Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market

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Abstract

This paper investigates the feasibility of the Northern Sea Route (NSR) using a speed optimisation model to minimise the required freight rate, by employing current data from a shipowner, by secondary data, conducting petroleum product transport on the NSR. The oil product tanker segment is used to assess route alternatives taking into account distance, ship size, ice breaking fees, fuel types and prices. Environmental policy elements are included in the cost analysis to account for low sulphur fuels from 2020, a prospective ban on the use of heavy fuel oil in the Arctic, and a possible global fuel tax.

1. Introduction

The Northeast Passage (NEP) is a maritime passage comprising of many routeing alternatives linking the Atlantic with the Pacific Ocean through the Russian Arctic coastline. The Northern Sea Route (NSR), which is part of NEP, is officially defined by Russia as the route stretching from Novaya Zemlya in the west to the Bering Strait in the east (Østreng and Eger, 2013)[1]. The recent focus on the NSR relates to the unprecedented reduction in the Arctic sea ice cover since 1979 (e.g. Stroeve et al., 2012; Parkinson and Comiso, 2013; Stroeve and Notz, 2018). Currently, there is a growing body of literature within climate science projecting future accessibility of Arctic routes throughout the 21st century. The NSR is estimated to become accessible for non-ice class ships by 2050 (Smith and Stephenson, 2013; Melia et al., 2016). Whilst ice extent and thickness will remain the main obstacles for navigation between 2030 and 2050, other ice and climatic conditions (e.g. ice ridging and pressure, waves, circulation, winds) will mainly affect shipping beyond 2050 (Aksenov et al., 2017). These developments have led to the re-emergence of the NSR as an alternative maritime route between Northwest Europe, Russian Arctic, North America and Northeast Asia.

After the first experimental transit of a non-Russian flagged merchant ship (MT Uikku) through the NSR in 1995 (Brigham and Armstrong, 1996), exploratory transit voyages[2] have increased since 2007 and peaked in 2013 with 2 and 71 transits respectively, followed by a rapid decline and use of the route mainly by Russian-flagged ships in 2014 (ARCTIS, 2013; NSRA, 2016; CHNL, 2019). Although the NSR offers shorter geographical distances up to around 60% depending on origin–destination (OD) (Mulherin, 1990), reductions in transport costs and transit times depend on a number of factors. Environmental factors (ice conditions, harsh climate), and safety concerns largely determine the use of the route. Moreover, geopolitical developments (re-direction of petroleum flows from the Barents and White Seas to the Baltic since 2014), decrease of piracy incidents in the Gulf of Aden during 2015, and most importantly, market conditions (drop in oil price levels during 2015, and variability of ice

[1] The term NSR is used hereinafter to denote either the NSR or the NEP for both transit and destination voyages.
[2] Transit voyages refer to voyages conducted between the Atlantic and the Pacific Oceans through the Arctic. Destination voyages originate or terminate within or outside the Arctic. Domestic voyages are those occurring within the boundaries of the NEP and/or NSR.

breaking fees coupled with the provision of expensive ice damage repairs), all contributed to a rapid decline in transit traffic.

Analysis of Arctic shipping feasibility has increased considerably since 2011 with liner shipping being the most studied transport system, and the NSR, the most studied route in the literature (Lasserre, 2014, 2015; Meng et al., 2016; Theocharis et al., 2018). On the other hand, less attention has been paid to bulk shipping, and more specifically on oil tanker segments (Song and Zhang, 2013; Zhang et al., 2016; Faury and Cariou, 2016). However, on average, 49% of the exploratory transit voyages which occurred in the NSR between 2009 and 2014 involved oil product tankers of various sizes, followed by a sharp decline to 10% between 2015 and 2018. Although, this is attributed to a mix of economic and geopolitical factors, it shows that the potential of the NSR both for destination and transit traffic mainly lies with bulk (liquid and dry) and specialised (e.g. LNG) rather than liner shipping in the short to medium-term. The studies reporting on the feasibility of Arctic routes also confirm that they are currently more competitive for single or round voyages and for bulk shipping, whilst their competitiveness increases for year-round liner operations only in the long-term (Theocharis et al., 2018).

This paper aims to examine the feasibility of the NSR against the oil product tanker segment at the tactical/operational level. First, the period 2011–2017 is simulated to examine route choice between the Suez Canal route (SCR) and the NSR, then the current (2018) situation is investigated. Environmental policy implications from 2020 onwards are also assessed. The main factors considered are distance, fuel types and prices, ice breaking fees and ship size. The required freight rate (RFR) is used to compare the break-even cost per tonne of alternative routes from the shipowner's perspective.

