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ORIGINAL ARTICLE

Evaluating the impact of Northern Sea Route fuel costs on bilateral trade between China and the EU

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Abstract

The accelerated melting of the Arctic ice leads to the navigation of the Northern Sea Route (NSR) linking Asia and Europe, shortening transport channel between China and the European Union (EU). This has a significant impact on the China-EU bilateral trade which is analyzed in the present study. We present a framework based on a general equilibrium model for analyzing the impact of the NSR on the trade and the economies of China and the EU. Different fuel cost scenarios, consisting of fuel prices and sailing speeds on ice, are also considered. Specifically, we measure the changes in shipping costs between China and the EU, brought about by NSR navigation. These are used as a basis to quantify changes in transport technology. The Global Trade Analysis Project (GTAP) model is used to predict the trade and economic impacts. The results show that the NSR can save 0.98% in shipping costs and generate an increase in the exports of China and the EU in the order of 14,986 and 8,228 million US dollars, respectively. Among these exports, the mining industry shows the fastest growth, while the electronics industry experiences the largest increase in trade volume. Our findings reveal the potential of the NSR as an alternative route and its positive impact on bilateral trade between China and the EU. The results can provide a basis for shipping companies and governments to make decisions regarding the use of Arctic routes.

Keywords Arctic navigation · Northern Sea Route · GTAP model · Bilateral trade · Shipping costs · Fuel prices · Sailing speed

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1 Introduction

China and the European Union (EU), the two largest traders in the world, are very important to each other. In 2023, China-EU trade amounted to $766 billion according to Chinese data; an increase of 17.9% compared to 2020. Concerning trade structure, China mainly exports low value-added equipment to the EU, such as processing exports of electrical appliances and non-processing exports of textiles. In contrast, its imports are dominated by technology-intensive and capital-intensive products, such as machinery and equipment and electronic equipment (Jiang et al. 2019) (Fig. 1).

Seaborne transportation is the dominant mode of transport between China and the EU, with 80% of traded goods transported by sea. Currently, the China-EU seaborne trade crosses the Suez Canal, from Chinese seaports, southwards through the Malacca Strait, Indian Ocean, the Mediterranean Sea, through the Gibraltar Strait, into the Atlantic Ocean and finally to northwestern Europe. The Suez Canal is an important transport channel, carrying about 13.5% of the world's freight (Lee and Wong 2021). According to the Suez Canal Authority, an average of 97 ships passed through the canal per day in 2023 (Chorev 2023). With the growing demand for international trade and the spread of larger ships, the Suez Canal is increasingly becoming a bottleneck due to capacity constraints (Li et al. 2022). In March 2021, the blockage of the canal by the Ever Given mega-containership, exposed not only the capacity pressures and security concerns facing the Suez Canal as a key route for global trade, but also emphasized the risks of trade's dependence on a single shipping lane and logistics network. The need to alleviate the pressure of congestion on

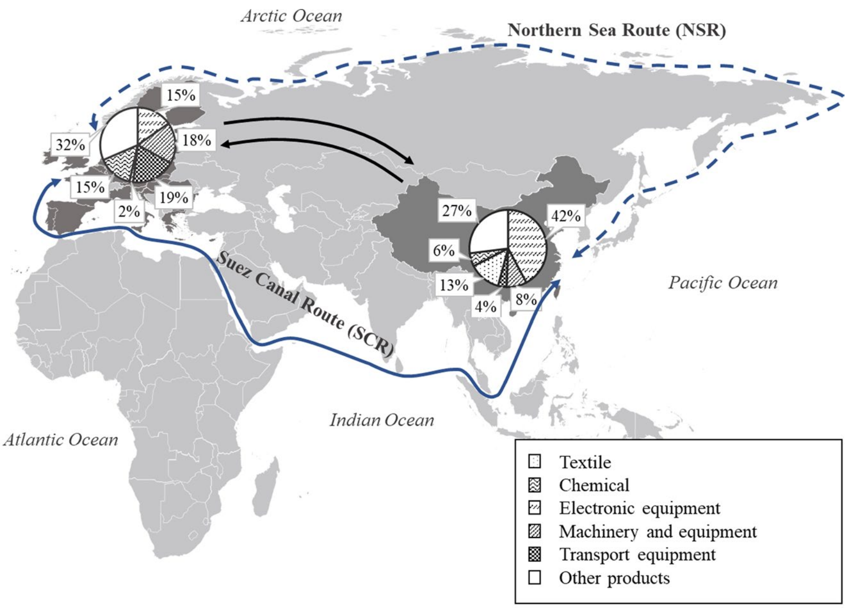

Fig. 1 China-EU main traded goods and shipping routes. *Source*: Authors, based on Eurostat data

traditional routes and promote the sustainable development of maritime trade has become an important issue for the shipping industry. With this background, shipping companies have begun to seek new routes to serve as alternatives to the traditional ones (Wang et al. 2023).

Climate reports stated that global warming is causing accelerated melting of sea ice, and that the summer sea ice in the Arctic Ocean could essentially disappear by 2050 (Cao et al. 2022; Wan et al. 2021). The melting of sea ice has increased the feasibility of Arctic navigation. As a shorter voyage between Asia and Europe, the potential economic value of the Northern Sea Route (NSR) is of great interest to the international community. The NSR is a speedy channel linking Europe and Asia, starting from the northern seas of Western Europe, heading east through the Arctic Ocean, and bypassing the Bering Strait to reach East Asian countries such as China, Japan, and Korea (Shu et al. 2023). Compared to traditional routes, the NSR can significantly reduce sailing distances between regions. For example, from Rotterdam to Shanghai, the distance via the NSR can be shortened by about 40% compared to the Suez Canal Route (SCR). Figure 1 shows the main traded goods between China and the EU at this stage, as well as the shipping routes for China-EU seaborne trade after the opening of the NSR. The total traffic volume on the NSR in 2022 was approximately 34 million tons, an increase of 8% compared to 2019 (CHNL Information Office 2023). This trend indicates that with the intensification of Arctic ice melting and advancements in navigation technologies, the role of the NSR as an alternative route is gradually strengthening.

Compared to the SCR, the NSR can reduce sailings distances considerably, at the same time avoiding the risks of navigating sensitive waters such as the Malacca Straits and the Mandab Strait in traditional routes. The NSR will provide a safer and more convenient shipping channel for trade exchanges between China and the EU. Its enormous commercial value will influence the existing international trade landscape, thus redistributing the demand for trade between China and the EU and offering new opportunities for the organization and optimization of bilateral trade relations. On one side, the shorter sailing distances would alter shipping costs and boost bilateral trade between China and the EU. On the other side, the continuous growth of bilateral trade drives shipping companies to invest more in China–Europe shipping routes, resulting in increased market competition. Shipping companies need to design effective route deployment strategies in response to changes in freight demand to reduce shipping costs and improve business efficiency. Therefore, it is vital to assess the potential impact of the NSR on the demand for bilateral trade between China and the EU.

