining sections of this article are as follows. Section 2 is literature review. A model for constructing geographic regional competition for Arctic routes is presented in Section 3. The data description and parameter determination are presented in Section 4. The results of the regional competitiveness analysis of Arctic routes are depicted in Section 5. Finally, conclusions are drawn.

2 Literature review

With the improvement of navigation environment of Arctic routes (Yao et al., 2022), many scholars have conducted quantitative and qualitative research on the economic feasibility of Arctic routes. Dai et al. (2021) studied the technical and economic potential of transporting liquefied natural gas (LNG) via the NSR. Li et al. (2023) compared the total cost of Arctic routes with the SCR in different seasons, demonstrating the economic feasibility of Arctic routes. Zhao et al. (2016) argued that in the short or medium term, the NSR is more likely to serve as a complementary route to liner networks. Jiang et al. (2021) found that using the NSR for container transportation has a greater profit potential than transshipment transportation; additionally, Arc4-class vessels have a greater profit potential than Arc7-class vessels. Liu and Kronbak (2010) investigated the economic potential of using the NSR as an alternative route between Asia and Europe by considering all major factors. Song and Zhang (2013) analysed the required freight rate

(RFR) of the Arctic Northeast Passage by comparing the SCR with the Northeast Passage route. Zhang et al. (2016) found that economically, Arctic routes are not preferable to traditional container shipping and may be attractive only to small and medium-sized tanker operators. Wang et al. (2018) proposed that if the ice conditions in the Arctic improve, some container shipping companies may seasonally shift to Arctic routes. Xu and Yin (2021) suggested that the icebreaking fee has a significant impact on the economic benefits of the NSR. At the optimal freight rate level, the NSR can lower transportation costs more than the SCR. Lasserre (2014) considered market factors to evaluate the potential profitability of Arctic routes. Koçak and Yercan (2021) believed that the Central Arctic Ocean and Northwest Passage routes may become cost-effective for transit voyages between Asian and European ports in a few decades. Bayirhan and Gazioğlu (2021) emphasised the importance of Arctic routes as new alternative routes for maritime trade. Munim et al. (2022) argued that operating expenses, navigational aspects, and environmental protection are the three most important criteria for deploying autonomous ships in Arctic routes. Wan et al. (2018) suggested that occasional use of the Northern Sea route (NSR), such as for a single transit, is unlikely to be more profitable due to higher unit transportation costs. However, in terms of the total profit earned from continuous use, this route may have economic competitiveness. Verny and Grigentin (2009) suggested that while shipping through the Suez Canal remains the cheapest option thus far, the NSR and the Trans-Siberian Railway appear to be roughly comparable secondary alternatives. Yangjun et al. (2018) found that as shipping speed decreases, companies' profits increase through the use of Arctic routes.

In addition, some scholars have studied the changes in shipping pattern brought about by the Arctic routes, including changes in market pattern and shipping network. Ding et al. (2022) predicted the evolution of shipping networks from 2017 to 2035 using an improved weighted network evolution model and extracted important flows in the networks through multiple connection analysis to construct a competitive network. The results showed that Guangzhou had the strongest domestic competition intensity among Chinese container ports. Faury and Cariou (2016) identified the competitive advantage of the NSR in certain months, such as from August to November and from July to November. Guo et al. (2022) explored the changes in the shipping connectivity pattern and network structure between the traditional route and Arctic routes using scenario simulations based on complex network theory and China-Europe shipping data under the background of the B&R Initiative.

Although the studies above considered the economic feasibility of Arctic routes from various perspectives, they neglected the impact of the time value of goods on transportation costs. In addition, there are few studies that comprehensively consider the Arctic routes, the China-Europe freight train and the traditional Suez Canal to analyse the future transport pattern in Eurasia. It should be noted that although the SCR still occupies a dominant position in the current Eurasian transport pattern, the development of the Arctic routes and the China-Europe freight trains will have an important impact on the Eurasian transport pattern. Therefore, it is necessary to study the competitive geographical areas of the Arctic routes, the China-Europe freight trains and the SCR, so as to provide a basis for the development of trade transportation strategies of countries along the routes. Based on the transportation cost equilibrium line model, this paper conducts research on the spatial competition patterns of Arctic routes, the traditional SCR, and the China-Europe freight train service. It aims to provide theoretical support for the planning of the future shipping market and the selection of logistics solutions between regions.

For the transportation cost equilibrium line model, the generalised transportation costs of different transportation modes are calculated first, and then the equilibrium point of the generalised transportation costs of different transportation modes is found. The transportation cost equilibrium line model is based on the extension of generalised transportation cost. At present, there are some researches on generalised transportation cost model. For instance, Hanssen et al. (2012) presented a model for analysing the generalised transport cost of an intermodal transport solution, and discussed the model results in the context of the transportation of fresh aquatic products from Norway to the Continental Europe. Sun et al. (2013) proposed a logit model based on dynamic generalised cost to compute the supply allocation of various transportation modes for passenger corridors. Cascetta et al. (2020) analysed the impact of Italian high-speed railways on transport accessibility through the generalised transportation cost model. Persyn et al. (2022) estimated road transport costs between and within European Union regions. However, there are few studies using transportation cost equilibrium line model. Lu et al. (2018) analysed the competition and cooperation spatial pattern between railway transport and shipping in China under the B&R Initiative by using the transportation cost equilibrium line model. By using the transportation cost equilibrium line model, the advantage areas of different transport modes can be analysed, and the transport spatial pattern can be described intuitively from the perspective of geographical visualisation. The transportation cost equilibrium line model has some advantages in the study of the geographic regional competition between the B&R and the Arctic routes, so this paper adopts the model to study.

3 Model establishment

3.1 Cost of the cargo time value

The theory of the cost of the cargo time value states that the value of goods changes over time. The cost of the cargo time value can be divided into the following two aspects (Feng and Sun, 2022):

1. Cost of capital occupancy: goods have value, and the time spent in transit ties up business funds, restricting the circulation of capital for the cargo owner. The cost of capital occupancy is

   $$T_\alpha = \lambda P_r T_i \tag{1}$$

   where λ is the daily interest rate of the bank, calculated based on the 1-year market quoted interest rate published by the National Interbank Funding Center in 2022, 3.65%; P_r is the initial value of goods; r is different types of goods; and T_i is the transportation time for transportation mode i.

2. Loss of goods value: the value of goods changes with supply and demand, consumer preferences, market conditions, and the technological content of products. Over time, products depreciate in value. In this study, the devaluation rate of goods is assumed to be constant; additionally, $dP/dt = -\omega P(t)$. Therefore, the time value function satisfies $P(t) = P_r e^{-\omega t}$, where P_r is the initial value of goods; ω is the devaluation rate

of goods, which is a constant; T_i is the time for transportation mode i; and T_u is the expected transportation time constraint. Thus, the loss in goods value at time T_i is

$$T_\beta = \Delta P = P(0) - P(T_i) = P_r - P_r e^{-\omega T_i} = P_r\left(1 - e^{-\omega T_i}\right) \tag{2}$$

Here, it is assumed that the shipper uses the transportation time of the faster mode of transportation, such as China-Europe block train railway transportation, as the benchmark for the expected transportation time T_u for various types of goods. Therefore, there are no additional benefits arising from saving transportation time. However, if goods cannot be delivered within the expected transportation time T_u, it will result in a corresponding loss of goods value. Let δ be the goods value sensitivity coefficient, which represents the degree of consideration given by the shipper to the time value cost of goods when choosing the mode of transportation. When $\delta < 1$, it indicates that the importance of the time value cost of goods is less than that of the transportation cost. When $\delta = 1$, it indicates that the importance of the time value cost of goods is equal to that of the transportation cost. When $\delta > 1$, it indicates that the importance of the time value cost of goods is greater than that of the transportation cost. The time value cost of goods can be calibrated using historical and statistical data. Therefore, the time value cost of goods is

$$g(P, \omega, t) = \delta\left(T_\alpha + T_\beta\right) = \delta\left[\lambda P_r T_i + P_r\left(1 - e^{-\omega T_i}\right)\right] \tag{3}$$

3.2 Classification of the time value of goods

The characteristics of the value of goods are studied based on two aspects: the time sensitivity of goods and the value of goods. Based on the time value, containerised goods between China and Europe are divided into four categories. To select representative goods for the study in segmented markets, this study refers to the literature and customs statistics (Feng et al., 2020). Taking a 40-foot container (FEU) as the standard, the value of goods for laptop computers, automotive components, fruits, and industrial parts is estimated, considering the characteristics and market value of each goods type. These values are used as the initial values of goods in the simulation analysis. For convenience of discussion, the average daily depreciation rate is calculated, as shown in Table 1.

