WORKING PAPER

ITLS-WP-18-07

Environmental Costs and Economics Implications of Container Shipping in the Northern Sea Route

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April 2018

ISSN 1832-570X

INSTITUTE of TRANSPORT and LOGISTICS STUDIES

The Australian Key Centre in Transport and Logistics Management

The University of Sydney

Established under the Australian Research Council's Key Centre Program.

NUMBER: Working Paper ITLS-WP-18-07

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ABSTRACT: The Northern Sea Route (NSR) has tremendous potential for marine shipping between Europe and Asia in terms of savings in transport time and distance. However, the Arctic area is environmentally vulnerable thus there is a trade-off between NSR's impacts on environment vs. its economic benefits, especially when compared with the traditional route through the Suez Canal route (SCR). This study estimates the market shares of different transport modes and alternative shipping routes for the container transport market between Europe and Asia, and the resultant environmental costs. Our analysis suggests that NSR can be a viable option under the status quo. However, its environmental costs tend to be higher than SCR due to small ship size and low load factor in the present, thus that the successful development of NSR can lead to worse environment outcomes. If these issues can be addressed, NSR can benefit from lower operational and environmental costs, which will lead to higher market share and social welfare.

KEY WORDS: ***Northern Sea Route (NSR), arctic shipping, environmental costs***

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DATE: April 2018

1. Introduction

Largely due to global warming and a series of linked processes, Arctic Ocean's sea ice has been retreating and it might be seasonally ice free in this century (Stroeve et al. 2014, Vavrus et al. 2012). As shown in Figure 1, NSIDC (2016) found that the Arctic sea ice extent in summer has declined gradually over time.

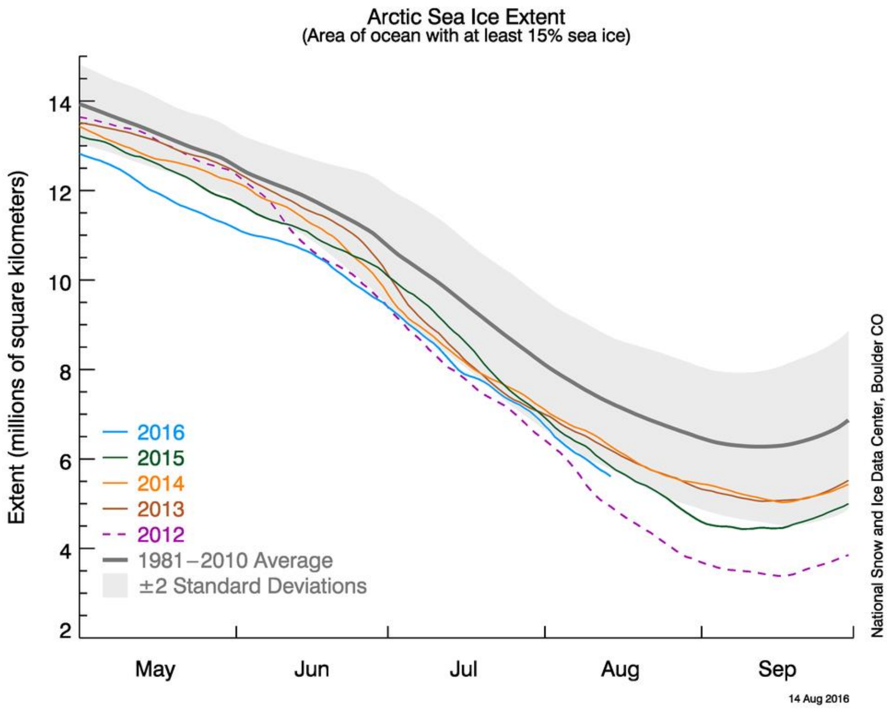

FIGURE 1 - ARCTIC SEA ICE EXTENT

SOURCE: (NSIDC 2016)

The continued reduction of sea ice spurred interests and efforts to use the Northern Sea Route (NSR) for commercial sailing. The NSR is a shipping lane '*running along the coast of the Russian Arctic from Novaya Zemlya in the west to the Bering Strait in the east*' (INSROP 2001). It connects Europe and North East Asia with an approximate 40% reduction in distance compared with route via the Suez Canal route (SCR) which is severely congested. The shorter distance can possibly bring savings in both fuel consumption and transport time. The Arctic shortcut also lowers the risk of maritime piracy and associated costs by avoid navigating in pirate-infested waters such as the Strait of Malacca and Gulf of Aden, which has been a major threat to the marine transport between Europe and Asia (Fu et al. 2010). The plunge of Russian rouble (RUR) after 2014 lowered the NSR tariff in USD by half, further increased the attractiveness of the NSR route. Over the last couple of years, the number of ships sailed through NSR reached its peak at 71 in 2013. Russia authorities are actively promoting NSR as a future international trade route and predicted a 20-time increase in shipment volume by 2030 (Russian Government 2015).