Existing literature provides an in-depth analysis of the economic potential of the Arctic routes (Meng et al. 2017; Theocharis et al. 2018), with more attention paid to the NSR (Liu and Kronbak 2010; Schøyen and Bråthen 2011; Theocharis et al. 2019; Xu and Yin 2021; Zhao et al. 2016; Zhu et al. 2018), and finds that among the cost components of Arctic shipping, fuel costs are a key one in determining the cost attractiveness of the NSR (Joseph et al. 2021; Lasserre 2014). Fuel costs are a function of fuel prices and fuel consumption. Fuel prices fluctuate with the international fuel market and fuel consumption is highly correlated with sailing speed (Cheaitou et al. 2022; Faury et al. 2020). Studies generally assume that vessels sail at design speeds in open water. However, in icy water, ice obliges vessels to sail far below their design speed, which means that fuel consumption and transit time savings on the NSR may be lower than expected. Speed through ice increases the uncertainty of the costs of Arctic shipping (Theocharis et al. 2019). This, apparently, involves a choice between higher speeds (in icy environments) and fuel consumption, vis à vis lower speeds and longer transit times. Variations in fuel prices and speed on ice lead to differences in the NSR's feasibility, so it is critical to explore the economic performance of the NSR, and changes in the impact on China-EU bilateral trade and economies based on different scenarios.

We assess the impacts of changes in trans-Arctic shipping costs on bilateral trade and the economies of China and the EU. Given that the commodities traded between China and the EU primarily consist of containerized cargo, we choose container-ships as the sample vessels. When considering the uncertainty of fuel cost variables, we focus on the impact of fuel prices and speed through ice on changes in shipping costs and bilateral trade. The study attempts to answer the following questions: (1) How do changes in shipping costs due to NSR navigation affect the bilateral trade of different commodities between China and the EU? (2) How do changes in fuel prices and speeds affect the cost competitiveness of the NSR? (3) What are the effects on bilateral trade and regional economies of vessels sailing at optimal speed on ice at different fuel prices?

To answer the above questions, a research framework for modeling the trade and economic impact of the NSR is proposed (Fig. 2). The framework consists of three main steps. The first step calculates the sailing distance between China and the EU. The second step calculates the change in shipping costs with the introduction of the NSR alternative. The third step predicts the changes in trade between China and the EU. Specifically, the first thing that needs to be identified are the sailing distances between China and the EU via the SCR and the NSR. The distances between selected ports are processed using the weighted average model to obtain the sailing distance between China and the EU. The second step utilizes cost-modeling to

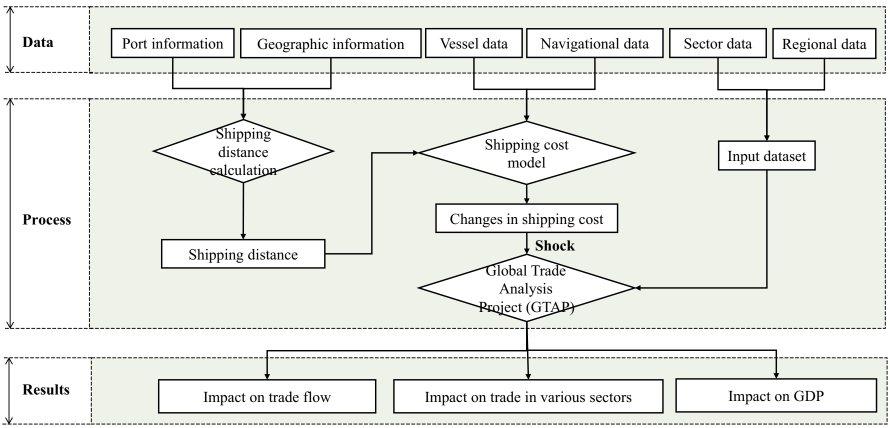

Fig. 2 Framework for assessing the impact of NSR navigation

identify changes in shipping costs due to the NSR navigation. We select conventional and ice-class vessels of the same deadweight tonnage as sample vessels and set vessel-related parameters and sailing conditions. Together with the sailing distances obtained in the first step, these parameters are entered into the cost-modeling as known data for calculating changes in shipping costs. In the final step, the changes in shipping costs obtained in the previous step are input as exogenous variables into the GTAP model to predict the impact of the NSR on China-EU bilateral trade and macroeconomics.

This paper contributes to the extant literature by presenting a simulation framework based on general equilibrium modelling (GTAP) to analyze the impact of the NSR on trade between China and the EU. The framework describes complex economic linkages and reflects correlations between changes in shipping costs and changes in trade demand. On this basis, different combinations of fuel prices and speeds are also considered to assess the impact of the NSR on bilateral trade under different scenarios. Besides, this study provides a basis for shipping companies and governments to make their respective decisions regarding Arctic shipping. Shipping companies can comprehensively consider the cost advantages of choosing trans-Arctic transportation. Governments can pre-plan industry and infrastructure development and design strategies geared towards new shipping routes, based on the potential impact of trans-Arctic shipping on commodity trades in different industries.

The remainder of this paper is organized as follows. Section 2 summarizes the related literature. Changes in distances (due to NSR) are estimated in Sect. 3. Section 4 presents the calculation methods and results of changes in shipping costs, with sensitivity analyses of fuel prices and sailing speeds. Section 5 presents a spatial macroeconomic model for measuring bilateral trade and economic impacts, and discusses different scenarios. Discussion, conclusions and policy implications are presented in the last section.

2 Literature review

Research on the NSR began at the end of the last century, focusing primarily on the Arctic climate and international law related to Arctic navigation (Theocharis et al. 2018). As research progressed, scholars investigated the economic impact of trans-Arctic shipping and explored the navigational value of the NSR.

Most of the studies on economic value focus on comparing the difference in shipping cost between the Arctic routes and traditional routes. There are two different views on whether trans-Arctic shipping is economically feasible. The first view is that Arctic routes *are* feasible. According to this, the NSR between Asia and Europe can reduce sailing distances by 30% to 60% compared to traditional routes, *prima facie* implying a great economic benefit (Liu and Kronbak 2010; Sun et al. 2020; Theocharis et al. 2019). Especially, as there is no fixed timetable or fixed route, tramp shipping on the NSR has the advantage of adaptability. Tramp shipping can improve supply chain flexibility and adaptability by adjusting routes according to climate and ice conditions (Faury et al. 2020; Schøyen and Bråthen 2011; D. Wang et al. 2020; H. Xu and Yin 2021; Gunnarsson and Lasserre 2023). By comparing, it was found that vessels can save 5% to 15% of shipping costs via the NSR (Furuichi and Otsuka 2015; Schøyen and Bråthen 2011; Zhao and Hu 2016). Another view is that Arctic routes are not economical, requiring certain conditions to be beneficial. Shorter distances do not mean savings in shipping costs. Additional navigational risks, investment in ice-class ships, levied ice-breaking fees, and other factors affect route total costs (Meng et al. 2017; Zhu et al. 2018). It is also necessary to consider investments in infrastructure along the route and measures to mitigate impacts of ship emissions (Lindstad et al. 2016; Cariou et al. 2019). In addition, there is controversy in academia and public opinion on whether the economic benefits of Arctic shipping would be offset by the environmental damages caused. After the International Maritime Organization (IMO) set emission reduction targets, various environmental regulations and standards were issued (Keltto and Woo 2020). Existing studies assumed different scenarios: fuel taxes, emission surcharges, alternative fuels in the Arctic, carbon limit regulations and so on (Theocharis et al. 2018). The conclusions of different studies also vary, with some finding that an Arctic carbon tax is not antithetical to profits (Cheaitou et al. 2022), while others suggest that the Arctic routes may not be feasible, considering its environmental impacts (Zhu et al. 2018).