3.3 Analysis model for the transport cost-time value balance

The transportation cost equilibrium line refers to the boundary that divides the service scope of different transportation modes and routes based on the difference in freight costs. The analysis steps and model are as follows (Lu et al., 2018):

1. Calculate the railway transportation cost for various city nodes in China to reach their destinations via the China-Europe Railway (based on transportation distance × railway freight rate).
2. Calculate the maritime freight cost for various city nodes in China to reach their destinations via the SCR. This cost includes the railway freight cost for transporting goods from city nodes to port cities (based on transportation distance × railway freight rate), as well as the maritime freight cost for port cities to reach Hamburg, Germany, via the SCR.

3 Calculate the maritime freight cost for various city nodes in China to reach their destinations via, among Arctic routes, the Northeast Passage. This cost includes the railway freight cost for transporting goods from city nodes to port cities (based on transportation distance × railway freight rate), as well as the maritime freight cost for port cities to reach Hamburg, Germany, via Arctic routes.

4 Calculate the cost of the time value of goods for various city nodes in China to reach Hamburg, Germany, via different transportation modes. Generally, the cost of the time value of goods is higher for goods transported to Europe via the SCR and Arctic routes compared to railway transportation.

5 To calculate and extract the transportation cost equilibrium line, we have *i* available transportation modes ($i = 1, 2, 3$) between location *A* and location *B*. The i^{th} transportation mode represents China-Europe railway transportation, SCR transportation, and Arctic route transportation. The i^{th} transportation mode has a transportation time of T_i (measured in days) from location *A* and location *B* and a freight cost of C_i (measured in US dollars per FEU). The generalised cost c for shippers to choose transportation mode *i* includes both the cost of the time value of goods and the freight cost. Therefore, the generalised cost G_i of choosing transportation mode *i* is

$$G_i = C_i + g(P, \omega, t) = C_i + \delta\left(T_\alpha + T_\beta\right) = C_i + \delta\left[\lambda P_r T_i + P_r\left(1 - e^{-\omega T_i}\right)\right] \quad (4)$$

Table 1 Basic attributes of goods based on their value characteristics

Category of goods	*Category characteristics*	*Category examples*	*Value of goods (ten thousand US dollars/FEU)*	*Average daily depreciation rate*
High-value and high-time-sensitive goods	The goods themselves have a high value, and they depreciate quickly	Mobile phones, computers, electronic components, medical devices, etc.	147	0.0433%
High-value and low-time-sensitive goods	The goods themselves have a high value, but in the short-term, prices tend to stabilise	Processed products, household items, chemical products, metal products, etc.	100	0.0012%
Low-value and high-time-sensitive goods	The goods themselves do not have a high value, but due to factors such as shelf life, they depreciate quickly	Fruits, flowers, fresh products, general clothing, etc.	50	0.1%
Low-value and low-time-sensitive goods	The goods have a low intrinsic value, and market prices fluctuate minimally, leading to insignificant depreciation in the short-term	Rubber, grains, plastics, mining and construction materials, industrial parts, etc.	10	0.001%

The transportation cost equilibrium line refers to the position in a certain region, location *j*, where the generalised cost $G_j^i = C_j^i + g(P, \omega, t)$ of each available transportation mode *i* becomes equal. This position is known as the equilibrium point of container transportation costs, and the line connecting these equilibrium points represents the transportation cost equilibrium line. On either side of the equilibrium line are the spatial advantage areas for different transportation modes.

Based on the transportation cost equilibrium line model, using the ArcGIS platform, the transportation cost raster layers for reaching Hamburg, Germany, from various city nodes in China are obtained through the kriging spatial interpolation method. The raster calculator is used to calculate the transportation cost raster layers for different transportation modes and routes, which are then merged and vectorised to obtain the container transportation cost equilibrium line with Hamburg, Germany, as the endpoint.

4 Data description and parameter determination

Considering the importance of Germany in the European Union and the significant position of the Port of Hamburg in Germany, this study calculates all data based on Germany, specifically Hamburg, as the transportation endpoint. For convenience, all EU-China containerised cargo departs from eight major Chinese container ports: Dalian Port, Tianjin Port, Qingdao Port, Shanghai Port, Ningbo-Zhoushan Port, Xiamen Port, Guangzhou Port and Shenzhen Port (Peng et al., 2022).

4.1 Determination of the transportation time

In this paper, the transportation time for the SCR, China-Europe freight trains, and Arctic routes is determined based on the transportation distance and speed. The transportation distance for the SCR and China-Europe freight trains can be obtained from the 'Distance & Time' website. The transportation distance for Arctic routes is referenced from the historical voyage data of the COSCO Shipping Group in the Northeast Passage (Cai et al., 2020). The average ship speed for container ships in the SCR is generally set at an economical speed of approximately 18 knots (nautical miles per hour). Container transportation to Hamburg, Germany, via the SCR requires approximately four port calls with an average stay of two days at each port. The average speed of China-Europe freight trains varies due to factors such as the route, season, and cargo volume. Based on the current operating conditions of China-Europe freight trains, an average speed of 700 km/day (29.2 km/h) is selected. Among Arctic routes, the Northeast Passage is a relatively new route, and historical data may be limited. Regarding the Northeast Passage, in recent years, the average sailing speed in the summer season has usually been approximately 10–15 knots per hour. Considering the current navigational conditions of Arctic routes, an average speed of 13 knots is selected for Arctic routes. Table 2 shows the shipping distances and travel times to Hamburg, Germany, from China's major container ports via the SCR and the Northeast Passage.

Table 2 Comparison of shipping distances between major container ports in China and Hamburg port

Port	*SCR*		*Northeast Passage*	
	Distance (nautical mile)	*Time (day)*	*Distance (nautical mile)*	*Time (day)*
Dalian	11,056	34	7,625	24
Tianjin	11,222	34	8,006	26
Qingdao	10,882	33	7,770	25
Shanghai	10,598	33	7,587	24
Ningbo-Zhoushan	10,511	32	7,731	25
Xiamen	10,103	31	8,097	26
Shenzhen	9,891	31	8,369	27
Guangzhou	9,928	31	8,429	27

4.2 Determination of container freight rates

According to the Shanghai Containerized Freight Index (SCFI) published by the Shanghai Shipping Exchange, under normal circumstances, the container freight rates for the Shanghai-Europe route are mainly approximately $1,000/TEU. Based on information from the China Maritime Service Network and relevant shipping websites, the container freight rates for the SCR are approximately $0.15/(FEU·km). According to data from Xinhua News Agency's China Economic Information Service and the current status of the China-Europe Railway Express, the container freight rates for the China-Europe Railway Express are approximately $0.7/(FEU·km).

The direct shipping costs of a vessel include fixed costs and variable costs. Fixed costs mainly consist of vessel depreciation, crew costs, insurance fees, vessel maintenance costs, and management fees, while variable costs include fuel costs, lubricant costs, canal fees, icebreaking and pilotage fees, and port dues. This paper uses a cost analysis approach to analyse and calculate the single-voyage transportation costs of, among Arctic routes, the Northeast Passage and the SCR (Zhu et al., 2018; Tseng et al., 2021).

1 Determination of sample ports

For convenience of analysis, this paper selects Shanghai Port, China's largest container port, as the starting point. Simultaneously, considering the significant share of China-Germany trade in bilateral trade between China and the European Union, this paper selects Hamburg Port, Germany's largest port, as the sample destination port.

2 Determination of sample vessel types

Due to the requirement of navigating through the 13-metre-deep Sannikov Strait along the Northeast Passage, which restricts the passage of fourth-generation and above container vessels, this paper considers that most vessels conducting trial navigation on Arctic routes are 1A/PC7 ice-class vessels. Therefore, this paper selects a 4,051 TEU container vessel (with a draft depth that meets the requirements of Arctic routes) and a 4,051 TEU 1A/PC7 ice-class container vessel as the sample vessel types. Due to the limitation of deadweight tonnage, the 4,051 TEU container vessel can load only 2,800 TEU when fully loaded (Xia and Hu, 2017). Based on data provided by the China Maritime Service Network and the website www.containership-info.com, the basic information of the 4,051 TEU container vessel is shown in Table 3.