A novel speed optimisation model is developed to minimise the RFR between the NSR and the SCR on a round voyage basis during the summer/autumn season. The speed constitutes a decision variable to the problem, contrary to other studies in which speed is an implicit input (Psaraftis and Kontovas, 2013). The model incorporates environmental policy elements reflecting a transition from high to low sulphur fuels from 2020 onwards to tackle air quality and enhance environmental protection as well as the potential to transition from heavy fuel oil (HFO) towards cleaner fuels by introducing a global fuel tax, and the ban on the use of HFO in the Arctic. The model employs up to date secondary data including vessel technical characteristics, capital and operating costs, and OD distances. Moreover, primary data concerning voyage-related costs and premiums were obtained from a product tanker shipowning company and a logistics company with extensive experience on the NSR.

The remainder of this paper is organised as follows: First, a literature review is provided in Section 2. The methodology is presented in Section 3, followed by the analysis of results in Section 4. The discussion of findings are provided in Section 5 and conclusions are drawn by reflecting on the results and future research opportunities.

2. Literature review

2.1. Feasibility of the NSR

The feasibility of the NSR for deep-sea shipping is determined primarily by local sea ice conditions and the extent of the annual navigation season (Stephenson et al., 2014; Yumashev et al., 2017). Speed through ice is also an important factor that increases the uncertainty concerning transit times, and affecting voyage and operating costs alike (Wergeland, 1992;

Mulherin et al., 1996; Kitagawa, 2001; Faury and Cariou, 2016; Pruyn, 2016). Cost factors, such as increased capital, fuel, and operating costs for different types of ice class ships (Erikstad and Ehlers, 2012; von Bock und Polach et al., 2015) and most importantly, ice breaking fees, largely affect the competitiveness of the NSR (Liu and Kronbak, 2010; Furuichi and Otsuka, 2015; Cariou and Faury, 2015; Gritsenko and Kiiski, 2016; Zhao et al., 2016; Xu et al., 2018). Moreover, revenue factors, such as average load factor, deadweight (dwt) utilisation and ship size are crucial in order to exploit economies of scale (Wergeland, 1992; Schøyen and Bråthen, 2011; Lasserre, 2014; 2015; Furuichi and Otsuka, 2015; Zhang et al., 2016; Xu et al., 2018). Yet difficult ice conditions, when they occur, may prevent larger ships using the route north of the New Siberian Islands, and therefore avoiding the shallow Sannikov Strait.

Whilst the literature on comparative studies of Arctic routes has increased considerably since 2011, so has the difficulty of identifying valid parameters regarding certain cost and operational factors (Lasserre, 2014, 2015; Meng et al., 2016; Theocharis et al., 2018). Minimal shipping activity on Arctic waters regarding full transits coupled with the complexity of Arctic maritime operations in harsh climate and sea ice, and the relatively small ice class fleet globally (Yumashev et al., 2017; Solakivi et al., 2017, 2018; Tseng and Cullinane, 2018), increase the variability of estimates and underline the difficulty of obtaining a global view on Arctic shipping economics. Solakivi et al. (2017, 2018) recently attempted to address this gap by statistically analysing and determining increased costs of ice class containerships, and bulkers and tankers respectively.

Whilst the literature on the feasibility of the NSR has grown considerably during the last decade, there have been only a few studies investigating tanker trades (e.g. Song and Zhang, 2013; Zhang et al., 2016; Faury and Cariou, 2016). Further, the extant literature investigates whether the NSR is a competitive alternative under specific conditions and certain periods of time. Whilst the impact of sea ice dynamics on the economics of the NSR has been explored (Faury and Cariou, 2016), there is a very limited understanding as to how fuel price levels, ice breaking fees and ship size affect the use of alternative routes in the context of oil tanker shipping (Zhang et al., 2016). Moreover, alternative fuel types and distances for oil product tankers have not so far been explored. Moreover, crucial economic factors which are coupled with inherent strategic and political issues encompassing the tanker trades and affect routeing patterns have not been addressed. This study aims to contribute to the literature by investigating the feasibility of the NSR for oil product tankers compared to the SCR by:

• Demonstrating quantitatively why the NSR was a competitive alternative for product carriers during 2011–2014 and not since 2015.

• Assessing the competitiveness of the NSR currently. Alternative fuel types and the forthcoming IMO 2020 sulphur limit are considered.

• Quantifying the impact of environmental regulations by considering the introduction of a global fuel tax or a ban on heavy fuel oil (HFO) in the Arctic.

• Considering distance by assessing three cases using indicative origins and destinations (ODs).

• Considering the factor of ship size by using four ship sizes to take into account of economies of scale between alternative routes.