Most studies on the impact of trans-Arctic shipping on trade use gravity models. The gravity model borrows from the concept of universal gravitation, assuming that the trade flow between two regions exhibits a direct proportionality to the magnitude of regional economic activities while displaying an inverse proportionality to the spatial separation between said regions. Ha and Seo (2014) discussed the contribution of the NSR to the container trade between Korea and the EU. Bensassi et al. (2016) used the gravity model to calculate changes in trade volumes between Asia and Europe after the opening of the Arctic route. Sui et al. (2021) used an improved gravity model to simulate long-term trade demand along the Arctic routes. It should be noted that freight demand is a derived demand, usually driven by demand from other economic activities, comprising production, trade and distribution, and affected by factors such as population, employment, macroeconomic indicators, consumption capacity, and exchange rates (Alises and Vassallo 2016). However, gravity models fail to consider the link between freight demand and economic activity and the underlying causes of freight generation. Additionally, gravity models focus on the analysis of aggregate trade flows, ignoring the impact of changes in transportation costs on the trade flows of individual commodities.

The computable general equilibrium (CGE) model can improve on the constraints of the gravity model. The model is based on the microeconomic theory of producers and consumers, which allows for a more realistic description of the interconnections between the various economic agents within a complex economic system (Robson et al. 2018). Currently CGE models are often used to analyze issues such as international trade and policy changes (Lee et al. 2016; Roberts et al. 2014). Buckley (1992) was one of the first scholars to introduce the spatial dimension into the fundamental computable general equilibrium model to study the impact of traffic factors on economic efficiency. Since then, the CGE model has been applied in the transport sector, covering issues such as road pricing, transport network changes, infrastructure investment, trade agreements and cross-border trade (Shahrokhi Shahraki and Bachmann 2018). The application of the theoretical framework of general equilibrium in the field of land transport is fairly mature: many works have explored the impacts of highways and railways on regional economies (Kim et al. 2004; Haddad et al. 2010; Betarelli et al. 2020).

Whilst the literature applying computable general equilibrium models in transportation has increased in recent years, few research works are on maritime transport (Bekkers et al. 2018; Countryman et al. 2016; Pereda and Lucchesi 2022; Shibasaki et al. 2018; Sou and Ong 2016). In fact, the relationship between maritime transport and trade is consistent with the description of the freight-economy relationship in CGE. Within the studies considering the Arctic routes in a general equilibrium perspective, Bekkers et al. (2018) and Countryman et al. (2016) utilized the gravity model to estimate the reduction in trade costs due to the shorter distances, and then introduced the change in trade costs into a global CGE model to examine the impact on trade. Whilst the impact of changes in shipping costs on trade has been explored, only costs related to distance have been considered, and limited understanding is available on how other cost variables affect international trade flows. However, changes in shipping costs following the NSR navigation are the main driver of changes in trade demand between China and the EU and need to be further analyzed.

Overall, many researchers have paid attention to analyzing the effects on trade of the Arctic routes, with most studies focusing on exploring trade changes using gravity models. Only a few works have explored the impact of trans-Arctic shipping on international trade potential in combination with the general equilibrium theory. However, these studies fall short of calculating changes in shipping costs, other than the shipping distances saved, thus generally ignoring the fact that changes in shipping costs are the underlying cause of changes in trade demand. This paper intends to portray the link between trade demand generated by economic production activities and shipping costs based on general equilibrium theory, and to analyze the impact of changes in shipping costs on China-EU bilateral trade after the NSR. Besides, the impact of changes in fuel prices and speeds on bilateral trade and economics is examined from the viewpoint of shipping cost components.

3 Impacts of NSR navigation on shipping distances

The NSR shortens the sailing distance between China and European countries. This section measures changes in sailing distances, as a result of the NSR alternative. Distances between gate ports connected by different routes between China and European countries are shown in Appendix A. Distances along the NSR vary between OD (origin–destination) ports in different geographical locations. It should be noted that the NSR can shorten distances between ports near the Arctic area, but for ports located closer to the equator, the NSR may not be profitable. For example, the sailing distance between Shanghai and Rotterdam is 10,641 nautical miles (nm) via the SCR and 8,265 nm via the NSR, which is a 22.3% reduction in sailing distance. However, when Shanghai and Piraeus are chosen as gate ports, the NSR distance increases from 7,890 nm to 11,015 nm.

When calculating NSR distances, most authors choose the largest port of the country or region as the representative port. Shanghai and Rotterdam are the most commonly used in this regard. (Lasserre 2014; Zhao et al. 2016). Other authors choose the ports with the largest import and export volumes (Shibasaki et al. 2018). China has a long coastline from north to south, and there are several international ports along the coast. The throughput of many of them is among the top in the world and selecting one port as a representative could not reflect the changes in shipping costs across the country. Several Chinese ports are therefore selected. The ports selected in Table 1 are the gate ports with the largest foreign trade cargo throughput in China and the EU and are important nodes in bilateral trade. Data on foreign trade cargo throughput of Chinese and EU ports are obtained from China Port Statistics and Eurostat, respectively. Using the average distance of the gate ports as the sailing distance of the NSR would result in inaccuracies. We therefore calculate a weighted distance, using as weights ports' share in the total foreign trade cargo throughput. The sailing distance between regions are calculated by the weighted average distance model according to the following formula:

$$D_{\mathrm{rs}} = \frac{\sum_{\mathrm{o}} \sum_{\mathrm{j}} w_{\mathrm{o}} w_{\mathrm{j}} d_{\mathrm{oj}}}{\sum_{\mathrm{o}} w_{\mathrm{o}} \sum_{\mathrm{j}} w_{\mathrm{j}}} \quad (1)$$

Table 1 Foreign trade cargo throughput of main ports in China and the EU

	Foreign trade cargo throughput (million tons)	Port share in total (%)
Chinese ports		
Ningbo-Zhoushan	53,679	19.40
Qingdao	44,458	16.07
Shanghai	38,864	14.05
Rizhao	31,909	11.53
Tangshan	29,589	10.70
Tianjin	28,468	10.29
Shenzhen	18,897	6.83
Dalian	16,350	5.91
Guangzhou	14,414	5.21
Yantai	14,222	5.14
Total	276,628	100
European ports		
Rotterdam	409,236	49.53
Antwerp	206,319	24.97
Hamburg	109,175	13.21
Piraeus	52,421	6.35
Le Havre	49,022	5.93
Total	826,173	100

, $where D_{rs}$ is the weighted average distance from region r to region s; port $o \in r; j \in s$; w_o and w_j are the weights of port o and j; d_{oj} is the sailing distance between port o and j.

As shown in Table 2, the variation in sailing distances between China and the EU depends on the calculation method. As expected, the average sailing distances diminish the geographical advantage of the NSR. When sailing distances are weighted, the NSR reduces the sailing distance between China and the EU by only 18.70%. Although the weighted change in sailing distance is not as large as the change obtained by selecting representative ports (Shanghai and Rotterdam), the distance reduction is still significant and will have an impact on shipping costs and bilateral trade between China and the EU.

4 Impacts of NSR navigation on shipping costs

4.1 Cost model

This section proposes a cost model to calculate the changes in shipping costs between China and the EU. The percentage change in shipping costs is then the main input into the GTAP model, in order to evaluate the impact of the NSR on bilateral trade and economics between China and the EU.