Table 3 The basic information of the 4,051 TEU container vessel

Title	*Parameter*	*Title*	*Parameter*
Maximum speed	24 kn	Main engine fuel consumption rate	0.171 kg-kw^{-1}-h^{-1}
Draft	12.5 m	Main engine power output	36,543 kw
Rated load capacity	4,051 TEU	Gross tonnage	41,482
Actual load capacity	2,800 TEU (14 t/TEU)	Net tonnage	24,001

3 Fixed costs

The data related to fixed costs are shown in Table 5.

4 Variable costs

Fuel costs: compared to the fuel consumption of auxiliary engines, the fuel consumption of the main engine is relatively significant. Therefore, only the fuel consumption of the main engine is considered in this paper when calculating the ship's fuel costs. According to the 'National Standard for the Fuel Consumption of Transport Ships', the fuel consumption of the ship's main engine is

$$Q_z = Q_{z1} + Q_{z2} \tag{5}$$

where Q_{z1} and Q_{z2} represent the fuel consumption of the main engine during normal sailing and manoeuvring, respectively.

$$Q_{z1} = 10^{-3}\left[\alpha + (1-\alpha)\frac{D_1}{D_0}\right]P_{z1}g_{ez1}t_1 \tag{6}$$

where α is the coefficient representing the influence of the ship's cargo weight on the fuel consumption of the main engine. For container ships, the range of α is typically between 0.90 and 0.98, and for α, we take the median value of 0.94. D_1 and D_0 reflect the actual cargo weight and rated cargo weight of the ship, respectively. P_{z1} is the power of the main engine under normal operating conditions, where the main engine power of an icebreaking vessel is approximately 1.236 times that of a 4051 TEU container ship. g_{ez1} is the fuel consumption rate of the main engine under normal operating conditions; t_1 represents the normal sailing time of the ship, measured in hours (h).

$$Q_{z2} = 10^{-3}q_{zj}t_2 \tag{7}$$

where Q_{z2} is the fuel consumption of the main engine during manoeuvring, where, in this paper, ice navigation is considered manoeuvring due to the varied operating conditions of the ship's main engine in ice zones. Specifically, for ice-class vessels, approximately 1,980 nautical miles of the Northeast Passage are considered ice navigation. q_{zj} is the hourly fuel consumption during manoeuvring, which is calculated based on the rated operating conditions of the main engine at 30% using an electronically controlled fuel injection system, according to the 'National Standard for the Fuel Consumption of Transport Ships'. t_2 is the duration of the ship's manoeuvring, measured in hours (h).

$$C_z = P_{z1}Q_{z1} + P_{z2}Q_{z2} \tag{8}$$

where C_z is the fuel cost and P_{z1} and P_{z2} represent the prices of heavy fuel oil (HFO) and marine diesel oil (MDO), respectively. According to the published fuel prices on the China Maritime Services website, in June 2023, the average price of IFO380 was approximately \$459/t, and the average price of MDO was approximately 525 USD/t. Q_{z1} and Q_{z2} represent the fuel consumption of the ship during normal and manoeuvring operations, respectively.

Assuming an average speed of 18 knots for normal navigation and 13 knots for ice navigation, after calculation, the fuel consumption per voyage of a 4051 TEU container ship is approximately 3,679.84 t. The main engine fuel consumption of an icebreaking vessel during normal sailing and manoeuvring is approximately 2,361.32 t and 346.37 t, respectively.

Canal fees: the transit fee rates for the Suez Canal are shown in Table 4.

Table 4 Suez Canal transit toll rates

Suez Canal net tonnage (scnt)	*5,000*	*5,001–10,000*	*10,001–20,000*	*20,001–30,000*	*30,001–50,000*
Transit fee rate (USD/scnt)	13.15	9.03	7.01	4.92	4.55

Source: Suez Canal Authority

The specific data regarding lubricant fees, icebreaking pilotage fees, and port charges are presented in Table 5. Table 5 provides a summary and comparison of the single-voyage costs between Arctic routes and the traditional SCR.

A cost-based pricing method is used to determine the container freight rate for Arctic routes, and the expected profit of Arctic routes is referenced from the SCR. After calculation, the freight rate for Arctic routes is approximately 0.20 USD/(FEU-km).

5 Analysis of competitive regions for arctic routes

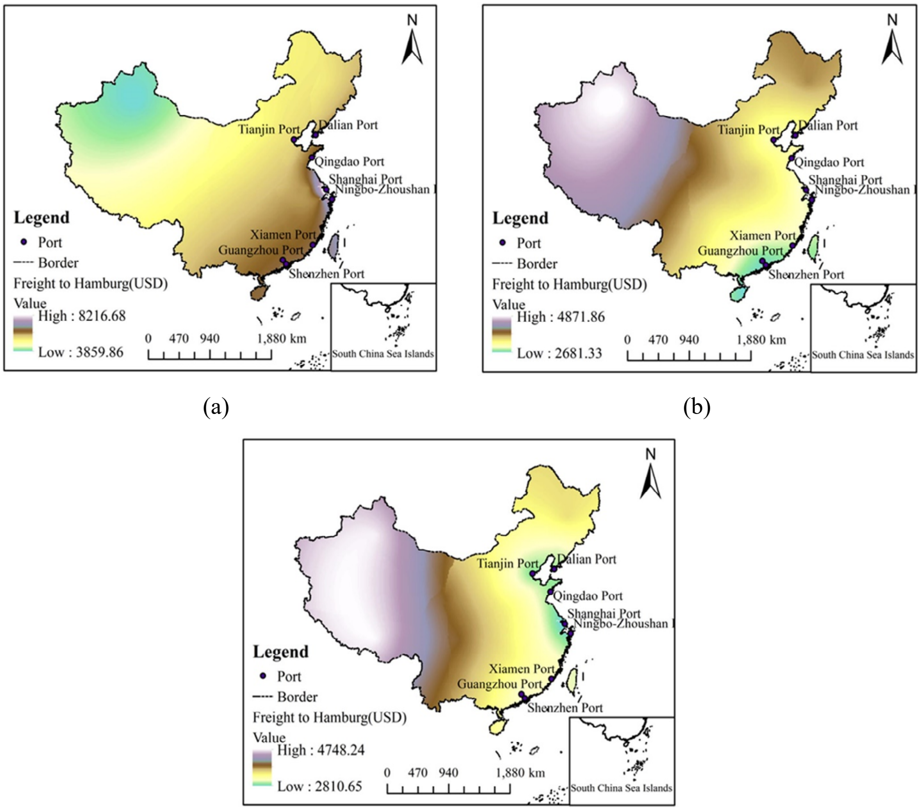
5.1 Analysis of competitive regions based on the direct transport cost

As shown in Figure 1, without considering the time value of goods, the direct transport cost for various types of cargo is the same. For container transport from mainland China to Europe, the minimum and maximum transport costs by the China-Europe Railway are \$3,859.86 and \$8,216.68, respectively, with an average cost of \$5,159.03. These results show a clear pattern of lower costs in the west and higher costs in the east. The minimum and maximum transport costs by the SCR are \$2,681.33 and \$4,871.86, respectively, with an average cost of $3,834.79. The minimum and maximum transport costs by Arctic routes are $2,810.65 and $4,748.24, respectively, with an average cost of $3,898.99.

Table 5 Comparison of single-voyage costs between Shanghai and Hamburg via the Suez Canal and Arctic routes

Title		*SCR (ten thousand US dollars)*	*Arctic routes (ten thousand US dollars)*	*Annotation*
Fixed costs	Vessel depreciation costs	16.73	15.81	The annual depreciation expense of a vessel is calculated as (new vessel value – scrap value)/expected service life. The price of a 4051 TEU container ship is approximately 45 million USD, with an average expected service life of approximately 20 years. The estimated scrap value is projected to be 8 million USD. For an icebreaking vessel, the price and estimated value after scrapping are 30% higher than those of a regular vessel.
	Crew costs	11	9.6	A container ship is typically equipped with approximately 20 crew members. According to the salary table for international seafarers in China (Shanghai), the monthly crew cost is approximately 100,000 USD. However, the crew cost for Arctic routes is 20% higher than that for regular routes.
	Insurance fees	8.14	7.69	The annual insurance cost is 2% of the vessel's value.
	Vessel maintenance costs	0.61	0.77	The annual maintenance cost for a regular container ship is approximately 1.5‰ of the vessel's construction cost. For ice-strengthened ships operating in icy areas, the annual maintenance cost is approximately 2‰ of the vessel's construction cost.
	Management fees	5.5	4.8	The management cost accounts for approximately 50% of the crew cost.
Variable costs	Fuel costs	168.90	126.57	
	Lubricant costs	8.45	6.33	These costs account for 5% of the fuel cost.
	Canal fees	28.24	0	
	Icebreaking and pilotage fees	0	58.8	According to the charging standards in Russia, the icebreaking fee is approximately 15 USD per ton.
	Port dues	8	0	Assuming that the cost for a single port is 20,000 USD.
Single-voyage costs		255.57	230.37	