On the other hand, the extreme environment and constantly changing ice condition in the NSR introduce substantial uncertainty and technical challenges to both ships and facilities. Infrastructures along the NSR are in poor conditions, largely remain at the same level at the time of Soviet Union (Blunden 2012, Hill, LaNore and Véronneau 2015, INSROP 2001). Ports along NSR can only provide basic repairs to ships beyond which ships will have to visit Murmansk or Vladivostok, which are far away outside the NSR. Fuel provision is available in ports on NSR although the conditions of these facilities are not transparent. Additionally, depths in anchorage areas and at the wharfs of these ports are generally limited, making it difficult for bigger ships to access and obtain technical support. In summary, although the Russian Government (2009) planned to build sufficient infrastructure along NSR, existing facilities do not meet shipping companies' basic requirements for cargo handling, navigation and rescue. This makes ship technical adaptations even more important, which has always been challenging. In addition to ice class requirements, escorting and ship traffic management in ice-covered regions are also necessary (Pastusiak 2016). Ships need to have enough size and sufficient engine power to navigate in ice-covered water, with or without the help of icebreakers. Under the regulation by Russian Government (2013) based on the time period and ice condition, ships are allowed to transport in different sea areas based on their ice class and whether they have icebreaker support.[1]

The growing interests in NSR shipping however have raised much environment concerns. With extremely cold temperature, ice and seasonal variability, the Arctic area is a unique ecosystem. Any disturbance including those caused by marine shipping may have unexpected impacts on regional or even global environments. Various environment regulations such as emission control are being introduced, which can influence the market structure of maritime sector. For example, the International Code for Ships Operating in Polar Waters (Polar Code) came into force on 2017 January 1st (IMO

[1] For example, ships with no ice reinforcement are only allowed to navigate with icebreaker support in the period of July to November 15th in easy ice condition areas. In comparison, a 1AS-class (Arc5) ship can navigate through NSR in most ice conditions in the same period and has no constraints on ice condition when supported by an icebreaker.

2015), which sets safety and environmental rules for shipping operations in the Arctic and Antarctic areas.

In summary, the emergence and growth in shipping via the NSR routes may bring some significant economic and policy issues related to shipping operations, market structures and environment concerns. This study aims to contribute to such debates by analysing the container shipping services in the Europe – Asia market. First, we will examine NSR's competitiveness and its market share taking into account factors such as international bunker price, latest tariff in NSR and ship size. The outcomes of such analysis will be subsequently used as inputs for the calculation of environmental costs of NSR transport.

The rest of this paper is organised as followed: Section 2 provides a literature review related to artic shipping. Section 3 presents the economic models and applications to calculate market share and environmental costs for container shipping in the Europe-Asia market. Section 4 discusses and interprets the results. Section 5 summarizes and concludes the paper.

2. Literature review

As the transit window on the Northern Sea Route is extending in recent years, there has been growing interests on analysing the related economic and operational implications to the maritime industry. The NSR routes has shorter distance for shipping services between Europe and Asia - about 40% saving in distance compared with the traditional Suez Canal route. Most of the ports in China, Japan and Korea could benefit from the shorter distance when travelling to major ports in Europe (Lee and Song 2014). Ports in Hong Kong, Taiwan and Philippines can achieve some savings for ports in Northern Europe.

The shorter distance, however, does not always translate into savings on time and cost. There has been no consensus on the best choice of model and parameters to estimate shipping time and cost on the NSR route (Lasserre 2014). Different conclusions have been reached, with many researchers conservative under current circumstance but conditionally optimistic in medium to long term (See Lasserre 2011, 2014, Lee and Song 2014, Liu and Kronbak 2010, Moe 2014, Pruyn 2016, Stamatopoulou and Psaraftis 2012, Verny and Grigentin 2009). Verny and Grigentin (2009) compared the costs of delivering one container from Shanghai to Hamburg and concluded that NSR would not be very profitable. NSR's transport cost is twice as high as that of SCR, roughly equivalent to the

Trans-Siberian railway. Studies however suggest that in the future NSR will be more competitive with lower tariffs (Lasserre 2014, Liu and Kronbak 2010, Stamatopoulou and Psaraftis 2012), savings on time (Lee and Song 2014, Pruyn 2016), and better infrastructure after the implementation of the Russian Government's plan (Moe 2014).

Rojas-Romagosa, Bekkers and Francois (2015) were optimistic for NSR's future and described it as 'a major development for the international shipping industry' (p.28). By utilising different production functions, they estimated that NSR will take over two-thirds of the transport volume from SCR on the Asia-Europe market, which also boosts trade between the two regions. Geo-economics structure along the NSR and SCR routes will also be shifted due to the re-allocation of cargo volumes.

There are concerns over environment issues, however. Ships can pollute the area in different ways—oil and chemical spills, emissions of harmful gases and greenhouse gases, discharge, noise and water from ballast tanks (Ostreng et al. 2015). Shipping in the Arctic area should follow the International Convention for the Prevention of Pollution from Ships (MARPOL), which is the "main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes"(IMO 2016). The convention includes six technical Annexes that aim to prevent pollution from ships, and the regulations are updated with amendments. The International Code for Ships Operating in Polar Waters (Polar Code) also came into force on 1 January 2017. The first part of the code is about the safety of shipping in polar waters under the International Convention for Safety of Life at Sea (SOLAS), covering a range of issues such as ships equipment, design and construction as well as operation and manning. The second part specifies prevention of pollution from shipping under MARPOL, including ships' discharge requirements and non-mandatory guidance. With the implementation of the Polar Code, ships intending to operate in Arctic and Antarctic waters need to undergo an assessment and apply for a Polar Ship Certificate (IMO 2016).

The Polar Code also places higher demand on port imperceptibly (Condino 2015). The stricter rules on discharge can introduce challenges for ships' waste management in Arctic area, because the waste reception facilities in ports along NSR are limited and it can be costly to upgrade these small and remote ports. As a result, ships may need more capacity to keep wastes on board to deal with possible long passages, delays and other severe situations in Arctic area. While the efforts by IMO are generally well received, Liu (2016) argued that effects of the Polar Code should not be overestimated, because it covers only a few but not all the hazardous threats. Fuel oil and ballast water issues are only listed as recommendations in the Polar Code. In terms of legal and regulation, many damages to natural resources cannot be addressed in the current frameworks (Walkowski 2015), and a separate regime for Arctic may need to be constructed as a starting point to develop an international environmental liability regime.