Earlier studies have considered capital cost, operating cost, fuel cost and transit fee when calculating Arctic shipping costs (Meng et al. 2017). Some authors have also considered port dues, cargohandling costs, and environmental costs (Sibul and Jin 2021; Wang et al. 2020; Zhu et al. 2018). This paper compares the shipping costs of the same container vessel, sailing through the NSR and the SCR. It is assumed that with the same gross tonnage and deadweight, the cargohandling costs and port charges at the origin and destination ports are the same, regardless of route. Therefore, the shipping cost of sailing the NSR, here, includes four parts: capital cost, operating cost, fuel cost and transit fee.

Compared with traditional routes, the special environment of the NSR causes some increased shipping costs. Firstly, the Russian authorities require vessels sailing in the Arctic Ocean to get the ice strengthening class approval. Compared with conventional vessels, ice-class vessels have a more complex structure and more sophisticated equipment. For example, ice-class vessels have additional provisions for hull construction, main engine power, shaft systems, gearboxes,

Table 2 Changes in sailing distance between China and the EU after the NSR navigation

	via SCR	via NSR	Change in sailing distance	
			in nm	Percent (%)
Shanghai to Rotterdam	10,641	8265	− 2376	− 22.33
Average	10,190	9095	− 1095	− 10.75
Weighted average	10,613	8631	− 1982	− 18.70

propellers, starters and cooling water systems (Ruiz-Capel et al. 2023). The main reason for the higher capital costs of ice-class vessels is that the hulls are reinforced with thicker steel plates and more powerful main engines and propulsion systems to allow them to navigate in icy waters (Solakivi et al. 2019). Secondly, trans-Arctic shipping faces special navigational risks. Thus, the operating costs of ice-class vessels in the NSR are also higher. These involve insurance premiums for ice-class vessels, maintenance and repair of ice-class equipment, and higher crew salaries. Thirdly, according to Russian government regulations, vessels need to be piloted by icebreakers in some sea zones of the NSR. Icebreaking fees depend on the gross tonnage and ice-class of the vessel and are related to the sailing season and the voyage in pilotage areas. Finally, the sea ice affects vessel speed and this affects fuel consumption. Besides, the higher power of the main engine in icy waters increase fuel consumption to a certain extent, which leads to an increase in fuel costs. The total shipping costs differential of a voyage is shown in Eq. (2):

$$\Delta C = \Delta VCC + \Delta VOC + \Delta VFC + \Delta VTC, \tag{2}$$

where ΔC is the total shipping cost differential from China to the EU via NSR and SCR; ΔVCC is the capital cost differential; ΔVOC is the operating cost differential, including insurance, maintenance cost and crew salaries;ΔVFC is the fuel cost differential; ΔVTC is the transit fee differential, which is the difference between the Suez Canal toll and icebreaking fees.

In calculating capital costs, we only consider chartering costs during the voyage. The difference in charter rates between the ice-class vessel and a conventional one, and the difference in sailing times between the two routes, give us the change in capital cost. The operating cost differential is determined by sailing times and daily operating costs. The fuel cost is determined by fuel consumption and fuel prices. Total fuel consumption is the product of the main engine fuel consumption rate and the sailing time. Changes in the main engine's fuel consumption rate and sailing time together determine the changes in fuel costs. Changes in transit fees are analyzed for a single voyage. The total shipping cost differential could be modeled as follows:

$$\Delta C = \left(\Delta C_c + \Delta C_o + p \cdot \Delta F\right) \cdot \Delta T + \Delta VTC, \tag{3}$$

where $\cdot C_c$ is the daily charter rate differential using an ice-class vessel via the NSR compared to a conventional vessel via the SCR;ΔC_o is the daily operating cost differential between the ice-class vessel and the conventional vessel;ΔF is the main engine fuel consumption rate differential of the ice-class vessel compared to the conventional vessel; ΔT is the sailing time differential between the two routes;p is fuel price.

The main engine fuel consumption rate is determined by the main engine parameters and vessel speed, and it is proportional to the third power of vessel speed (Cariou et al. 2019; Wang et al. 2021). The change in the main engine fuel consumption rate could be formulated as:

$$\Delta F = k \cdot m \cdot \left(v_{NSR}^3 - v_{SCR}^3\right), \quad (4)$$

where k is the fuel consumption rate per unit power of the main engine;m is a coefficient related to the main engine and vessel speed;v_{NSR} is the actual average vessel speed via NSR; v_{SCR} is the actual average vessel speed via SCR.

Voyage distance and vessel speed determine the sailing time differential, ΔT. This could be calculated as:

$$\Delta T = \frac{D_{NSR}}{v_{NSR}} - \frac{D_{SCR}}{v_{SCR}}, \quad (5)$$

where D_{NSR} is the voyage distance between China and the EU through NSR; D_{SCR} is the voyage distance between China and the EU through SCR.

4.2 Changes in shipping costs

Affected by ice conditions, vessels are currently allowed to sail only in low-latitude waterways along the northern coast of Russia. With the limited water depth of the Sannikov Strait, the draft of vessels sailing through the NSR cannot exceed 13 m (Xu and Yin 2021; Zhao et al. 2016). Besides, influenced by the mandatory pilotage section of the NSR, the icebreaking width of the icebreaker also limits the type of Arctic vessels. Most of the studies select 3,000 to 5,000 TEU container vessels as reference in their work (Lasserre 2014; Liu and Kronbak 2010; Zhao et al. 2016). After considering ice conditions, minimum depth of the strait and icebreaker width, the representative vessel chosen here is the 4,250 TEU container vessel *CMA CGM Caimep*, with a beam of 32.2 m and a draft of 12.6 m (Clarksons 2020). To facilitate the comparisons of shipping cost differentials between the two routes, it is assumed that the same size vessel is used in the different routes. In transport activities along the NSR, Arc4 ice-class vessels are the most widely used, accounting for about 63% of the vessels sailing through the route (Joseph et al. 2021). Therefore, the Arc4 ice-class vessel is selected as the sample vessel for Arctic shipping. The special navigational environment of the Arctic has resulted in increased vessels costs, compared to traditional routes, including capital costs, operating costs, fuel costs and transit fees.

Specifically, capital costs of a voyage are related to sailing time and charter rate. The average time charter rate of a Panamax container vessel in 2020 was $14,012/day (Clarksons 2020). Ice-class vessels are more costly than conventional vessels. There is no clear evidence regarding the proportion of capital cost premiums for different classes of ice-class vessels. We set the capital cost premium for Arc4 ice-class vessel at 20% based on previous studies (Koçak and Yercan 2021; Wang et al. 2020, 2023).

As regards operating costs, the Moore Maritime Index (MMI) estimates daily average costs of $3,072, $1,195, and $406, for manning, maintenance, and insurance costs, respectively. Due to the special environment of the Arctic, daily operating costs along the NSR are higher than those of the SCR. It is assumed that the daily manning, maintenance, and insurance costs of a vessel sailing on the NSR would increase by 10%, 20% and 20%, respectively (Lasserre 2014; Solakivi et al. 2019; Theocharis et al. 2018).