Figure 1 Distribution of the direct transportation cost for various transportation modes and channels, (a) China-Europe Railway (b) Suez Canal route (c) Arctic route (see online version for colours)

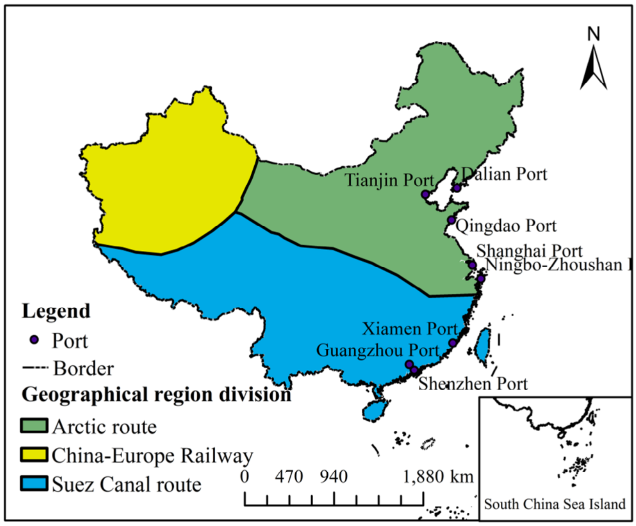


(a) (b) (c)

In terms of the position and coverage of the transport cost equilibrium line, the proportion of the coverage area for Arctic routes, the SCR, and the China-Europe Railway is approximately 8:10:5, as shown in Figure 2. Specifically, the northwestern region of China (including all of Xinjiang, Tibet, and the western parts of Qinghai and Gansu) falls within the advantageous coverage area of China-Europe Railway transport. The advantageous coverage area of Arctic routes is primarily concentrated in the northeast and central regions of China, including Inner Mongolia, Heilongjiang, Jilin, Shanxi, Shaanxi, Ningxia, Gansu, Jiangsu, Henan, Anhui, the Bohai Sea region, and the Yangtze River Delta region. The advantageous coverage area of the SCR is mainly concentrated in the southwest and southeast coastal regions of China, including Tibet, Qinghai, Sichuan, Yunnan, Guizhou, Guangxi, Hunan, Chongqing, Hubei, Jiangxi, and the Pearl River Delta region.

Overall, without considering the time value of goods, the advantageous coverage area of the SCR has the highest proportion, accounting for approximately 43.48% of the national area. The SCR is followed by Arctic routes, covering approximately 34.78% of the national area, while the China-Europe Railway, due to its high direct transportation cost, does not have an advantage and covers only approximately 21.74% of the national area. If Arctic routes are considered a supplement to the traditional SCR, maritime transportation accounts for a proportion as high as 78.26%. This result means that, except for western regions such as Xinjiang and Tibet, maritime transportation is the most economical for goods transportation in China.

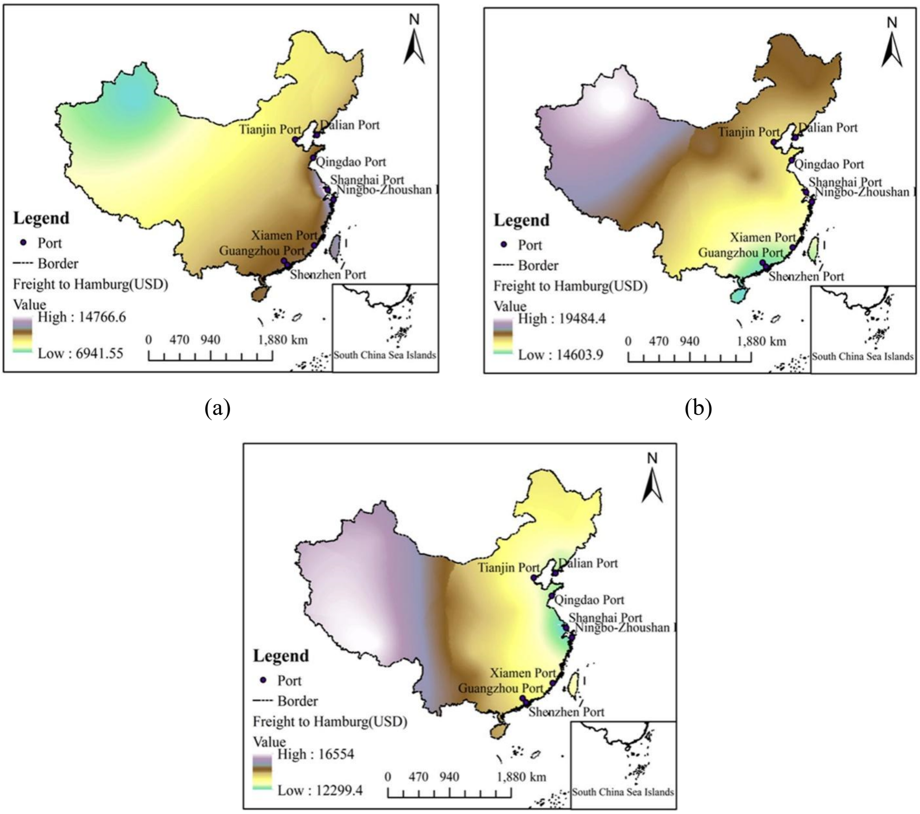
Figure 2 Regional division of the direct transportation cost for various transportation modes and channels (see online version for colours)



5.2 Analysis of competitive regions based on the time value of goods

While the direct transportation cost of maritime shipping is generally lower than that of the China-Europe Railway, the time cost of maritime transportation in most regions is significantly higher than that of the China-Europe Railway. Taking Guangzhou, located in the southeastern coastal region, as an example, the time required to transport containers from Guangzhou Port to Hamburg, Germany, via the traditional SCR and Arctic routes (Northeast Passage) is approximately 31 days and 27 days, respectively, while transportation by the China-Europe Railway to Hamburg takes only 13 days. However, not only is the time cost related to the time saved, but it is also directly linked to the freight value of containers. For instance, considering a container with a freight value of $100,000 per FEU (forty-foot equivalent unit), every extra day spent at sea will incur nearly $100 in interest losses. When maritime transportation takes approximately 20 days longer than rail transportation, the losses can amount to $2,000. This calculation considers only the cost of capital occupancy, and when considering the time value loss of different types of goods, the time value cost of goods becomes even higher. Therefore, based on the time value of goods, it is necessary to calculate the differences in transportation time costs among different transportation modes and channels for each city node and to analyse the distribution pattern of transportation costs for different types of goods.

Figure 3 Distribution of transportation costs for high-value, high-time-sensitive goods, (a) China-Europe Railway (b) Suez Canal route (c) Arctic route (see online version for colours)



(a) (b)

(c)

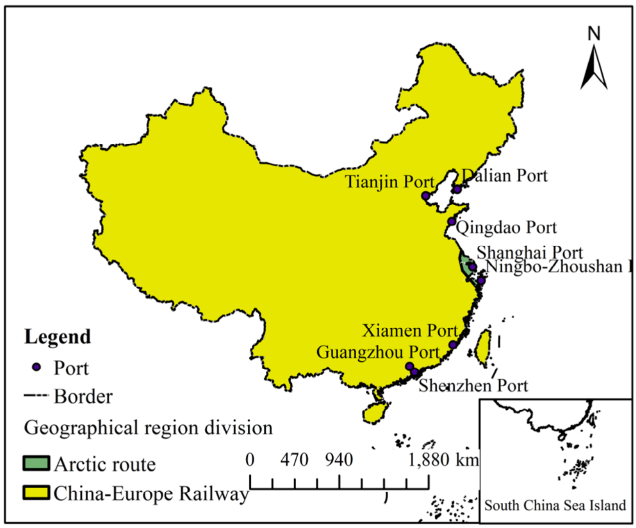
5.2.1 *Analysis of high-value and high-time-sensitive goods*

As indicated in Figure 3, considering the time value cost of goods, from the transportation cost perspective, the minimum transportation cost for high-value and high-time-sensitive goods transported by the China-Europe Railway is $6,941.55, while the maximum cost is $14,766.56, with an average transportation cost of $9,275.78. For high-value and high-time-sensitive goods transported via the SCR, the minimum transportation cost is $14,603.90, the maximum cost is $19,484.35, and the average transportation cost is $17,172.85. For high-value and high-time-sensitive goods transported via Arctic routes, the minimum transportation cost is $12,299.40, the maximum cost is $16,554, and the average transportation cost is $14,716.24.