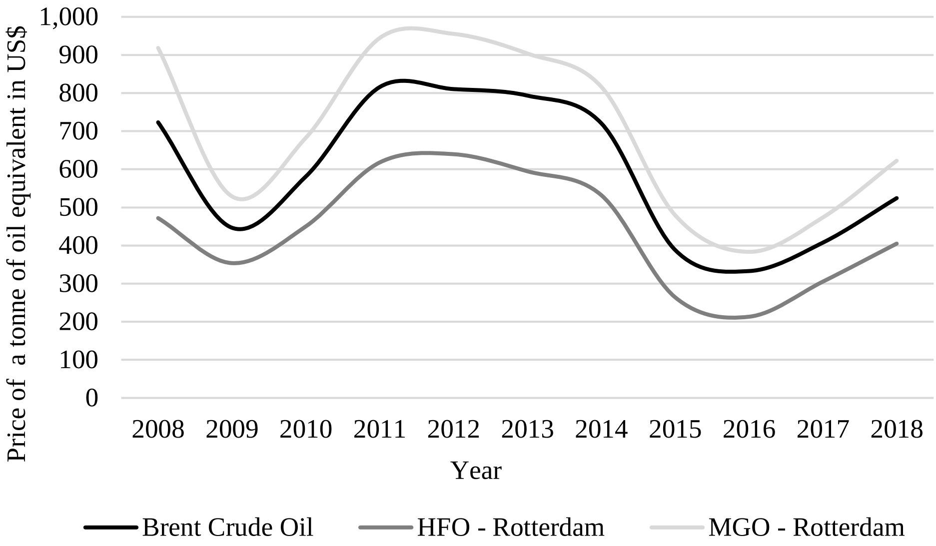
• Developing a comprehensive speed optimisation model to determine the minimum RFR. The speed here is a decision variable to the problem rather than an implicit input, which is used to calculate other variables, such as the RFR (Psaraftis and Kontovas, 2013).

• Employing up to date secondary data, and primary data concerning crucial factors that have not been considered in past studies.

2.2. 2011–2017: From high to low fuel prices and insurance premiums

The NSR witnessed an increase in transit voyages involving non-Russian flagged vessels during the period 2009–2013. There was extensive use of the passage, where the gradual sea ice retreat along with high fuel prices and a competitive ice breaking tariff policy induced non-Russian operators to explore the NSR as an alternative to traditional routes such as the Suez and Panama Canal routes (Gritsenko and Kiiski, 2016). In addition, it boosted destination traffic. These developments also coincided with the launch of Russia's new "Arctic Strategy 2020" in 2009, concerning further development of the NSR (ARCTIS, 2019a, 2019b). Another equally important reason behind this surge in transit traffic was the increased number of piracy incidents off the Gulf of Aden during the period 2009–2014, which also meant additional insurance premiums when transiting via the SCR (Tanker Company, 2019). A large number of product carriers of 47 and 162,000 dwt operated along the NSR between 2011 (41.4%) and 2014 (51%) (CHNL, 2019; NSRA, 2016). The sharp decline of product carriers' voyages originating from the Barents and White Seas in 2014 is attributed to a redirection of condensate and naphtha flows to the Baltic (Bambulyak et al., 2015; Tanker Company, 2019).

The decline of interest since 2015 is associated with the fall in global oil prices and a drop in piracy insurance premiums, which reduced the economic potential of the route, since both fuel cost and oil-related commodity prices declined respectively. Moreover, a lower RFR was not sufficient to cover potential ice damage repairs due to the remoteness of ports and low number of shipyards. Thus, the cost to repair ice damages can increase dramatically. Moreover, official ice breaking fees declined due to the depreciation of the rouble since 2015, but these were still higher than the discounted ones offered before 2013. The NSR being a shorter route lost its comparative advantage over the SCR for tanker voyages between the Atlantic and the Pacific. Not only did the cost differential between the NSR and SCR narrow due to lower voyage costs in the latter, but also low commodity prices and hence a lower value of cargo on-board meant that transit time was not very important. Fig. 1 shows the annual average prices of Rotterdam-based HFO and marine gas oil (MGO) in US$ per tonne for the period 2008–2018, both correlated to the price of Brent crude oil, which is converted from barrels to metric tonnes. Following an almost 40% decline in the price of Brent crude between 2008 and 2009, HFO and MGO prices dropped by 25% and 42% respectively. Then, they rose during 2010, and maintained an average of 600 and 900 US$/t respectively between 2011 and 2014. Subsequently, HFO and MGO prices fell to an average of 260 and 450 US$/t respectively during the period 2015–2017. Currently (2018), the average prices for HFO and MGO are around 400 and 600 US$/t respectively (Clarksons, 2019).