Fuel costs are affected by four factors: fuel price, main engine power, sailing distance, and vessel speed. Due to the higher speed of container vessels, their fuel costs account for a large portion of shipping costs. With reference to the data in the Third IMO GHG Study 2014 report, the unit fuel consumption of the engine is set at 180 g/kWh (Wang et al. 2021). It is assumed that ice-class and conventional vessels use the same type of heavy fuel oil. The average fuel price for IFO 380 is $350/t in 2020 (Clarksons 2020). The Northern Sea Route Association (NSRA) divides the Arctic Seas into seven zones: Pechora Sea, Kara Sea West, Kara Sea East, Laptev Sea, East Siberian West, East Siberian East, and Chukchi Sea. It can be seen from the data released by the National Snow and Ice Data Center (NSIDC) of the USA that there are differences in the ice thickness of each sea area. Furthermore, changes in the extent of sea ice have obvious seasonal characteristics. The navigable period is divided into two phases based on the seasonal division of the northern hemisphere: the summer-autumn period (from July to November), and the winter-spring period (from December to June). Based on the research of Faury and Cariou (2016) and Xu and Yin (2021), the annual average ice cover distance of the NSR is assumed to be 2,350 nm. We assume that the vessels sail at commercial speeds along the SCR which consists of both icy- and open water areas. We set the ice-class vessels to sail at commercial speed in open water, and with reference to actual navigation data in the Arctic, the average speed of an ice-class vessel sailing in icy water is set at 11 knots (CHNL Information Office 2021).

Transit fees for the two routes are the canal tolls in SCR and the ice-breaking fees on the NSR. According to the Suez Canal Authority, Suez Canal Net Tonnage (SCNT) is the basis for canal tariffs. Chen et al. (2018) used regression methods to calculate the SCNT of containerships. Here, the Suez Canal toll, calculated by the Toll Calculator, is $268,159. In calculating the icebreaking fees, some authors assumed that these are related to the gross tonnage of the vessel. For example, Furuichi and Otsuka (2015) determined the fees for the NSR to be $5/GT, relying on reports from operators involved in commercial shipping on the NSR over recent years. Theocharis et al. (2019) established the toll rate for Arc4 ice-class vessels transiting the NSR at $6.7/GT. Moe and Brigham (2017) set the icebreaking fees for vessels between $4.1/GT and $10.9/GT, by referencing data from both the North Sea Rout Association (NSRA) and the Russian Rosmorport enterprise. Other scholars developed a variety of icebreaking fee scenarios using the Suez Canal tolls as a benchmark, including setting the icebreaking fee at 50%, 100% and 200% of the Suez Canal tolls (Xu et al. 2018; Zhao et al. 2016). This study uses the NSR icebreaking fee evaluation method announced by the Russian government as the basis for our calculation. In this calculation method, the icebreaking fee is not only related to vessel gross tonnage, but also to the ice thickness, navigational season, and the number of areas requiring icebreaker assistance. Although Arctic icebreaking services are currently not mandatory, to ensure safety of navigation we assume that vessels require icebreaking services in some areas of the Arctic. It is assumed that an ice-class vessel requires icebreaking assistance in three zones in the summer-autumn season, and that ice conditions are more severe in the winter and spring seasons, with all zones requiring ice-breaking services. Considering the ice conditions throughout the year, the average icebreaking fee of a single voyage is $394,193.

We use the parameters set above as a baseline scenario and we apply the cost model to calculate the shipping costs through the SCR and the NSR. The calculation results, based on navigational environment data in 2020 and utilizing 4,250 TEU container vessels as sample, are presented in Table 3.

4.3 Sensitivity analysis

The results in Table 3 show that the shipping costs of the NSR are more competitive in the assumed baseline scenario. However, the economic feasibility of the NSR can change when fuel prices and sailing speeds vary. This section provides a sensitivity analysis of fuel prices and speeds to assess their impact on changes in shipping costs after the NSR alternative. The first factor analyzed is fuel prices. These are influenced by market fluctuations and usually change due to political considerations, decisions made by oil-exporting countries, and IMO regulations (Meng et al. 2017). Recognizing the importance of fuel prices and their volatility, extant literature has examined various fuel price scenarios. For instance, Furuichi and Otsuka (2015) looked at scenarios of $300/t, $650/t, and $900/t; Sibul and Jin (2021) adopted values of $250/t, $430/t, $580/t, and $700/t; Xu et al. (2018) considered a range between $100/t and $700/t.

The second factor is sailing speeds in icy waters. Here, prevailing uncertainty is considerable and speed largely depends on the ice condition. For the speed settings in the ice area, Furuichi and Otsuka (2015) assumed speeds from 12.8 to 14.1 knots; Xu and Yin (2021) set the speed from 0.3 to 13.8 knots. Based on historical data and previous studies, we set the fuel price range from $250 to $650/t, and the speed on the ice areas from 5 to 15 knots.

To analyze the impact of uncertainty on shipping costs, a sensitivity analysis of fuel prices and speeds on ice is performed based on navigation environment data in 2020. The relative cost differences between the two routes for different combinations of fuel prices and speeds on ice are shown in Fig. 3. The x axis measures the range of fuel price fluctuations, the y axis reflects the changes in speed on ice. Axis z shows the shipping cost differential via NSR compared to SCR. The changes in shipping costs are expressed in percentage terms.

Table 3 Changes in shipping costs between China and the EU after the NSR navigation

Cost component	via SCR	via NSR	Change in shipping costs	
			Total ($)	Percent (%)
Capital cost	269,401	326,790	57,389	21.30
Operating cost	89,845	107,485	17,640	19.63
Fuel cost	710,102	495,909	− 214,192	− 30.16
Transit fee	268,159	394,193	126,034	47.00
Total	1,337,507	1,324,377	− 13,130	− 0.98

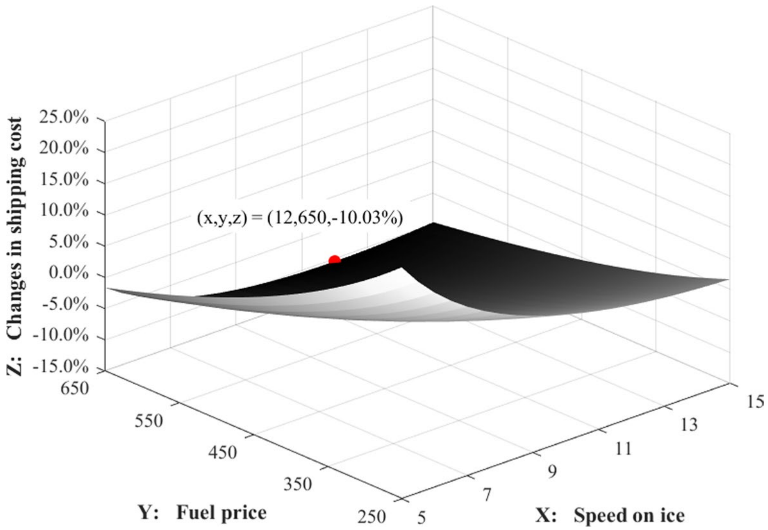

Fig. 3 Impact of vessel speed and fuel price on changes in shipping costs

Figure 3 illustrates how changes in shipping costs vary for different combinations of fuel price and speed. The percentage change in shipping costs is negative in most combinations, which means that the NSR has lower shipping costs compared to the SCR. With the vessel speed kept constant, rising fuel prices make the advantage of the NSR increasingly apparent. As mentioned above, the NSR is more competitive under high fuel prices, so the percentage of shipping cost savings via the NSR expands with increases in fuel prices.