From the position and direction of the transportation cost equilibrium line, the coverage area ratio between Arctic routes and the China-Europe Railway is approximately 1:34, while the SCR has a coverage area of 0. The reason is that the SCR has a longer transportation time, and the time value cost of high-value and high-time-sensitive goods is excessively high. Compared to Arctic routes and the China-Europe Railway, the SCR does not have any competitive advantage. Specifically, cities in the southeastern coastal region of China, including Shanghai, Ningbo, and Shenzhen, belong to the coverage area of Arctic routes, while other regions belong to the coverage area of the China-Europe Railway.

Overall, considering the time value of goods, for transporting high-value and high-time-sensitive goods, the China-Europe Railway is the most cost-effective option, as shown in Figure 4.

Figure 4 Division of high-value, high-time-sensitive cargo transportation areas (see online version for colours)

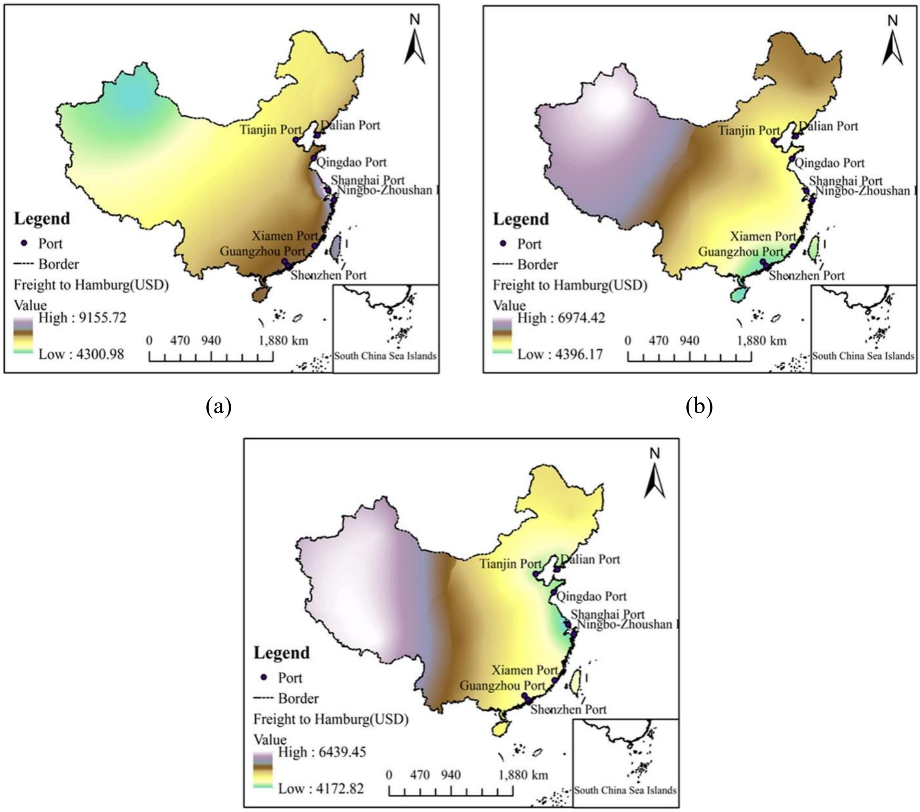


5.2.2 *Analysis of high-value and low-time-sensitive goods*

As depicted in Figure 5, considering the time value cost of goods, from the transportation cost perspective, the minimum freight cost for transporting high-value and low-time-sensitive goods via the China-Europe Railway is $4,300.98, while the maximum freight cost is $9,155.72, with an average transportation cost of $5,748.63. For the SCR, the minimum freight cost for transporting high-value and low-time-sensitive goods is $4,396.17, the maximum cost is $6,974.42, and the average transportation cost is $5,752.92. For Arctic routes, the minimum freight cost for transporting high-value and low-time-sensitive goods is $4,172.82, the maximum cost is $6,439.45, and the average transportation cost is $5,452.84.

From the perspective of the position and trend of transportation cost equilibrium lines, the coverage area ratio of Arctic routes, the SCR, and the China-Europe Railway is approximately 4:2:5, as shown in Figure 6. Specifically, the northwest region of China (including Xinjiang, Tibet, Qinghai, most of Gansu, and western Inner Mongolia) falls within the coverage area of the China-Europe Railway. The coverage area of Arctic routes is concentrated in the northeastern, central, and southeastern regions of China, including Inner Mongolia, Heilongjiang, Jilin, Shanxi, Shaanxi, Ningxia, Henan, Hubei, Jiangxi, Fujian, the Bohai Sea region, the Yangtze River Delta region, and the northern parts of Sichuan, Chongqing, and Hunan. The coverage area of the SCR is mainly concentrated in the southern regions of China, including Yunnan, Guizhou, Sichuan, Guangxi and Guangdong.

Figure 5 Distribution of transportation costs for high-value, low-time-sensitive goods, (a) China-Europe railway (b) Suez Canal route (c) Arctic route (see online version for colours)



Overall, considering the time value cost of goods, in the transportation of high-value and low-time-sensitive goods, the China-Europe Railway seems to have a competitive advantage, but its coverage area is mostly concentrated in the northwest region of China, which has relatively lagging economic development and lower demand for export trade to Europe. On the other hand, although the coverage area of Arctic routes is slightly smaller than that of the China-Europe Railway, it is mainly concentrated in the northeastern, central, and Yangtze River Delta regions of China, where there is a strong demand for goods transportation. Therefore, the competitive advantage of Arctic routes may be more apparent. If the container freight rates of Arctic routes are further reduced, their competitiveness will be greatly enhanced.

Figure 6 Division of high-value, low-time-sensitive cargo transportation areas (see online version for colours)

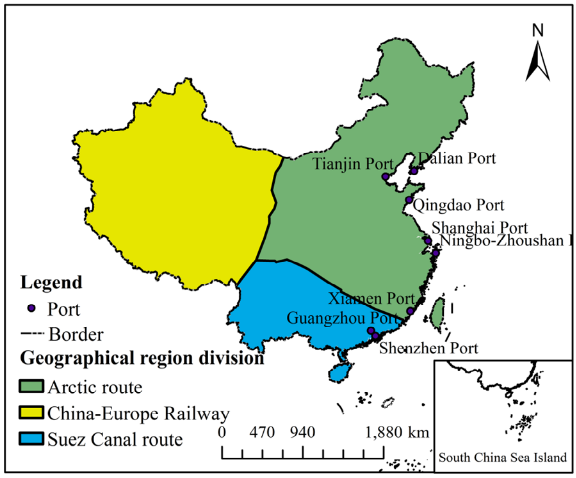
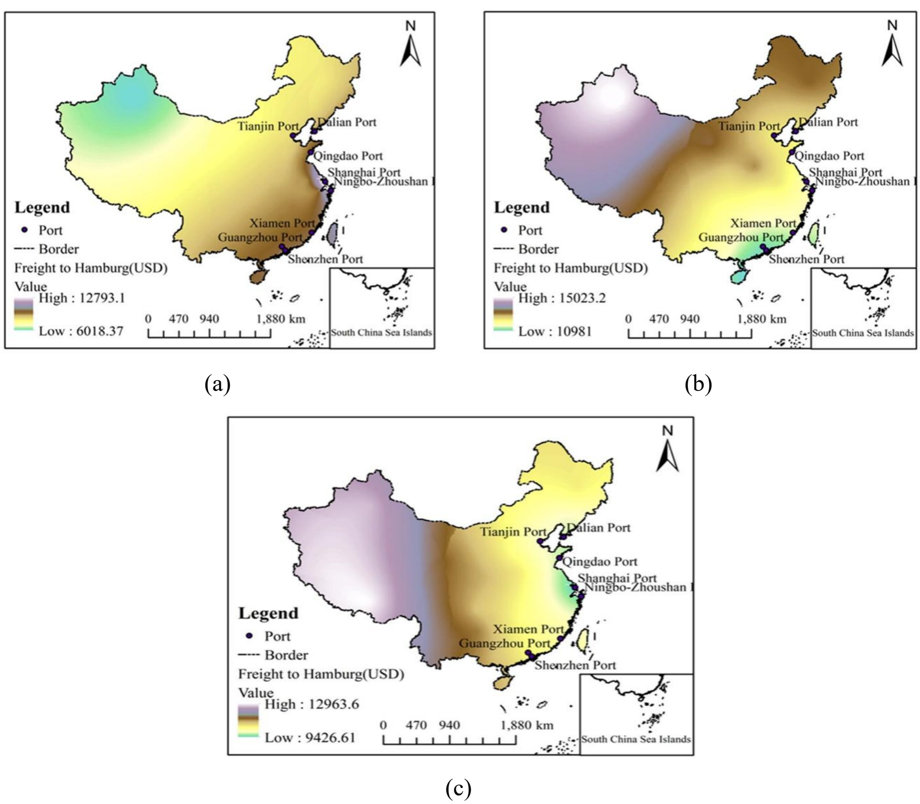