Sources: BP (2018), Clarksons (2019).

Figure 1. Annual average price of a tonne of oil equivalent between 2008 and 2018

2.3. Today to 2020 and beyond: towards alternative fuel types and operational modes

The International Maritime Organisation (IMO) extension of the limit on sulphur fuel content from the so-called Emissions Control Areas (ECAs)[3] – currently at 0.10% – to a global level is expected to have a significant impact on fuel costs, types of fuel used as well as on capital expenses. More specifically, the global sulphur content in marine fuels (outside ECAs) must be reduced from the current maximum level of 3.50% to a 0.50% m/m (mass by mass) from 2020 (IMO, 2018, 2016a). Currently, the options for the maritime transport industry to address these regulations extend from the adoption of abatement technologies to the use of alternative fuels. Abatement technologies may refer to exhaust cleaning systems (scrubbers) that are able to remove sulphur oxides (SOx) from the exhaust gas before these are emitted to the atmosphere. Alternative fuels relate to low sulphur heavy fuel oil (LSHFO) or distillates such as MGO, or other fuels such as liquefied natural gas (LNG), liquified petroleum gas (LPG), methanol, ethanol and biofuels. Whilst the global fleet may use the cheap heavy fuel oil (HFO) until 2020, it is expected that the share of MGO will increase between 2019 and 2020, and that the share of LSHFO will be preferred in the medium to long-term (IEA, 2018). On the other hand, the classic high sulphur HFO will still be in use post-2020 for those operators that will invest in scrubbers. In addition to IMO 2020 sulphur resolution, there have been discussions within IMO to extend the ban on HFO from the Antarctic to the Arctic, which is also recommended in the Polar Code (IMO, 2010, IBIA, 2018). These changes are expected, once again, to have an impact on routeing patterns, and therefore affect the use of certain canals and routes.

3. Methodology

The analysis in this paper consists of two parts. First, the periods 2011–2014 and 2015–2017 are assessed to explain how fuel price levels, ice breaking fees and increased insurance premiums can affect route choice. Second, the current situation is investigated concerning fuel

[3] Currently, ECAs (SOx and Particulate Matter only) constitute the Baltic and the North Sea areas in Europe, and the North American and US Caribbean Sea areas in North America as well as the Hawaiian Islands area (IMO, 2018).

prices, and lower piracy premiums compared to 2015. Alternative operational modes, such as investment on scrubbers to abide with the upcoming IMO 2020 sulphur fuel requirements, and the use of MGO as a potential alternative to HFO in the Arctic, are included in the analysis. Moreover, it is assumed as in Cariou and Faury (2015), and Lindstad and Eskeland (2015) that a fuel tax on HFO is imposed in the future. The comparison between SCR and NSR is based on a speed optimisation model, which minimises the RFR of a route alternative by using four product tanker sizes and three OD pairs as inputs. Subsequently, a sensitivity analysis is conducted to assess how fuel prices, ice breaking fees and reduced speed on ice affect the minimum RFR of both the SCR and NSR.

3.1. Model

The model developed in this paper is based on the optimal speed which determines the minimum unit cost on a US$ per tonne basis, that is, the equilibrium freight rate or required freight rate (RFR). Alderton (1981) distinguishes between the "least-cost speed" (LCS), which maximises profit on a per tonne basis and the "most profitable speed" (MRS), which maximises profit on a per day basis. The former optimises the speed where cost equals revenue i.e. the long-run equilibrium point between supply and demand whereas the latter considers the short-term period where freight rates, port and waiting times fluctuate accordingly. The parameters and variables used in the model are presented in Table 1.

The fuel consumption is expressed as a function of speed and displacement (Barrass, 2004; MAN Diesel and Turbo, 2013a; Psaraftis and Kontovas, 2013; Psaraftis and Kontovas, 2014; Adland et al., 2018; Jia et al., 2017):

$$F\left(s_{L,B}^{*}, \nabla\right) = F_{dL,dB} * \left(\frac{s_{L,B}^{*}}{s_{dL,dB}}\right)^{a} * \left(\frac{P+L}{\nabla}\right)^{2/3} \quad (1)$$

Where a is approximated at three for tankers (Psaraftis and Kontovas, 2013). A fuel consumption function of this form depends on speed and payload (Psaraftis and Kontovas, 2013, Psaraftis and Kontovas, 2014). A fully laden and a ballast return voyage are considered, as is the normal practice in tanker markets, although triangulation through carrying backhaul cargoes is possible in oil products trades. The objective is to minimise the total RFR of a route alternative (either RFR_{NSR} or RFR_{SCR}) per round voyage:

$$min\ RFR_{NE} + RFR_{E} * z \quad (2)$$

where RFR_E and RFR_{NE} denote the RFR of a round voyage (sum of laden and ballast voyages) for either ECA or non-ECA legs respectively.