In terms of environmental damage per ton-kilometre, shipping is among the least harmful transport modes (Cullinane and Cullinane 2013). Reduced sailing distance leads to less emissions per trip (Furuichi and Otsuka 2013). However, the annual emissions per ship may increase because of the higher total transport volume (Corbett et al. 2010, Lindstad, Bright and Strømman 2016, Rojas-Romagosa, Bekkers and Francois 2015). Lindstad, Bright and Strømman (2016) argued that the negative effects of emissions in Arctic outweigh the advantage of shorter distance, even if ships use cleaner fuels. Corbett et al. (2010) found that the small black carbon particles produced by ship's engine will severely influence Arctic ice, snow, and cloud. Ostreng et al. (2015) discussed the ecosystem in Arctic area with a special focus on impacts from ships. The vulnerability of Arctic area's ecosystems is the result of varies adaptations that Arctic animal have made to live in the extreme environment. Disturbance caused by shipping, such as the interruption of animals' seasonal migration to and from the Arctic area, can further interfere animals' other activities such as feeding, mating, giving birth, etc., although currently there are few documented evidences available.

In summary, many studies have raised environmental concerns for the NSR operation. Although such effects are mainly associated with shipping volumes and activities, few studies have considered inter-related factors such as the (endogenous) choices of ship size, market share of different transport modes, and competition between the NSR and SCR routes. This study aims to analyse the viability of NSR with comprehensive data including the ship size, fuel cost and navigation tariff, so that the traffic volumes and resultant environmental costs can be analyzed. Most previous investigations on environmental issues in Arctic and polar areas tend to be pragmatic, with more attention dedicated to economic issues such as fishery. In this study, we also consider emissions related pollution and global warming costs. Ballast water's impact is not included because ships do not have too many cargo handlings or stopovers alongside NSR.

3. Model and application

3.1 Model specifications

For the calculation of market shares of alternative routes, we consider the cargo owners that choose from alternative shipping options. Their choice decisions are considered with a logit model, where the choice probabilities or market share are determined by the generalised cost of each transport option (Fiorenzo-Catalano 2007, Stamatopoulou and Psaraftis 2012). The specification is as follows

$$P_i = \frac{e^{-\lambda c_i}}{\sum e^{-\lambda c_k}} \qquad (1)$$

$$c_i = p_i + VOT * t_i \qquad (2)$$

Where

P_i: probability to the selected option *i*

λ: a logit scale factor, always positive in the order of 10^{-3}

c_i: generalized cost of option *i*

t_i: total travel time of the option *i*

p_i: transport and other costs of option *i*

VOT: value of time

As discussed in the following sections, the mode share model will be applied to the updated industry data to obtain traffic volumes and needed shipping operations. For the calculation of resultant environment costs, both air pollution and global warming effects are considered. The air pollution cost (*CAP*) of a ship in one trip is:

$$CAP = \sum \varepsilon * f_j * p_j \qquad (3)$$

Where

ε: the total fuel consumption

f_j: emission factor of pollutant *j*

p_j: air pollution cost of pollutant *j*

For the cost of global warming (*CGW*), greenhouse gas emissions are first translated to Global Warming Potential in 20-year horizon (GWP) as CO_2 equivalents (Lindstad, Bright and Strømman 2016). The global warming cost is:

$$CGW = \sum \varepsilon * f_j * GWP_j * p_{co2} \qquad (4)$$

Where

GWP_j: pollutant j's Global Warming Potential

p_{co2}: price of CO_2 emission

The total environmental cost (*CE*) is simply the sum of CAP and CGW defined above.

3.2 Applications of the models

NSR and SCR sailing scenarios

Following Lasserre's (2014), a complete loop between Rotterdam and Shanghai is selected to compare NSR's feasibility with other transport options. We consider that ships sailing via NSR are 1AS-class (Arc5) ice-strengthened and those through SCR are normal container ship. Though Suezmax *Vladimir Tikhonov* transited through north of the New Siberian Islands in NSR successfully from 23^{rd} to 30^{th} in 2011, such operations are much dependent on the ice condition and time period (Pastusiak 2016). Ships normally need to transport via the Sannikov strait with a draught limit of 13 meter. Due to this limitation, the TEU capacity is set as 4,500 for NSR (Panamax). For the SCR, the average TEU capacity of 156 ships operating between Rotterdam and Shanghai was 15,333 in mid 2016 (see Table 1), thus in this study the capacity of SCR is assumed to be 15,000 TEU. NSR's operation season is set as 180 days per year.

TABLE 1 – SHIPS TRANSPORTING BETWEEN ROTTERDAM AND SHANGHAI IN MID 2016

Total ships	156
Average DWT	164,714
Average TEU capacity	15,333
Average speed, knots	22.97

Source: authors' calculation using Alphaliner data retrieved in 2016

The current fuel price is 255 USD/ton for IFO380 fuel oil (BunkerIndex 2016). The NSR tariff fee in USD is now half as before thank to the devaluation of RUR since 2014 (Yahoo Finance 2016). The Russian government does not charge tariff for using NSR. However, payments for icebreaking support and escort are needed for a permit to sail via NSR. Northern Sea Route Administration (2014) divided NSR into 7 sea zones and charge ice-break pilotage tariff depending on the ship's DWT, ice-strengthened condition and number of pilotage zones. 1AS-class ice-strengthened ship can transport independently in most of the medium and easy ice-conditioned areas. Considering the long navigation season, here a 4-zone pilotage is assumed and the transit fee is 245 thousand USD/trip. According to Suez Canal Authority (2016), the transit fee in SCR of a 160,000 DWT container ship is about 418 thousand USD/trip. The other assumptions and costs are summarized in Table 2. The calculated costs of transporting per TEU between Rotterdam and Shanghai are 1,027.51 via NSR and 560.23 via SCR, respectively.