Figure 7 Distribution of transportation costs for low-value, high-time-sensitivity goods, (a) China-Europe Railway (b) Seuz Canal route (c) Arctic route (see online version for colours)



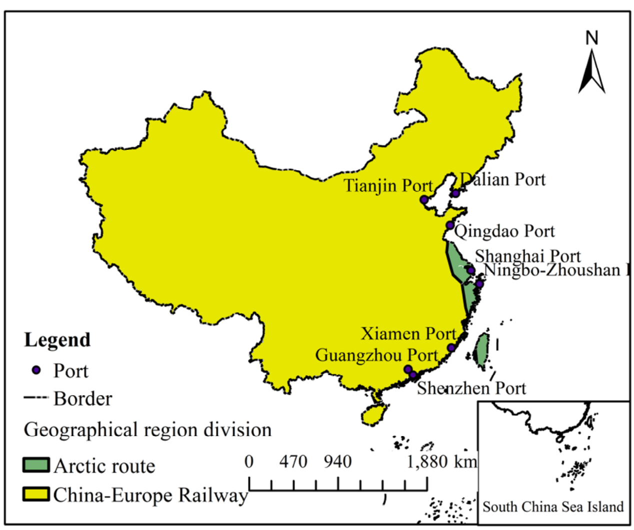
5.2.3 Analysis of low-value and high-time-sensitive goods

As Figure 7 shows, considering the time value cost of goods, from the transportation cost perspective, the minimum freight cost for transporting low-value and high-time-sensitive goods via the China-Europe Railway is \$6,018.37, the maximum cost is \$12,793.09, and the average cost is \$8,040.11. For the SCR, the minimum freight cost for transporting such goods is \$10,981, the maximum cost is \$15,023.16, and the average cost is \$13,108.86. For Arctic routes, the minimum freight cost for transporting low-value and high-time-sensitive goods is \$9,426.61, the maximum cost is \$12,963.6, and the average cost is \$11,433.84.

From the perspective of the position and trend of the transportation cost equilibrium line, the ratio of the coverage area between Arctic routes and the China-Europe Railway is approximately 5:61. The SCR does not have any advantage in terms of the coverage area due to its long transportation time and high time value cost, even though the goods themselves have low value. Specifically, the advantageous coverage area of Arctic routes is mainly concentrated in the southeastern coastal areas of China, including cities such as Jiangsu, Zhejiang, and Shenzhen, while other regions belong to the advantageous coverage area of the China-Europe Railway.

Overall, considering the time value cost of goods, the competitive advantage of the China-Europe Railway in transporting low-value and high-time-sensitive goods remains unchanged, as shown in Figure 8.

Figure 8 Division of low-value, high-time-sensitive cargo transportation areas (see online version for colours)

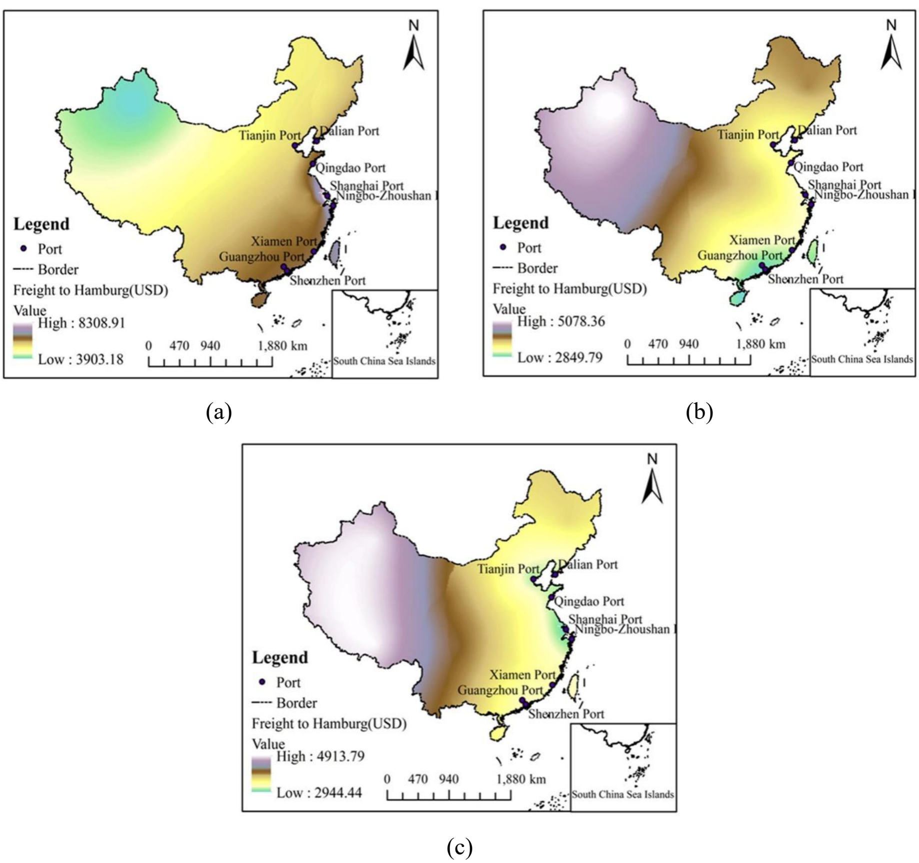


5.2.4 Analysis of low-value and low-time-sensitive goods

As Figure 9 shows, considering the time value cost of goods, from the transportation cost perspective, the minimum freight cost for transporting low-value and low-time-sensitive goods by the China-Europe Railway is \$3,903.18, the maximum cost is \$8,308.91, and the average cost is \$5,216.93. For the SCR, the minimum freight cost for transporting such goods is \$2,849.79, the maximum cost is \$5,078.36, and the average cost is \$4,023.18. For Arctic routes, the minimum freight cost for transporting low-value and low-time-sensitive goods is \$2,944.44, the maximum cost is \$4,913.79, and the average cost is \$4,051.60.

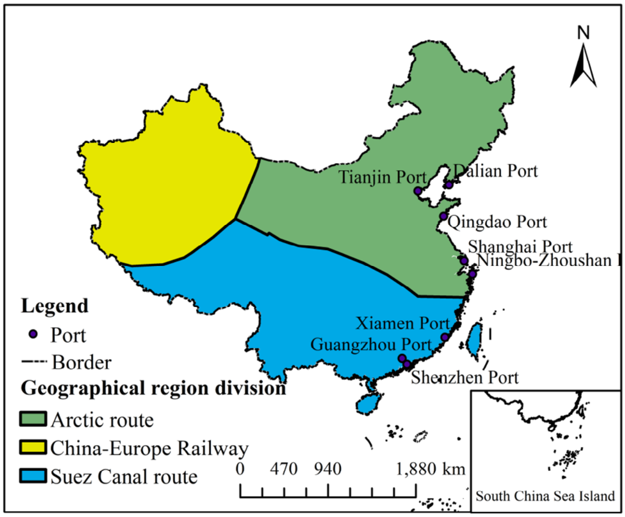
From the perspective of the position and trend of transportation cost equilibrium lines, the proportional coverage area of Arctic routes, the SCR, and the China-Europe Railway is approximately 8:9:5, as shown in Figure 10. Specifically, the northwest region of China (including all of Xinjiang, Tibet, and the western parts of Qinghai and Gansu) falls within the advantageous coverage area of the China-Europe Railway. The advantageous coverage area of Arctic routes is mainly concentrated in the northeast and central regions of China, as well as the Yangtze River Delta region, including Inner Mongolia, Heilongjiang, Jilin, the Bohai Rim region, Shanxi, Shaanxi, Ningxia, Gansu, Henan, and the Yangtze River Delta region. The advantageous coverage area of the SCR is mainly concentrated in the central, southwest, and southeast coastal regions of China, including most areas of Tibet and Qinghai, as well as Yunnan, Guizhou, Sichuan, Hubei, Hunan, Jiangxi, Guangxi, Fujian, and the Pearl River Delta region.