The RFR is a function of distance, optimal speed, total cost inputs and cargo carrying capacity of a particular vessel size for each leg and voyage:

$$RFR_{E,NE} = \frac{1}{W}\left[\left(\frac{D_{E,NE}}{s_{L,B}^{*} * 24}\right) * \left(\left(F\left(s_{L,B}^{*}\right) * P_f + b * E_f * F\left(s_{L,B}^{*}\right) * F_t\right) + \left(C_o + C_c + g * C_s\right)\right) + C_{TIR}\right] \quad (3)$$

subject to

$$\underline{S} \leq s_L^{*},\ s_B^{*} \leq \overline{S} \quad (4)$$

Table 1. Parameters and variables used in the model

Parameters:	
P	average weight of a payload of oil products including fuel, fresh water, stores, ballast water, baggage and crew in metric tonnes (m.t.)
W	average weight of cargo on board in metric tonnes (m.t.)
$D_E,\ D_{NE}, D_T$	distance for ECA and non-ECA legs respectively, and total distance in nautical miles (n.m.)
P_f	fuel price in US$ per tonne **(**HFO outside ECAs or MGO inside ECAs)
C_o	operating cost in US$ per day
C_c	capital cost in US$ per day
C_{TIR}	transit cost (canal tolls or ice breaking fees), insurance premiums, and ice damage repairs in US$ per round voyage
C_s	capital cost of exhaust cleaning systems (scrubber) in US$ per day
E_f	emissions factor of a particular fuel type
F_t	fuel tax in US$ per tonne
S_{dL}, S_{dB}	design speed for laden voyage and ballast voyage in knots
$\overline{S}$	upper sailing speed
$\underline{S}$	lower sailing speed
F_{dL}, F_{dB}	fuel consumption at design speed for laden voyage and ballast voyage
L	Lightweight of a product tanker
∇	Displacement of a product tanker
Variables:	
$s_L^*,\ s_B^*$	optimal speed for laden and ballast voyage respectively
$s_E^*,\ s_{NE}^*$	optimal speed for ECA and non-ECA legs respectively
s^*	round voyage optimal speed
z, b, g	Binary variables, equal to 1 when an ECA leg is included, and a fuel tax and/or scrubber are considered respectively, and 0 otherwise
$T_E,\ T_{NE},\ T_T$	time for ECA and non-ECA legs respectively, and total transit time

$$z, b, g \in \{0,1\} \tag{5}$$

The term $\frac{1}{W}$ transforms RFR to RFR in US$ per tonne, whilst the term $\left(\frac{D_{E,NE}}{s_{L,B}^{*}*24}\right)$ calculates the days at sea per round voyage for each leg. The variable *z* equals 1 when an ECA leg is included or 0 otherwise, such as in alternative operational modes or in OD pairs which do not involve ECAs. Variables g and b denote the use of a scrubber and the introduction of a fuel tax respectively, where $g, b = 1$, when these are included in the model or $g, b = 0$ otherwise. The fuel tax is considered at 100 US$/t and the CO_2 emissions factor for HFO is 3.114 (Cariou and Faury, 2015, Lindstad and Eskeland, 2015, IMO, 2015). The use of hybrid scrubbers is considered by using the assumptions of Lindstad et al. (2017). The lower and upper speed limits in this model are 5 and 16 knots respectively. The minimum speed on ice is defined as the speed in which a vessel cannot sail independently (MAN Diesel and Turbo, 2013b, Trafi, 2017a, Solakivi et al., 2017), and the maximum assuming that the design speed is 90-95% of the maximum depending on ship size (Lindstad et al., 2011). Port dues and time as well as cargo handling, fuel cost in port and auxiliary fuel consumption are assumed the same when comparing alternative routes against the same ODs and hence are not taken into account in this model.