TABLE 2 - TRANSPORT ASSUMPTIONS AND CALCULATED COSTS THROUGH NSR AND SCR, ROTTERDAM-SHANGHAI

	NSR	SCR	
Construction cost, million US$	180	145	NSR: (Verny and Grigentin 2009) SCR: (the Maersk Group. 2016)
DWT	40,000	160,000	NSR: (Verny and Grigentin 2009) SCR: (the Maersk Group. 2016)
TEU capacity, TEU	4,500	15,000	NSR: assumed based on Panamax ship SCR: concluded and modified from Alphaliner service data
Load factor, eastbound	45%	60%	(Lasserre 2014)
Load factor, westbound	70%	87%	(Lasserre 2014)
TEU transported per trip, eastbound	2,025	9,000	
TEU transported per trip, westbound	3,150	13,050	
Distance, km	15,793	19,550	Calculated on GIS MapInfo (Lasserre 2014)
Maintenance, days per 180 days	5	2	(Lasserre 2014)
Suez Canal delay, days		2	(Lasserre 2014)
Ports called at	1	5	
Stop days at port, per trip	2	10	2 days in each port
Stop days, total	2	12	

Average sailing speed, knots	17.71	23.00	NSR: average speed inside NSR: 14 kts; outside: 20 kts (Lasserre 2014) SCR: concluded and modified from Alphaliner service data
Sailing time (days)	20.60	19.65	
Total segment time (days)	22.60	31.65	
Total possible segments, 180 days	7.74	5.62	
Total TEUs transported	20,036	61,997	
Cost analysis (for 180 days)			
Crew, thousand USD	858.00	780.00	130.000USD monthly for a crew of 23. NSR:+10% premium (Lasserre 2014)
Insurance: H&M, P&I, thousand USD	370.44	248.68	NSR: 20% extra charge (Lasserre 2014) SCR: 0.343%/yr of ship building cost (Furuichi and Otsuka 2013)
Capital cost, thousand USD	9,000.00	7,250.00	Service 10 yrs, straight-line depreciation
Maintenance, thousand USD	985.50	793.88	1.095%/yr of ship building cost (Furuichi and Otsuka 2013)
Port dues, thousand USD	265.13	2,454.90	0.428 USD/GT/call
Transit fees, thousand USD	1,897.11	2,350.53	
Average transit fee per trip, thousand USD	245.00	418.00	NSR: (NSRIO 2013) SCR: (Suez Canal Authority 2016)
Fuel consumption rate, tons/day	78.76	300.00	(Notteboom and Cariou 2009)
Sailing days per segment	20.60	19.65	
Fuel consumed per trip, tons	1,622.47	5,896.23	
Bunker price, IFO 380, USD/t	255.00	255.00	IFO 380 Port Rotterdam (BunkerIndex 2016)
Fuel cost per trip, thousand USD	413.73	1,503.54	
Fuel cost, total thousand USD	3,203.63	8,454.82	
Total cost, 180 days, thousand USD	**16,579.82**	**22,332.81**	
Handling cost per TEU, USD	200.00	200.00	100USD/TEU for loading and discharging respectively. Assumed based on (Hackett 2009)
Total cost per TEU, USD	**1,027.51**	**560.23**	

Market shares of different transport options

Railway and air transport are also included in addition to NSR and SCR options. Railway is another alternative to transport between North East Asia and North West Europe. The whole journey from Shanghai to Rotterdam takes approximately 18 days through the New Eurasian Land Bridge and costs about 2,500 USD/TEU. In 2015, the New Eurasian Land Bridge transported a total of 53,000 TEUs between Europe and Asia (International Infocenter For the New Silkroad 2016). The air transport fee is about 3 USD/kg, which means the cost of one TEU equivalent is about 42,000 USD and the transport time is two days.

Tavasszy et al. (2011) obtained the λ value as 0.0045, which fits well the Eurostat database covering the transports between Europe and the rest of the world. Following Stamatopoulou and Psaraftis (2012), the average cargo value is assumed to be 25,000 USD and owner's value of time is calculated as 6.85% of cargo value per year (4.69 USD/day). Table 3 shows the market shares of different transport options. During NSR's navigation season, it can contribute 12.88% of the total transport volume between Europe and Asia, which makes up 6.44% of the annual volume. NSR can get some market share from the traditional SCR mainly because of its shorter transport time. The low market share of railway is due to its relative high cost and limited time advantage. Although railway transport has shorter distance and higher speed, the high cost and the incompatibility of each country's rail along the New Eurasian Land Bridge impairs its potential efficiency.

TABLE 3 - MARKET SHARES OF DIFFERENT TRANSPORT OPTIONS

	NSR	SCR	Rail	Air
Total segment time, days	22.60	31.65	18.00	2.00
Cost per TEU, USD	1,027.51	560.23	2,500.00	42,000.00
General cost	1,133.54	708.74	2,584.45	42,009.38
Market share (180 days)	12.88%	87.10%	0.02%	0.00%
Market share (annual)	6.44%	93.54%	0.02%	0.00%

Estimation of environmental cost

Carbon dioxide (CO_2), carbon monoxide (CO), Sulphur oxides (SO_x), nitrogen oxides (NO_x), nitrous oxide (N_2O), methane (CH_4), Non-methane volatile organic compound (NMVOC), black carbon (BC), organic carbon (OC) and particulate matter (PM2.5) in ship effluent are considered in the estimation of environmental cost (*CE*). SO_x, NO_x, NMVOC and PM2.5 are used to calculate the air pollution cost (*CAP*), while CO_2, CO, N_2O, CH_4 and BC are used to evaluate their impacts on global warming (*CGM*). Only the two maritime transport options, NSR and SCR, are compared due to the focus of this study, and large variation of cost estimates in the literature. The emission factors are mainly adapted from Peters et al. (2011), and the factor of PM2.5 is from Jiang, Kronbak and Christensen (2013). Table 4 summarizes the estimation of harmful gases and greenhouse gases emission in NSR and SCR respectively.