Figure 9 Distribution of transportation costs for low-value, low-time-sensitive goods



Overall, considering the time value of goods, the SCR has a slightly greater competitive advantage than Arctic routes for transporting low-value and low-time-sensitive goods. To make Arctic routes more competitive compared to the traditional SCR, it is necessary to consider further reducing the container freight rates of Arctic routes in the region.

Figure 10 Division of low-value, low-time-sensitive cargo transportation areas (see online version for colours)



5.2.5 *Comparative analysis*

The comparison of the advantageous coverage areas of various transportation modes and channels is shown in Table 6. In general, the China-Europe Railway Express has the largest coverage in terms of competitive advantage in the transportation of high-value and high-time-sensitive goods, high-value and low-time-sensitive goods, and low-value and high-time-sensitive goods, accounting for 97.14%, 45.45%, and 92.42% of the national coverage, respectively. In the calculation results in Section 5.1 without considering the time value, the advantage area of the European freight train covers the smallest area. Through the comparison of these two results, it is shown that the advantages of China-Europe freight trains lie in the rapid and stable transport of goods, and for the goods with high time sensitivity, China-Europe freight trains have great advantages.

The SCR has the largest coverage in the transportation of low-value and low-time-sensitive goods, covering approximately 45.45% of the country. However, it has no advantage in the transportation of high-value and high-time-sensitive goods or low-value and high-time-sensitive goods. Arctic routes have a competitive advantage in the transportation of high-value and low-time-sensitive goods and low-value and low-time-sensitive goods, covering approximately 36.36% of the national coverage. Refer to Table 7 for specific details. If the Arctic Northeast Passage is considered a supplement to the traditional SCR, maritime transportation has an absolute advantage in the transportation of low-time-sensitive goods (including high-value and low-time-sensitive goods and low-value and low-time-sensitive goods), except for the northwest region, accounting for 54.55% and 77.27% of the national coverage, respectively. For high-time-sensitive goods, shippers should choose the China-Europe Railway Express as much as possible, and if only maritime transportation is considered, Arctic routes are the most economical.

Table 6 Comparison of the advantageous coverage areas of various transportation modes and channels

Transportation modes and routes	*High-value and high-time-sensitive goods*	*High-value and low-time-sensitive goods*	*Low-value and high-time-sensitive goods*	*Low-value and low-time-sensitive goods*
Proportion of the advantageous area for Arctic routes	2.86%	36.36%	7.58%	36.36%
Proportion of the advantageous area for the China-Europe Railway Express	97.14%	45.45%	92.42%	22.73%
Proportion of the advantageous area for the SCR	0	18.18%	0	40.91%

Table 7 The characteristics of this study and other studies

	Methods	*Problems*	*Results*
Benedyk and Peeta (2018)	Binary probit model	Views of freight decision makers on container shipping on the NSR	For freight decision makers with an annual throughput of more than 1,000 TEUs, the probability of using the NSR is 33.5% lower than using the traditional route, that is, the probability of choosing the NSR is 33.25%
Wang et al. (2018)	Logit model	Investigate shipping companies' choices between the NSR and SCR under different cases	With the change of transportation cost of the Arctic routes, the probability of container ships choosing the Arctic routes is between 3.26–69.19%
Zeng et al. (2020)	Bootstrapped multinomial logit model	The commercial prospects and potential of shipping via the NSR from the Northeast China, East China, and South China regions in the context of the B&R Initiative	In the case of changes in economic, natural conditions and shippers' preferences, the market share of the Arctic routes is relatively small, accounting for less than 1%, and the main driving force affecting China's foreign transport in the future is the China-Europe freight train
This study	Transportation cost equilibrium line model	Sino-European trade geographic regional competition under the B&R and Arctic Routes	Arctic routes have a competitive advantage in the transportation of high-value and low-time-sensitive goods and low-value and low-time-sensitive goods, covering approximately 36.36% of the national coverage

According to the research results, the SCR dominates the Sino-European trade at present. However, with the development of China-Europe freight trains and Arctic routes, SCR, China-Europe freight trains and Arctic routes have different geographical advantages in different cargo types. Therefore, for different geographical regions in China, one of the foreign transport routes should be developed according to its geographical location and main trade goods, so as to improve the efficiency of China's overall foreign trade transport.

In addition, in order to analyse the validity of this study, the study in this paper is compared with the existing relevant studies. Three relevant representative studies were selected for comparison: Benedyk and Peeta (2018), Wang et al. (2018), Zeng et al. (2020). The comparison is shown in Table 7.

As can be seen from Table 7, the results of various studies are different, and there are several reasons for this.

1 The research object of Benedyk and Peeta (2018) and Wang et al. (2018) is freight decision makers, while the research object of Zeng et al. (2020) and this paper is the competitive share of the transport market Sino-European transport market.

2 Benedyk and Peeta (2018) and Wang et al. (2018) only analysed the competition between the Arctic routes and the SCR, while Zeng et al. (2020) and this paper analysed the competition between the Arctic routes, the SCR and the China-Europe freight trains. Therefore, the latter two studies are more comprehensive in this regard.

3 Benedyk and Peeta (2018), Wang et al. (2018) and Zeng et al. (2020) only analysed the share of Arctic routes. This paper not only analyses the share of the Arctic routes in Sino-European trade, but also analyses the advantageous regions of the Arctic routes, and visually depicts the spatial pattern of transportation from the perspective of geographic visualisation. This paper shows some advantages in this aspect.

5.3 Suggestions

Through the analysis above, it was found that the commercial operation of Arctic routes can to some extent change the future development pattern of maritime transportation. In the transportation of high-value and low-time-sensitive goods, the transportation time of Arctic routes can meet the expectations of shippers. Shipping companies can adopt incentives such as improving transportation service quality or further reducing transportation costs to attract market demand. The northern region of China and the southeastern coastal cities are advantageous competitive areas for Arctic routes. From this perspective, it would be beneficial to establish transshipment centres for Arctic routes in the Yangtze River Delta and Bohai Rim regions, creating an efficient organisation and utilisation of Arctic routes.

6 Conclusions

This article is based on the background of the commercial operation of Arctic routes and adopts the theory of the time value of goods to construct an analysis model of transportation cost equilibrium. It divides and analyses the geographic competitive areas of Arctic routes, the SCR, and the China-Europe Railway Express. From the perspective of goods transportation, Arctic routes have a competitive advantage in the market for high-value and low-time-sensitive goods, face intense competition in the market for low-value and low-time-sensitive goods, and have potential in the market for high-value and high-time-sensitive goods and low-value and high-time-sensitive goods. From the perspective of the regional division, compared to the southern and western regions of China, the northern and eastern regions of China have more economical transportation of container goods through Arctic routes. With the increase in the scale of container transportation, considering the diversion of transportation routes, Arctic routes can to some extent assist the traditional SCR in gradually radiating to the northern regions of China. From this perspective, it would be beneficial to establish transshipment centres for Arctic routes in the Yangtze River Delta and Bohai Rim regions, facilitating the efficient organisation and utilisation of Arctic routes.

However, there are still some problems in this paper that need to be improved in the future outlined below:

1. This paper focuses on the use of transportation costs to analyse the geographic regional competition between the B&R and the Arctic routes. However, it should be noted that the factors affecting the competitiveness of cargo transportation between the B&R and the Arctic routes are not only cost, but also geopolitical and economic factors, which should be taken into account in the future.
2. This paper studies the transport pattern between China and Europe based on the current navigation environment of the Arctic routes, but does not analyse the change of the competition pattern caused by the change of the navigation environment of the Arctic routes in the future. Further research on this aspect can be done in the future.

Acknowledgements

The open access fee of this work is supported by China Merchants Energy Shipping.

References

Bayirhan, İ. and Gazioğlu, C. (2021) 'New maritime trade routes in the Arctic Region: one of the strongest alternative to the Suez Canal', *International Journal of Environment and Geoinformatics*, Vol. 8, No. 3, pp.397–401.