By differentiating Eq. (3) with respect to speeds s_L^* and s_B^* and set each partial derivative equal to zero respectively, that is, $\frac{\partial RFR}{\partial_{s_L^*}} = 0$ and $\frac{\partial RFR}{\partial_{s_B^*}} = 0$, with the values of s_L^* and s_B^* subject to lower and upper limits, i.e. $\underline{S}$ and $\overline{S}$, the RFR or unit cost per tonne is minimised and the solution gives the optimal speed for laden and ballast voyages, and for both ECA and non-ECA legs of the voyage respectively:

$$s_L^* = \sqrt[a]{\frac{(C_O+C_C+g*C_S)*{S_{dL}}^{a}*\nabla^{2/3}}{((a-1)*F_{dL})*(P_f+b*E_f*F_t)*(P+L)^{2/3}}} \text{ and } s_B^* = \sqrt[a]{\frac{(C_O+C_C+g*C_S)*{S_{dB}}^{a}*\nabla^{2/3}}{((a-1)*F_{dB})*(P_f+b*E_f*F_t)*(P+L)^{2/3}}}$$

(6), (7)

This optimal speed, $s_{L,B}^*$, depends on operating and capital costs (including those when a scrubber is installed on a vessel) as well as the price of fuel and fuel tax per tonne, payload and displacement. It does not depend on freight rates and distance, as is the case for a speed that maximises profit per day (Alderton, 1981, Ronen, 1982, Evans and Marlow, 1990). Besides, distance affects the economics of a route alternative through the RFR equation. It is also assumed that the optimal speed is not affected by charterparty obligations or any other constraints (Psaraftis and Kontovas, 2014, Cariou and Faury, 2015, Adland and Jia, 2018).

The optimal round voyage speeds on ECA and non-ECA legs are calculated by using the harmonic mean of s_L^* and s_B^* for each leg as the special case of two numbers:

$$s_E^* = \frac{2*s_L^**s_B^*}{s_L^*+s_B^*} \text{ and } s_{NE}^* = \frac{2*s_L^**s_B^*}{s_L^*+s_B^*} \tag{8), (9}$$

The optimal speed per round voyage is then determined by the total distance and time:

$$T_T = T_E + T_{NE} \tag{10}$$

where time within and outside ECAs is defined as follows:

$$T_E = \frac{2*D_E}{s_E^* * 24} \text{ and } T_{NE} = \frac{2*D_{NE}}{s_{NE}^* * 24} \tag{11), (12}$$

and the optimal speed is:

$$s^* = \frac{2*D_T}{T_T * 24} \tag{13}$$

The RFR differential between SCR and NSR is defined as:

$$\Delta RFR = RFR_{SCR} - RFR_{NSR} \tag{14}$$

This speed model is consistent with Fagerholt et al., (2015) and Fagerholt and Psaraftis (2015), where two distinct voyage legs are defined, i.e. within and outside ECAs and two different optimal speeds exist on each leg due to different fuel types and prices, and the non-linear relationship between speed and fuel consumption. It should be noted that when the use of scrubber is assumed, this permits the use of HFO inside ECAs. Equally, the switch to distillates such as MGO to comply with IMO 2020 policy means that this fuel is used on all voyage legs.

3.2. Assumptions and data

3.2.1. Distances and routes

The geographical implications on costs and economies of scale for alternative routes are investigated by assuming three OD pairs after considering real transits. The distance on the NSR refers to the deep-water high-latitude route north of the New Siberian Islands. The reason for this is that the route via Sannikov Strait – almost same nautical miles (n.m.) with the high latitude route – imposes draught restrictions (13m depth), which prevent large vessels utilising the NSR (Mulherin et al., 1996). The Bloomberg vessel movement platform was used to track all NSR voyages between 2011 and 2018. It was found that almost all product tanker voyages considered in this study used the high-latitude route (Bloomberg, 2019). Transit traffic data from CHNL also show that this route was used extensively in 2016–2018 (CHNL, 2019). Yet, there is a trade-off between bathymetry in the Sannikov Strait and difficult ice conditions on the high-latitude route (Stephenson et al., 2014). In addition, distances when operating in Emission Control Areas (ECAs) are included in Table 2. The choice of ODs is based on the frequency of ports used and oil products transported. Fig. 2 shows that most of the times condensate cargo was transported from the port of Vitino in the White Sea to ports in South Korea, whereas jet fuel and gas oil were mostly shipped from ports in South Korea to the Amsterdam-Rotterdam-Antwerp (ARA) area. Naphtha was mainly shipped from either Mongstad in Norway or Ust-Luga in the Baltic to ports in Asia. Heavy fuel oil is not included in the analysis, since there was only one transit voyage involving at least a non-Russian port (NSRA, 2016; CHNL, 2019; Bloomberg, 2019). Using the NSR as the basis of comparison, Vitino-Daesan, being the shortest OD pair, was chosen as a representative short-haul, whereas the Yeosu-Rotterdam pair was chosen as a long-haul in terms of distance. The pair of Mongstad-Mizushima in between them is considered as a medium-haul. Fig. 3 illustrates the respective routeing alternatives, whilst port characteristics are presented in Appendix A.