However, the results are less straightforward when the changes in total shipping costs are assessed by varying the speed under the same fuel price conditions. When the vessel sails at a low speed, its increase will gradually reduce the difference in shipping costs between the NSR and the SCR. The reason for this is that increasing speed on ice reduces sailing time on the NSR, saving capital costs and operating costs. Despite the consequent increase in fuel costs due to higher speeds, total shipping costs of the ice-class vessel along the NSR are on a downward trend. The optimal speed on ice gives the best percentage change in transportation cost at each fuel price. For example, at a fuel price of $650/t, the optimal speed is 12 knots, and the NSR shipping costs are reduced by 10.03%. As vessel speeds continue to increase, the rapid increase in fuel costs outweighs the reduction in capital costs and operating costs, which in turn increases the total shipping costs of the NSR and leads to a reduction in the economic advantage of this route.

Figure 4a shows the relationship between vessel speed on ice and changes in shipping costs. When the fuel price is $250/t, even at a vessel speed of 15 knots, the change in shipping costs is positive, meaning that there is no cost advantage to trans-Arctic shipping. When the fuel price is $650/t, the changes in shipping costs are all negative after speed on ice exceeds 5 knots, implying lower trans-Arctic shipping costs. The figure shows that the curve shifts downwards as fuel prices rise,

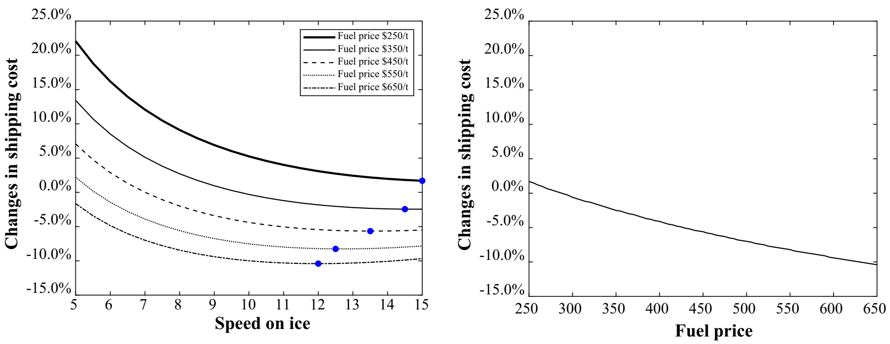

Fig. 4 **A** Relationship between optimal speed on ice and changes in shipping costs under different fuel prices. **b** Relationship between fuel price and changes in shipping costs, with optimal speed on ice

indicating that the NSR is preferred at higher fuel prices. Dots on the curves show the optimal speeds on ice for that fuel price. When fuel price increases from $350/t to $650/t, the optimal speed on ice decreases from 14.5 to 12 knots. Figure 4b shows the relationship between fuel prices and changes in shipping costs when the vessel is sailing at optimal speed. The curve is monotonically decreasing. The NSR becomes increasingly cost-competitive as fuel prices rise when the vessel is sailing at optimal speed.

5 Economic analysis

5.1 Linkage between reduction in shipping costs and trade

5.1.1 GTAP model

We use the GTAP model to analyze the impact of changes in shipping costs on China-EU trade after the NSR alternative. GTAP is an international trade analysis framework jointly developed by the U.S. International Trade Commission and the World Trade Organization (Roberts et al. 2014). It is widely used in quantitative analysis of trade policy changes, simulating the impact of policy changes on national imports and exports, gross domestic product, social welfare, etc. (Ferrari et al. 2023; Betarelli et al. 2020). GTAP is a multi-regional CGE model that considers the spatial dimension and has the same theoretical framework as the CGE model, starting from the assumption of perfect competition. Factor and commodity prices are variable, with producers seeking to minimize production costs and consumers seeking to maximize utility. When the 'economic system' attains equilibrium, commodity and factor markets, savings and investment, all reach equilibrium. The GTAP model designs a virtual international transport sector based on trade transport relationships, where production technology affects the cost of trade transport, which in turn affects total global transport demand.

The GTAP model introduces an exogenous variable, ams_{irs}, which reflects unobservable elements of transport costs such as ease of customs clearance and level of transport infrastructure. ams_{irs} measures the reduction in the effective price of commodity i during the transfer process when it is exported from region r to s.

$$qxs_{irs} = -ams_{irs} + qim_{is} - \sigma_m^i \cdot \left(pms_{irs} - ams_{irs} - pim_{is}\right), \tag{6}$$

$$pim_{is} = \sum_r \theta_{irs} \times \left(pms_{irs} - ams_{irs}\right) \tag{7}$$

where: σ_m^i is the import substitution elasticity of commodity i.

qxs_{irs} is the percentage change in the quantity of import commodity i from region r to s. pms_{irs} is the percentage change in the price of import commodity i from region r to s. qim_{is} is the percentage change in the total quantity of import commodity i in region s. pim_{is} is the percentage change in the average price of import commodity i in region s. ams_{irs} is the technical change caused by the hidden trade cost. ams_{irs} can be described as an implicit technological parameter for modeling advances in transportation technology and reduction of transport costs. In the GTAP model, transport costs are endogenous variables that cannot be directly shocked. Therefore, the reduction of transport costs can be translated into advances in transportation technology, meaning an increase in the transportation technology coefficient. Since the opening of the NSR reduces shipping costs between China and the EU, we also assume that the reduction in shipping costs is equivalent to an increase in transportation technology, which is expressed by adjusting the magnitude of the exogenous variable ams_{irs}.

5.1.2 Database construction

The GTAP database is massive and includes real input and output data from multiple countries and regions around the world. The base year of the GTAP 10.0 database is 2014, and this basic data cannot effectively reflect the current state of the global economy and trade. To improve the accuracy of the simulation results, this paper adopts the dynamic recursive approach to update the database. This introduces a time dimension and a recursive framework in the GTAP model to account for dynamic changes and feedback effects in the model (Lakatos and Walmsley 2012). Using data from the International Monetary Fund (IMF) and Centre for Prospective Studies and International Information (CEPII), the five variables of GDP, population, capital stock, skilled labor, and unskilled labor in the GTAP database are extrapolated to 2020.

The GTAP 10 database consists of 141 national economies, each containing 65 industry sectors. Given the focus of the study on China-EU bilateral trade, countries and regions are aggregated into three groupings: China, the EU, and the Rest of the world. According to the bilateral trade categories between China and the EU, production activities are divided into 15 sectors: grains crops, animal products, mining industries, proceed food, textiles, light industries, chemical, metal products, electronic equipment, machinery and equipment, transport equipment, heavy industries, utilities, construction, other services.

5.2 Bilateral trade impacts

As expected, the reduction in shipping costs increases bilateral trade between China and the EU. In terms of the regional structure, bilateral trade flows both increase after the NSR alternative, with China's exports to the EU increasing by 1.91% and the EU's exports to China increasing by 1.86% (Table 4). This growth in bilateral exports affects other markets, causing a negative impact on export trade to the rest of the world.