TABLE 4 - EMISSION FACTORS AND ESTIMATION OF EMISSION VOLUME, PER SHIP, PER TRIP

		Emission, t	
	Emission Factor, kg/t	NSR	SCR
CO_2	3,130.00	5,078.33	18,455.19
CO	7.40	12.01	43.63
SO_x	54.00	87.61	318.40
NO_x	78.00	126.55	459.91
N_2O	0.08	0.13	0.47
CH_4	0.30	0.49	1.77
NMVOC	2.40	3.89	14.15
BC	0.35	0.57	2.06
OC	1.07	1.74	6.31
PM2.5	11.79	19.13	69.52

Air pollution costs are adapted from Korzhenevych et al. (2014) and converted into USD. Because only costs in European sea areas are available, cost in other sea areas from Suez Canal to Asian sea areas are assumed to be equal to *Mediterranean Sea*'s cost level. The rationale is that air pollution cost is usually positively correlated with the economic development in the coastal areas. *Mediterranean Sea's* costs are lower than other European sea areas in general. Arctic sea area outside Europe is assumed to be equal to the cost in *Remaining North-East Atlantic*, which is the lowest in the five regions mentioned in European Commission (2016). NSR's remaining sea areas' pollution cost in Asia is also calculated with *Mediterranean Sea's* costs. Ship's travelling distance in each sea area is estimated based on sea route information. Resultant air pollution cost (*CAP*) is shown in Table 5. Transporting one TEU between Rotterdam and Shanghai can lead to 593.04 USD air pollution cost via NSR and 596.13 USD via SCR.

The GWP_{20} of each pollutant in Arctic and rest of world areas are shown in Table *6* (Adapted from Lindstad, Bright and Strømman 2016). Normalised global warming impacts in unit of ton CO_2 equivalents are also presented. In this research, the cost of CO_2 is calculated as 100USD/ton, a relatively high value. The cost of global warming (*CGW*) in both NSR and SCR are presented. The CO_2 equivalent of one TEU is 3.29 ton in NSR and 2.14 ton in SCR and their global warming cost are 328.58 USD and 214.00 USD, respectively.

TABLE 5 - TOTAL AIR POLLUTION COST (CAP), USD PER SHIP, PER TRIP

	NSR				SCR		
	North Sea	Arctic Sea	Other	**NSR total**	North Sea	Other	**SCR total**
Ratio of total distance	5.42%	38.09%	56.49%	100.00%	2.66%	97.34%	100.00%
Pollution Cost							
SO_x	54,495.40	146,135.56	500,718.13	701,349.09	97,194.14	3,135,530.31	3,232,724.46
NO_x	61,626.01	163,772.61	199,705.99	425,104.61	109,911.80	1,250,572.21	1,360,484.00
NMVOC	669.24	1,567.74	2,491.13	4,728.11	1,193.61	15,599.65	16,793.27
PM2.5	40,391.13	61,061.99	301,863.28	403,316.40	72,038.76	1,890,287.99	1,962,326.75
Total *CAP*	157,181.77	372,537.90	1,004,778.54	**1,534,498.21**	280,338.31	6,291,990.16	6,572,328.48
***CAP* per TEU**				**593.04**			**596.13**

TABLE 6 - GWP AND GLOBAL WARMING COST (CGW), PER SHIP, PER TRIP

	GWP_{20}		NSR, ton CO_2 equivalents		SCR, ton CO_2 equivalents
	Arctic	Other	Arctic	Other	Other
CO_2	1.00	1.00	1,934.33	3,143.99	18,455.19
CO	1.80	1.80	8.23	13.38	78.54
N_2O	265.00	265.00	13.10	21.29	125.00
CH_4	30.00	30.00	5.56	9.04	53.07
BC	1,700.00	345.00	2,521.43	831.70	4,882.08
Total			8,502.07		23,593.87
Per TEU			**3.29**		**2.14**
Cost of CO_2	100.00				
Total *CGW*			**850,206.97**		**2,359,386.79**
***CGW* per TEU**			**328.58**		**214.00**

4. Analyses and discussions

4.1 Sensitivity tests on market share

The aforementioned calculation results show that the NSR can achieve competitive market share in the assumed scenario. Sensitivity analysis on several variables (e.g. NSR tariff, fuel cost and cargo value as reported in the appendixes) shows that the market share will not be changed significantly for variations in these variables. Higher fuel cost and tariff in NSR will make SCR more competitive. When the cargo becomes more valuable, its value of time will raise and some market share will shifted to NSR. Figure 2 displays the relationship of shipping distance when using NSR (km) and market share. Setting Rotterdam as the port used in Europe, several Asian ports' NSR distances and market shares are listed as in Table 7. Lee and Song (2014) noted that northern ports and countries with shorter NSR distances can better benefit from the NSR. For example, for the port of Yokohama in Japan, NSR can gain around 20% market share in its navigation period. However, in Singapore, NSR can only get about 4.2% market share, with the remaining dominated by the SCR option.