Table 2. OD pairs and distances

Origin – Destination (OD) Distance (n.m.)	Suez Canal (SCR)	Northern Sea Route (NSR)	Difference between NSR – SCR
Yeosu – Rotterdam (Long-Haul)	10,872 (ECA: 413)	7,276 (ECA: 629)	-33%
Mongstad – Mizushima (Medium-Haul)	11,605 (ECA: 912)	6,668 (ECA: 84)	-43%
Vitino – Daesan (Short-Haul)	12,943	6,487	-50%

Source: Dataloy Distance Table.

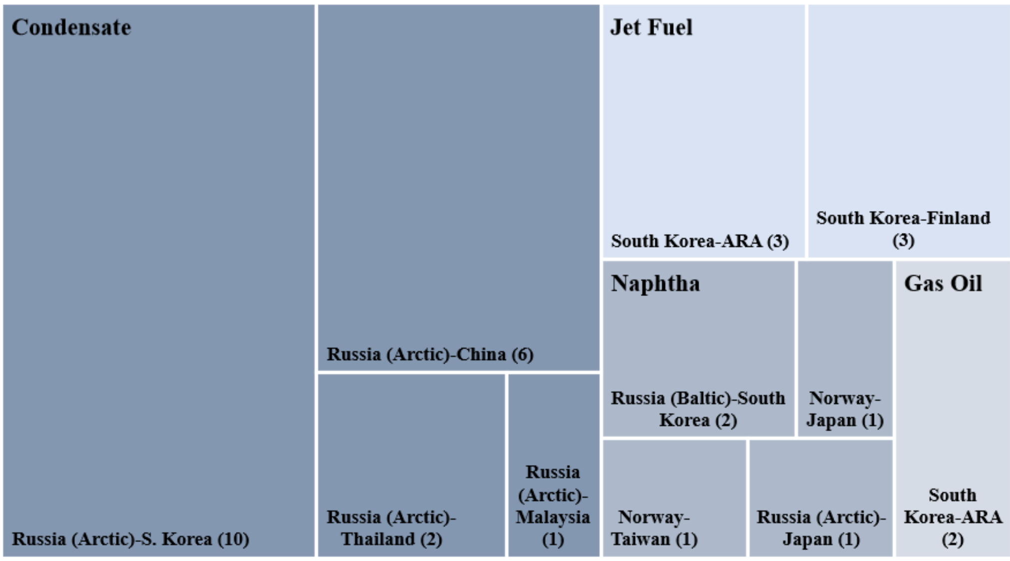


Fig. 2. Frequency of transit voyages and clean oil products for tankers between 47,000–162,000 dwt in 2011–2018. (CHNL, 2019; Bloomberg, 2019).