With respect to trade structure, exports of various industries are impacted to varying degrees. Figure 3 depicts the changes in exports of main traded goods between China and the EU. Exports of main traded goods between China and the EU are expected to increase from $334 billion and 199 to $345 billion and 204, respectively. Table 4 provides more detail about the commodities exchanged between China and the EU. What stands out is the growth of the mining industry, with export trade between China and the EU increasing by 6.70% and 6.57%, respectively. There are two main reasons for the significant change in the trade volume of mining commodities. Firstly, shipping costs for minerals account for a large share of trade costs, and trans-Arctic shipping leads to lower commodity trade costs, thus boosting import demand. Secondly, trans-Arctic shipping promotes the development of several

Table 4 Changes in trade volumes between China and the EU after the NSR navigation (%)

Commodity	China exports		EU exports	
	To EU	To ROW	To China	To ROW
Grains crops	1.88	– 0.32	2.33	– 0.04
Animal products	1.53	– 0.30	1.86	– 0.04
Mining industries	6.70	– 0.15	6.57	– 0.25
Proceed food	1.91	– 0.36	2.14	– 0.06
Textiles	1.98	– 0.31	3.93	0.38
Light industries	2.36	– 0.35	3.28	0.11
Chemical	2.38	– 0.28	2.69	– 0.01
Metal products	2.92	– 0.35	3.58	0.06
Electronic equipment	2.41	– 0.29	4.83	0.48
Machinery and equipment	2.99	– 0.40	3.69	0.13
Transport equipment	2.64	– 0.32	2.27	0.07
Heavy industries	2.55	– 0.38	3.55	0.17
Utilities	– 0.26	– 0.33	0.16	– 0.05
Construction	– 0.26	– 0.31	0.13	– 0.05
Other services	– 0.28	– 0.33	0.11	– 0.07
Total	1.91	– 0.29	1.86	– 0.08

industries, and the increase in production expands the demand for raw materials such as minerals.

As one of the main commodity categories of China's exports to the EU, the rise in exports of textiles is not as evident as expected. The reduction in trade costs raises the import demand of the EU and boosts China's exports. However, China's economic development and industrial expansion lead to higher labor prices and a consequent rise in commodity production costs. Part of the export trade is lost due to a relative increase in the total price of commodities. Besides, textile exports from the EU to China increase by 3.93%. Lower trade costs improve the competitiveness of EU textiles and this, together with the Chinese income growth, boosts import demand for EU textiles.

The reduction in trade costs expands the cost competitiveness of EU exports of electronic equipment, resulting in a 4.83% increase in exports to China. Bilateral trade in machinery and equipment grows in parallel, with all changes about 3%. This is because of the expansion of output in the various industrial sectors within regions, driving increased demand for imports of machinery and equipment products. In addition, although there are no shipping costs involved in the trade of utilities, construction and services, there is a slight change of around 0.4% in the export trade of these industries (Fig. 5).

Table 4 shows the changes in bilateral trade between China and the EU under the baseline scenario. To further assess the impact of optimal speed through ice and fuel price on commodity trades, this study proposes different simulation scenarios. Considering the volatility of the oil market, we establish three fuel price scenarios, with vessels sailing at the optimal speed through ice at each fuel price. The first scenario uses a low price, set at $250/t. The second scenario has the same oil price as the baseline scenario, being the average price of IFO 380 in 2020, which was $350/t. The third scenario assumes a high fuel price of $650/t. Table 5 shows the results of the changes in bilateral trade under the three scenarios. As can be seen, in scenario

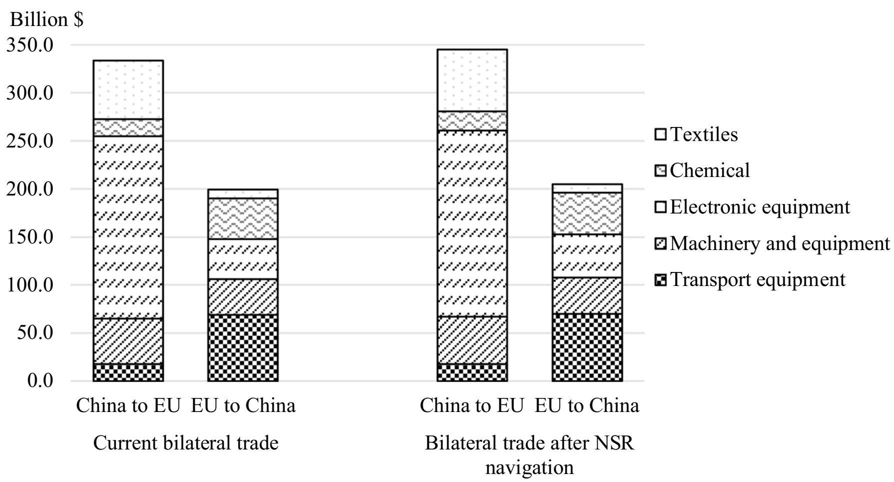

Fig. 5 Exports of China-EU main traded goods

Table 5 Changes in bilateral trade between China and the EU under various scenarios (%)

	Base scenario		Scenario 1		Scenario 2		Scenario 3	
	China-EU	EU-China	China -EU	EU-China	China-EU	EU-China	China-EU	EU-China
Grains crops	1.88	2.33	− 3.25	− 4.02	4.34	5.37	19.93	24.67
Animal products	1.53	1.86	− 2.63	− 3.20	3.51	4.28	16.14	19.66
Mining industries	6.70	6.57	− 11.55	− 11.32	15.43	15.12	70.89	69.48
Proceed food	1.91	2.14	− 3.30	− 3.69	4.41	4.92	20.24	22.63
Textiles	1.98	3.93	− 3.41	− 6.77	4.55	9.04	20.90	41.56
Light industries	2.36	3.28	− 4.07	− 5.65	5.44	7.54	24.99	34.66
Chemical	2.38	2.69	− 4.11	− 4.63	5.48	6.19	25.20	28.44
Metal products	2.92	3.58	− 5.04	− 6.17	6.73	8.24	30.94	37.84
Electronic equipment	2.41	4.83	− 4.15	− 8.32	5.55	11.12	25.48	51.08
Machinery and equipment	2.99	3.69	− 5.15	− 6.37	6.88	8.50	31.61	39.08
Transport equipment	2.64	2.27	− 4.56	− 3.92	6.09	5.24	27.98	24.06
Heavy industries	2.55	3.55	− 4.40	− 6.12	5.87	8.17	27.00	37.56
Utilities	− 0.26	0.16	0.45	− 0.28	− 0.60	0.38	− 2.74	1.74
Construction	− 0.26	0.13	0.45	− 0.23	− 0.60	0.31	− 2.75	1.41
Other services	− 0.28	0.11	0.48	− 0.20	− 0.64	0.26	− 2.94	1.21
Total	1.91	1.86	− 3.71	− 3.38	4.96	4.52	22.78	20.75

1, there is no positive impact of trans-Arctic shipping on bilateral trade, even when the vessel sails at optimal speed. With rising fuel prices, bilateral trade is clearly boosted in the NSR in scenario 2 and scenario 3. Under scenario 3, bilateral trade benefits more from the NSR. Comparing the baseline scenario and scenario 2, it can be seen that, under the same fuel price, the positive impact on bilateral trade is more pronounced when the vessel sails at the optimal speed. Export trade growth rates for China and the EU increase by 2.94 and 2.65 percentage points, respectively, above the baseline scenario.