Benedyk, I.V. and Peeta, S. (2018) 'A binary probit model to analyze freight transportation decision-maker perspectives for container shipping on the Northern Sea Route', *Maritime Economics & Logistics*, Vol. 20, No. 9, pp.358–374.

Cai, M., Cao, W. and Hu, B. (2020) 'An analysis of economic and future development of Arctic Northeast Passage', *Journal of Transport Information and Safety*, Vol. 38, No. 3, pp.105–111, 147, in Chinese.

Cascetta, E., Cartenì, A., Henke, I. and Pagliara, F. (2020) 'Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives', *Transportation Research Part A: Policy and Practice*, Vol. 139, No. 9, pp.412–428.

CGTN (2023) *China-Europe Freight Train Services See Solid Growth in First 11 Months* [online] https://english.www.gov.cn/news/202312/06/content_WS656fe5f6c6d0868f4e8e1ee7.html (accessed 6 December 2023).

Cheng, Z., Zhao, L. and Li, H. (2022) 'Key factors that influence the performance of China Railway express operations: case studies of ten lines in China', *International Journal of Shipping and Transport Logistics*, Vol. 14, No. 4, pp.395–431.

Dai, L., Jing, D., Hu, H. and Wang, Z. (2021) 'An environmental and techno-economic analysis of transporting LNG via Arctic route', *Transportation Research Part A: Policy and Practice*, Vol. 146, No. 4, pp.56–71.

Ding, C., Li, Z., Chen, X. and Shi, X. (2022) 'The evolution and competition patterns of shipping networks under the influence of an Arctic route system', *Maritime Policy & Management*, Vol. 49, No. 4, pp.510–527.

Du, Y., Meng, Q. and Shi, W. (2019) 'Impact analysis of the traffic convoy system and toll pricing policy of the Suez Canal on the operations of a liner containership over a long-haul voyage', *International Journal of Shipping and Transport Logistics*, Vol. 11, Nos. 2–3, pp.119–144.

Faury, O. and Cariou, P. (2016) 'The Northern Sea route competitiveness for oil tankers', *Transportation Research Part A: Policy and Practice*, Vol. 94, No. 12, pp.461–469.

Feng, F. and Sun, J. (2022) 'Time value based route and port selection for China and Africa multimodal transportation', *Journal of Transportation Systems Engineering and Information Technology*, Vol. 22, No. 2, pp.45–53, in Chinese.

Feng, F., Lang, J., Liu, C. and Jia, J. (2020) 'Analysis of competitiveness of China and Europe in the context of 'One Belt and One Road' based on goods segmentation and logit model', *Journal of Technology Economics*, Vol. 39, No. 3, pp.119–128, in Chinese.

Guo, J., Guo, S. and Lv, J. (2022) 'Potential spatial effects of opening Arctic shipping routes on the shipping network of ports between China and Europe', *Marine Policy*, Vol. 136, No. 2, p.104885.

Hanssen, T.E.S., Mathisen, T.A. and Jørgensen, F. (2012) 'Generalized transport costs in intermodal freight transport', *Procedia – Social and Behavioral Sciences*, Vol. 54, No. 10, pp.189–200.

Jiang, M., Hu, M. and Leibrecht, M. (2021). 'Profitability of container shipping via the Arctic Northeast Passage: a simulation and regression analysis', *Marine Policy*, Vol. 133, No. 11, p.104738.

Koçak, S.T. and Yercan, F. (2021) 'Comparative cost-effectiveness analysis of Arctic and international shipping routes: a fuzzy analytic hierarchy process', *Transport Policy*, Vol. 114, pp.147–164.

Lasserre, F. (2014) 'Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector', *Transportation Research Part A: Policy and Practice*, Vol. 66, pp.144–161.

Laulajainen, R. (2009) 'The Arctic sea route', *International Journal of Shipping and Transport Logistics*, Vol. 1, No. 1, pp.55–73.

Li, Z., Ding, L., Huang, L., Ringsberg, J.W., Gong, H., Fournier, N. and Chuang, Z. (2023) 'Cost-benefit analysis of a trans-Arctic alternative route to the Suez Canal: a method based on high-fidelity ship performance, weather and ice forecast models', *Journal of Marine Science and Engineering*, Vol. 11, No. 4, p.711.

Liu, M. and Kronbak, J. (2010) 'The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe', *Journal of transport Geography*, Vol. 18, No. 3, pp.434–444.

Lu, M., Chen, Y. and Lu, Y. (2018) 'The competition and cooperation spatial pattern between railway transport and shipping in China under the Belt and Road Initiative', *Geographical Research*, Vol. 37, No. 2, pp.404–418, in Chinese.

Munim, Z.H., Saha, R., Schøyen, H., Ng, A.K. and Notteboom, T.E. (2022) 'Autonomous ships for container shipping in the Arctic routes', *Journal of Marine Science and Technology*, Vol. 27, No. 1, pp.320–334.

Peng, Y., Zhang, X., Li, Z. and Du, D. (2022) 'Evolution of freight spatial pattern of China's coastal ports facing the Polar Silk Road', *Research in Transportation Business and Management*, Vol. 45, p.100900.

Persyn, D., Díaz-Lanchas, J. and Barbero, J. (2022) 'Estimating road transport costs between and within European Union regions', *Transport Policy*, Vol. 124, pp.33–42.

Song, Y.P. and Zhang, A.F. (2013) 'The economy analysis of sailing in the Arctic Northeast Passage', *Applied Mechanics and Materials*, Vol. 409, pp.1253–1257.

Sun, Q., Zhu, L. and Chen, B. (2013) 'A dynamic generalized cost based logit model for passenger corridors', *Journal of Transportation Systems Engineering and Information Technology*, Vol. 13, No. 4, pp.15–21.

Tseng, P.H., Zhou, A. and Hwang, F.J. (2021) 'Northeast Passage in Asia-Europe liner shipping: an economic and environmental assessment', *International Journal of Sustainable Transportation*, Vol. 15, No. 4, pp.273–284.

Verny, J. and Grigentin, C. (2009) 'Container shipping on the Northern Sea route', *International Journal of Production Economics*, Vol. 122, No. 1, pp.107–117.

Wan, Z., Ge, J. and Chen, J. (2018) 'Energy-saving potential and an economic feasibility analysis for an Arctic route between Shanghai and Rotterdam: case study from China's largest container sea freight operator', *Sustainability*, Vol. 10, No. 4, p.921.

Wang, H., Zhang, Y. and Meng, Q. (2018) 'How will the opening of the Northern Sea route influence the Suez Canal route? An empirical analysis with discrete choice models', *Transportation Research Part A: Policy and Practice*, Vol. 107, pp.75–89.

Xia, Y. and Hu, M. (2017) 'Comparative analysis on the geographical location advantage of the Arctic routes and the traditional routes', *World Regional Studies*, Vol. 26, No. 2, pp.20–32, in Chinese.

Xu, H. and Yin, Z. (2021) 'The optimal icebreaking tariffs and the economic performance of tramp shipping on the Northern Sea route', *Transportation Research Part A: Policy and Practice*, Vol. 149, pp.76–97.

Yangjun, W., Ren, Z., Shanshan, G. and Longxia, Q. (2018) 'Investigating the effect of Arctic sea routes on the global maritime container transport system via a generalized Nash equilibrium model', *Polar Research*, Vol. 37, No. 1, p.1547042.

Yao, S., Hu, H. and Yang, J.B. (2022) 'A probabilistic safety assessment framework for arctic marine traffic using the evidential reasoning approach', *International Journal of Shipping and Transport Logistics*, Vol. 14, No. 3, pp.266–301.

Zeng, Q., Lu, T., Lin, K.C., Yuen, K.F. and Li, K.X. (2020) 'The competitiveness of Arctic shipping over Suez Canal and China-Europe Railway', *Transport Policy*, Vol. 86, pp.34–43.

Zhang, Y., Meng, Q. and Ng, S.H. (2016) 'Shipping efficiency comparison between Northern Sea route and the conventional Asia-Europe shipping route via Suez Canal', *Journal of Transport Geography*, Vol. 57, pp.241–249.

Zhao, H., Hu, H. and Lin, Y. (2016) 'Study on China-EU container shipping network in the context of Northern Sea route', *Journal of Transport Geography*, Vol. 53, pp.50–60.

Zhu, S., Fu, X., Ng, A.K., Luo, M. and Ge, Y.E. (2018) 'The environmental costs and economic implications of container shipping on the Northern Sea route', *Maritime Policy & Management*, Vol. 45, No. 4, pp.456–477.