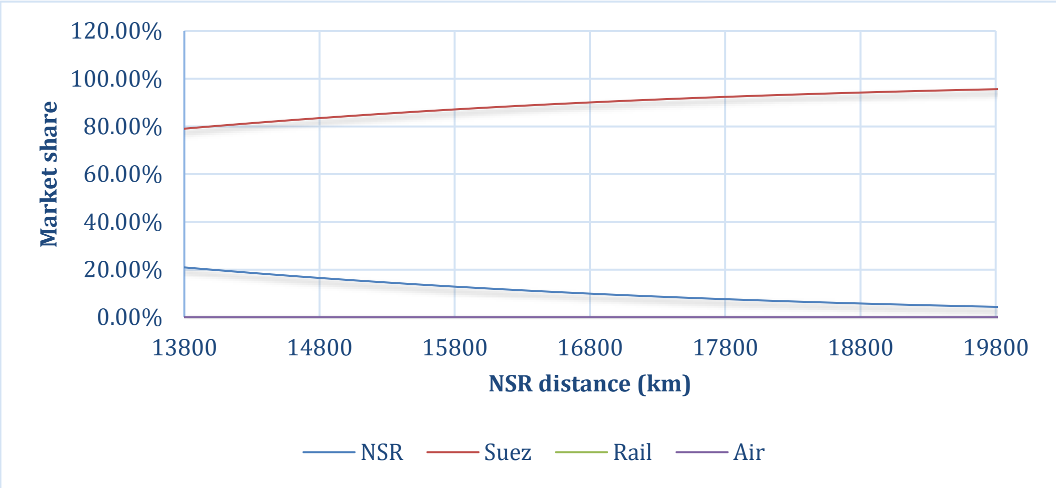

Figure 2 - Change of 180-day navigation period market share depending on NSR distance (km)

Table 7 - Market Share from different Asian ports to Rotterdam

		Market Share (180 days)			
Port	NSR distance (km)	NSR	SCR	Rail	Air
Yokohama	13,865	20.60%	79.38%	0.02%	0.00%
Pusan	14,994	15.73%	84.25%	0.02%	0.00%
Shanghai	15,793	12.88%	87.10%	0.02%	0.00%
Keelung	16,466	10.83%	89.15%	0.02%	0.00%
Hong Kong	17,329	8.62%	91.36%	0.02%	0.00%
Singapore	19,961	4.19%	95.79%	0.02%	0.00%

4.2 Sensitivity analyses on environmental cost

Table 8 shows the environmental cost (*CE*) based on aforementioned assumptions. The environmental cost in NSR is slightly higher, which is mainly because it has more severe impacts on global warming. The total environmental cost between Rotterdam and Shanghai is calculated based on an annual transport volume of 10 million TEU. In order to explore how transport cost can influence the total environmental cost, changes of cost in NSR and SCR and total annual environmental cost are plotted. In Figure 3. The *x* axis reflects the times that NSR cost has changed from original cost and *y* axis reflects the changes of SCR cost. *z* shows the total environmental cost (*CE*).

TABLE 8 - ENVIRONMENTAL COST (CE) FOR THE TRANSPORTATION OF ONE TEU

	NSR	SCR
Cost of pollution, USD (*CAP*)	593.04	596.13
Cost of global warming, USD (*CGW*)	328.58	214.00
Environmental cost, USD (*CE*)	921.63	810.13

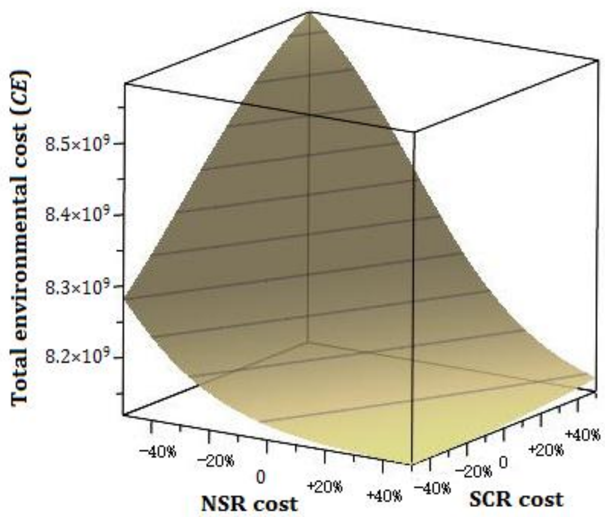

FIGURE 3 – NSR, SCR COSTS CHANGES' EFFECT ON ENVIRONMENTAL COST, USD/YR

From the figure it can be seen that NSR transport cost is negatively correlated with the total environmental cost, which means higher NSR cost will finally lead to less total environmental cost. However, the SCR cost is positively correlated with the environmental cost. The rationale behind is that the NSR has higher environmental cost per TEU, thus higher cost in NSR or lower cost in SCR will lead more market share flow to SCR, which is cheaper and more environmental friendly in this study, and the total environmental cost is lowered as more TEU are transported in SCR.

Transport cost can change in several ways. For example, higher transport cost in SCR can be the result of higher transit cost via Suez Canal or implementation of emission tax alongside the SCR. However, given the fact that SCR is actually the environmental friendly route in this study, higher cost in this route can increase the total environmental cost. As a result, when the option of shipping via NSR is considered, emission tax on the NSR route can in the end leads to higher environment costs globally, as ships will navigate through the less regulated sea areas, in this case, NSR.

4.3 Alternative scenarios and assumptions

Better load factor

Lasserre (2014) assumed load factors in NSR and SCR based on historical transport volumes between Europe and Asia. The load factors in NSR, 45% eastbound and 70% westbound, are both lower than those in SCR, which are 60% and 87% respectively. The lower load factors in NSR raise up the average transport cost and environmental cost. A scenario that NSR has same load factors to SCR is therefore analysed. The higher load factors do not change the total transport cost of each ship, however the average cost per TEU is lowered. The NSR transport cost is now 847.37 USD. The new market shares are reported in Table 9 and environmental costs are summarized in
Table *10*.