5.3 Economic impacts

Changes in trade flows can translate into economic impacts. Table 6 summarizes the trade volume and GDP impacts of the NSR alternative. Under the base scenario, the NSR has positive effects on GDP, both of China's and the EU's. China's GDP will increase by 0.081% ($12,580 million) compared with the 0.015% ($3,107 million) growth in the EU. The rest of the world will experience a slight decline in GDP. The reduction in shipping costs promotes the expansion of bilateral trade between China and the EU, with consequent economic growth and employment. However, as trade costs between China and the EU decrease, other countries may experience negatively impacts in their own trade. Regarding GDP growth, China would benefit the most from the NSR alternative, with GDP increasing by $12,580 million, which is about 4 times higher than in the EU. The GDP of the rest of the world will decline by $13,070 million.

With respect to the trade scale, China's imports and exports both grow by 0.217% and 0.012%, respectively. The percentage change in trade volumes indicates that import expansion will be greater than export expansion in China, implying

Table 6 Changes in trade and GDP of China and EU after the NSR alternative

	Exports (%)	Imports (%)	GDP (%)	GDP (million $)
Base scenario				
China	0.153	0.217	0.081	12,580
EU	– 0.025	0.012	0.015	3107
ROW	– 0.032	– 0.046	– 0.026	– 13,070
Scenario 1				
China	– 0.264	– 0.374	– 0.151	– 21,689
EU	0.043	– 0.021	– 0.026	– 5264
ROW	0.055	0.080	0.045	20,906
Scenario 2				
China	0.352	0.500	0.202	28,961
EU	– 0.058	0.028	0.035	5916
ROW	– 0.074	– 0.106	– 0.060	– 23,802
Scenario 3				
China	1.619	2.295	0.928	143,116
EU	– 0.265	0.130	0.160	32,887
ROW	– 0.338	– 0.489	– 0.276	– 133,325

a negative change in the trade balance. Total imports from the EU show a slight increase, while total exports are negatively affected and decline. While the growth in Chinese import demand has a stimulating effect on EU merchandise exports, the expansion of EU industrial output leads to a rise in pre-existing higher labor prices, resulting in a significant increase in production costs. For other countries that are not facilitated by the NSR, the relative increase in product prices will eventually reduce the demand for imports of EU products and ultimately result in lower total EU exports. Changes in total imports and exports lead to changes in the trade balance of each region, with China and the EU experiencing a decrease in their trade surpluses and the rest of the world showing an increase in their surpluses (or a decrease in their deficits).

From the results of the different scenario simulations, it is found that China's trade and economy is more affected by the NSR than that of the EU. Comparing the baseline scenario with scenario 2, the economy is promoted more significantly by sailing at optimal speed on ice compared to the baseline speed under the same fuel price conditions, and China's GDP will increase by $16,381 million more. Another finding is that trans-Arctic shipping has a positive impact on the economies of China and the EU only with higher fuel prices.

6 Discussion and conclusions

This paper contributes to the existing literature by presenting a simulation framework for analyzing the impact of changes in shipping costs, due to the NSR, on the bilateral trade and economies of China and the EU. We further investigate how fuel prices and sailing speeds through ice affect the economics of the NSR. The main findings of the study are listed below.

Firstly, the NSR navigation reduces shipping costs between China and the EU and promotes bilateral trade and economic growth. In terms of the volume of commodity exports, the extent to which export trade benefits varies by industry sector. Exports are positively affected in all industries except utilities, construction and services; exports from the mining sector rise most notably. From the perspective of regional economic indicators, the Chinese and European economies are positively impacted by the NSR. Compared with the EU, China's economic and trade benefits from the NSR are more significant.

Secondly, fuel prices and sailing speeds on ice substantially affect the competitiveness of the NSR. Generally, the NSR cost advantage increases when fuel prices rise. Vessels reach the optimal speed faster at high fuel prices, and the cost advantage of the NSR is the most obvious in that case.

Finally, under the same fuel price conditions, it is more beneficial for bilateral trade to sail through the icy waters at optimal speed than under the baseline scenario. Besides, at a fuel price of $650, sailing with optimal speed has the most significant positive effect on bilateral trade and regional economy, with China's GDP growth approaching 1%.

For shipping companies, the NSR can be used as an alternative route. Arctic shipping can be beneficial at high fuel prices, and sailing at optimal ice speed can maximize cost savings. Under low fuel prices, trans-Arctic commercial transport is not recommended. For the Chinese government, the role of the NSR in promoting China-EU trade should be strategically important. China, however, needs to accelerate industrial upgrading and the structural optimization of foreign trade, consolidating its traditional advantages in export to the EU while strengthening new competitive advantages in technology or capital-intensive products, and expand its trade with the EU. At the same time, China should deepen China-EU economic and trade cooperation, expand the scale of bilateral economic and trade cooperation, and promote the transformation of China's trade with the EU from quantity to quality, thus achieving mutual benefits.

It is worth noting that this research has only considered the average year-round conditions of Arctic navigation, but not the specific navigational conditions of different seasons. Arctic navigation is seasonal and uncertain, with different speed limits for sailing through ice in each season. Differences in shipping costs between seasons are not portrayed. The results of this study may change if seasonal speed constraints are considered. This issue needs further research. Furthermore, the continuing melting of the sea ice causes navigational conditions to change from year to year. Hence, predicting trends in the impact of trans-Arctic shipping on international trade is a focus for future research. When analyzing long-term impacts, it is necessary to consider the impacts caused by trade policies or regulations, as well as epidemics, etc., to construct a more realistic simulation framework and improve the accuracy of its results. In addition, carbon emissions from vessels have a significant impact on the Arctic region, and this study has not considered the environmental costs of Arctic shipping and this is something left to future research. Finally, in view of the rise in mining exports and other bulk commodities, future studies could examine bulk shipping activities, over and above container shipping which was our scope here.

Appendix A

	Rotterdam	Antwerp	Hamburg	Piraeus	Le Havre
Distance via *SCR*					
Ningbo-Zhoushan	10,561	10,546	10,851	7811	10,357
Qingdao	10,937	10,922	11,227	8187	10,733
Shanghai	10,641	10,626	10,930	7890	10,436
Rizhao	10,945	10,930	11,234	8194	10,740
Tangshan	11,161	11,146	11,451	8411	10,957
Tianjin	11,206	11,191	11,495	8455	11,001
Shenzhen	9855	9840	10,145	7105	9651
Dalian	11,050	11,035	11,340	8300	10,846
Guangzhou	9867	9852	10,156	7177	9663
Yantai	11,024	11,009	11,314	8274	10,820
Distance via *NSR*					
Ningbo-Zhoushan	8314	8390	8236	11,063	8485

	Rotterdam	Antwerp	Hamburg	Piraeus	Le Havre
Qingdao	8288	8364	8210	11,037	8459
Shanghai	8265	8341	8188	11,015	8437
Rizhao	8324	8400	8247	11,050	8472
Tangshan	8485	8561	8408	11,211	8633
Tianjin	8530	8606	8452	11,256	8678
Shenzhen	9087	9163	9009	11,836	9258
Dalian	8372	8448	8295	11,098	8520
Guangzhou	9141	9217	9063	11,890	9312
Yantai	8349	8425	8271	11,075	8497

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