TABLE 9 - MARKET SHARES OF DIFFERENT TRANSPORT OPTIONS WITH HIGHER LOAD FACTORS IN NSR

	NSR	SCR	Rail	Air
Total segment time, days	22.60	31.65	18.00	2.00
Cost per TEU, USD	847.37	560.23	2,500.00	42,000.00
General cost	953.41	708.74	2,584.45	42,009.38
Market share (180 days)	24.95%	75.03%	0.02%	0.00%

Market share (annual)	12.48%	87.51%	0.02%	0.00%

TABLE 10 - ENVIRONMENTAL COST (CE) OF EACH TEU WITH HIGHER LOAD FACTORS IN NSR

	NSR	SCR
Cost of pollution, USD (*CAP*)	463.95	596.13
Cost of global warming, USD (*CGW*)	257.05	214.00
Environmental cost, USD (*CE*)	721.00	810.13

As can be seen in Table 9, NSR can get approximately 25% market share during its navigating season, which makes up 12.48% of the total annual volume. The environmental cost of NSR, with higher load factors, is lower than that in SCR now, as more TEU are carried per ship.

However, such benefits are unlikely to be achieved in the near future. Because facilities in NSR and Arctic areas are far from good, few of these ports will receive a stopover or cargo loading/unloading/transit. Thus, it will probably take quite some time before load factors in NSR can catch up to the level of SCR.

Bigger ship in NSR

Due to the draught limitation in the Sannikov strait (number 1 in Figure 4 (Pastusiak 2016)), this study selected a Panamax container ship to transport in NSR. There are cases when larger ships can pass through (for example, *Vladimir Tikhonov* passed through the NSR successfully in 2011 when both the temperature and ice condition are so good that the ship could pass from the north of New Siberian Islands). Therefore, we consider the case when bigger ships can be used in NSR. We consider the case that the construction cost of a 1AS-class Suezmax ship is 500 million USD and its DWT and TEU capacity are the same to the Suezmax ship. Fuel consumption rate in NSR is set as 200 t/day as the average speed in NSR is 17.71 knots, which is slower than the speed in SCR. The average transit fee is also changed and the new value is 607.7 thousand USD/trip. For this scenario, Table 11 presents the new market shares of different transport options and
Table *12* shows the environmental costs.

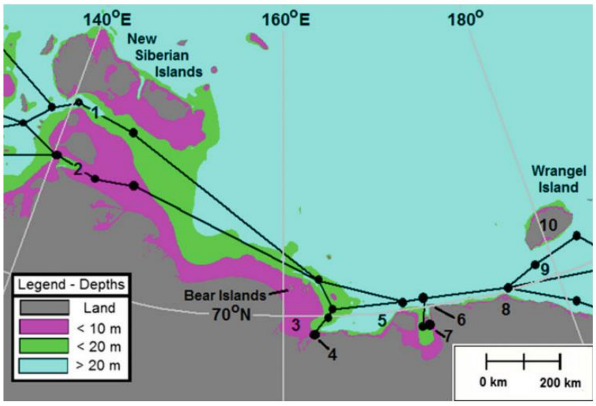

FIGURE 4 - ROUTES FOR THE CROSSING OF THE EAST SIBERIAN SEA

Source: (Pastusiak 2016)

TABLE 11 - MARKET SHARES OF DIFFERENT TRANSPORT OPTIONS WITH BIGGER SHIP IN NSR

	NSR	SCR	Rail	Air
Total segment time, days	22.60	31.65	18.00	2.00
Cost per TEU, USD	852.71	560.23	2,500.00	42,000.00
General cost	958.75	708.74	2,584.45	42,009.38
Market share (180 days)	24.50%	75.48%	0.02%	0.00%
Market share (annual)	12.25%	87.73%	0.02%	0.00%

TABLE 12 - ENVIRONMENTAL COST (CE) OF EACH TEU WITH BIGGER SHIP IN NSR

	NSR	SCR
Cost of pollution, USD (*CAP*)	451.78	596.13
Cost of global warming, USD (*CGW*)	250.32	214.00
Environmental cost, USD (*CE*)	702.10	810.13

The average cost of NSR in this new scenario is 852.71 USD/TEU, which is about 170 USD cheaper than the previous consideration of Panamax container ship. The reduced cost is mainly due to the economics of scale from the larger ships. The lower price bring NSR more market share to about 24.50% in its navigation season and 12.25% annually. Additionally, the environmental cost in NSR is now reduced below that in SCR.

There are challenges using larger ships in NSR. First, ice strengthened Suezmax ships are very expensive and it is unclear how these ships can be used when NSR is not navigable. In addition, unless the facilities alongside NSR can be substantially improved, ports in the region may not be able to fully support regular navigation of such large ships. Therefore, although our simulation suggests the benefits of using larger ships, in practice they may not be achievable.

5. Conclusions

NSR can potentially become an attractive alternative route connecting Europe and Asia in addition to SCR. This study considers mode choices and market share splits among different transport modes and alternative shipping routes, so that the traffic volume via NSR can be estimated and the resultant environment costs can be calculated. The effects of influencing factors, including load factor, fuel cost, tariff cost, ship size, are also tested. Our analysis suggests that NSR can be a viable option under the status quo, capture a fair market share in the current market. However, its environmental costs tend to be higher than SCR due to small ship size and low load factor in the present, thus that the successful development of NSR can lead to worse environment outcomes. As a result, shifting traffic volumes from SCR to NSR, such as imposing emission charges or higher canal fees on SCR, can be undesirable from the perspective of environmental effects. If higher load factors and larger ships can be achieved on NSR, both operational and environmental costs can be reduced, which will lead to higher market share of NSR and social welfare. To achieve these objectives, however, investment in both ships and regional facilities should be made.

Though we tried to base on analysis on real industry data and previous studies as much as possible, we are forced to make certain assumptions such as NSR’s navigation window, insurance cost, construction cost of ice strengthened ship and air pollution costs in the NSR route. In addition, our study has not considered environment issues such as shipping noise, spill and other disturbance. These are important issues, on which limited studies and data are available. Studies on these topics, probably from various disciplines, will allow the maritime industry to better understand the benefits and costs of NSR, so that it can benefit the shipping industry as well as the global community.

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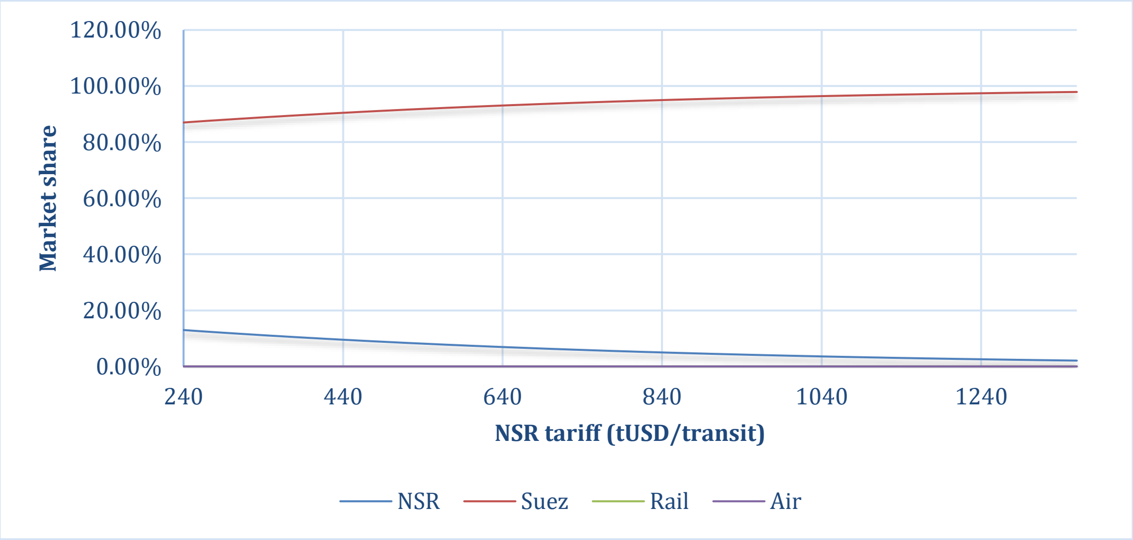
Appendixes

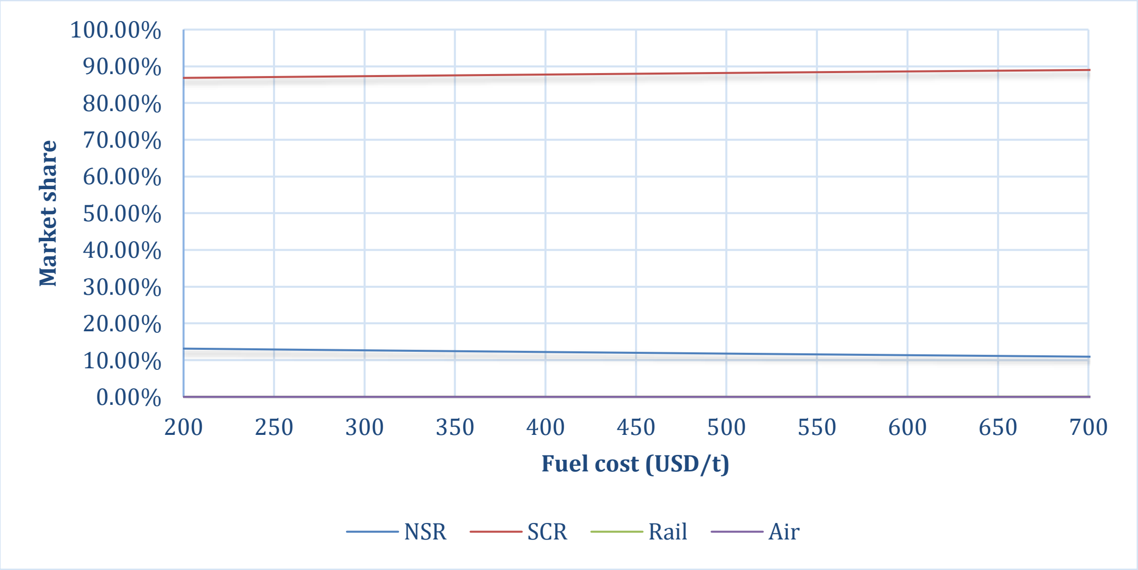
APPENDIX A - POLLUTION COST IN DIFFERENT SEA AREAS (USD/T)

	North Sea	Arctic Sea (*Remaining North-East Atlantic*)	Other Sea Areas (*Mediterranean Sea*)
SO_x	11,476.00	4,379.00	10,117.00
NO_x	8,984.50	3,397.50	2,793.50
NMVOC	3,171.00	1,057.00	1,132.50
PM2.5	38,958.00	8,380.50	27,935.00

APPENDIX B - CHANGE OF 180-DAY NAVIGATION PERIOD MARKET SHARE DEPENDING ON NSR TARIFF (USD/TRANSIT)



APPENDIX C - CHANGE OF 180-DAY NAVIGATION PERIOD MARKET SHARE DEPENDING ON FUEL COST (USD/T)



APPENDIX D - CHANGE OF 180-DAY NAVIGATION PERIOD MARKET SHARE DEPENDING ON CARGO VALUE (USD/TEU)