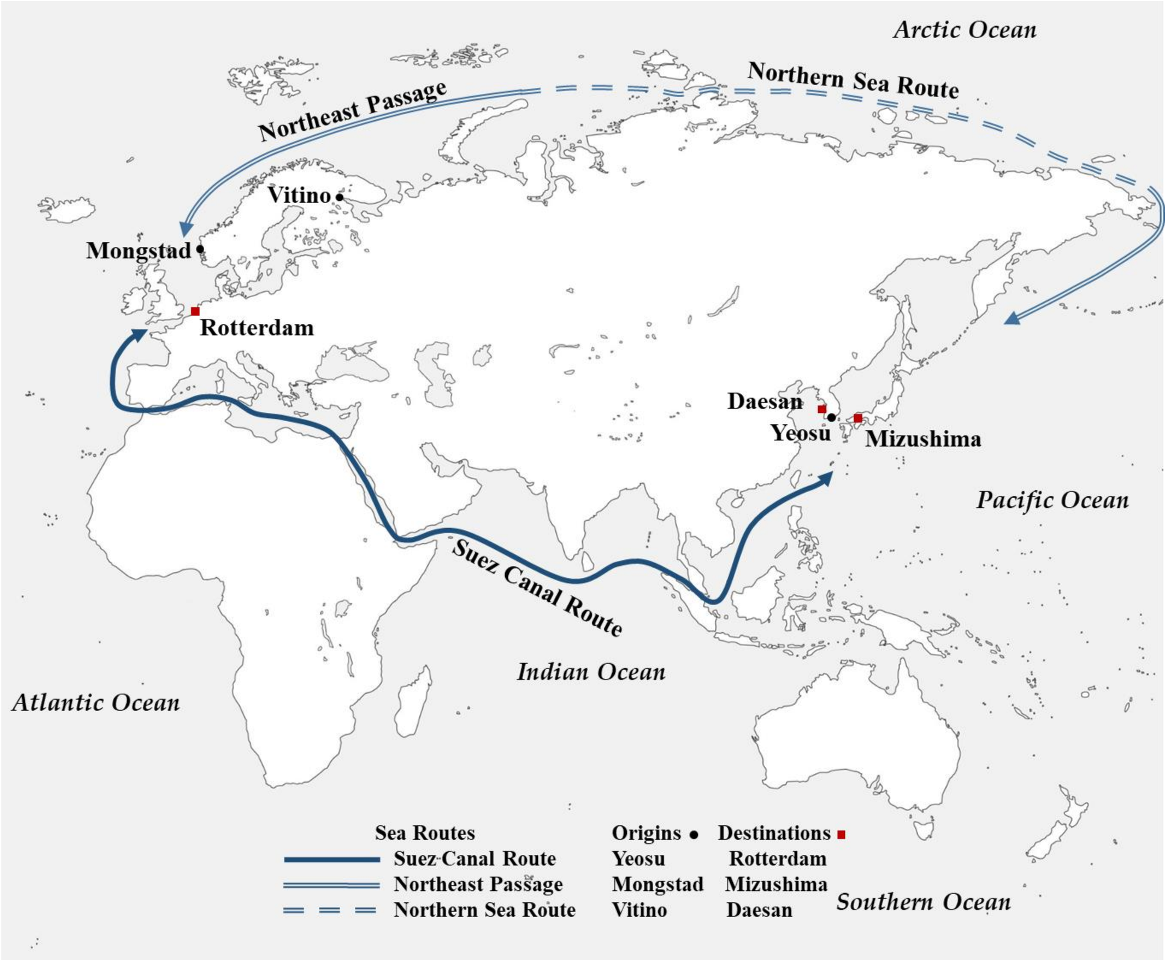


Fig. 3. Route alternatives and OD pairs. (Authors, based on ANU, 2019).

Table 3. Vessel characteristics and newbuilding prices

Ship Size	DWT (Tonnes)[a]	Length Overall (m) [a]	Draught (m) [a]	Beam (m) [a]	Design Speed (knots) [a]	Fuel Consumption (tonnes/day HFO/MGO) [b]	Max. Speed (knots)	Tonnes per Centimetre Immersion (TPC)[b]	Ballast Capacity (Tonnes) [c]	Fuel Tank Capacity (tonnes of HFO/MGO) [d]	Newbuilding price (M.US$)[c]
LR3 – Suezmax	150,000	274	16.1	48	15	47.4/50.3	16	117.8	52,500	3,150/2,685	59.3
LR2 – Aframax	115,000	250	15	44	15	41.4/44	16	97.2	41,400	2,415/2,058	50.5
LR1 – Panamax	75,000	225	14.2	32.3	15	34.1/36.2	16	66	28,500	2,310/1,816	43.3
MR – Handymax	50,000	183	12.4	32.2	15	29.1/30.9	16	51.4	21,000	1,616/1,377	34.9

Based on representative vessel sizes and capacities of the global product and crude oil tanker fleet ([a]MAN Diesel and Turbo, 2013c, MAN Energy Solutions, 2018, [b]calculations based on [a] and MAN Diesel and Turbo, 2013c, MAN Energy Solutions, 2019a, email communication with MAN Energy Solutions, 2019b, Barrass, 2005, IMO, 2016b, [c]Clarksons, 2019, [d]Clarksons, 2019, calculations based on Platts, 2017).

3.2.2. Vessel characteristics and fixed costs

Most of the voyages concerning vessels below 10,000 dwt and 10–24,000 dwt comprised of domestic traffic. In contrast, larger vessels, such as Medium Range (MR), Large Range 1, 2 and even one Large Range 3 (LR1, LR2, LR3) were mainly employed for either transit or destination voyages in the period under consideration (CHNL, 2019)[4]. Therefore the sizes chosen in this study are MR, LR1, LR2 and LR3 oil product tankers. The choice of LR3 size was made to facilitate the analysis of economies of scale, although currently clean petroleum product (CPP) trades involing such sizes are limited, but they could be used in dirty products or crude trades as well. The ice class 1A (Arc4) is chosen for the comparison between ice and non ice class ships, as this currently represents the majority of the global ice class fleet (Trafi, 2017b; Solakivi et al., 2018). Moreover, ships which transited the NSR from 2009 to 2018 were of 1A ice class in most of the cases (NSRA, 2016; CHNL, 2019). The technical characteristics, and capital and operating costs of these vessels are presented in Tables 3 and 4. The choice of tankers is based on global average sizes and characteristics of product tankers (MAN Diesel and Turbo, 2013a, 2013c; MAN Energy Solutions, 2018, 2019a, 2019b). Table 5 shows that these values are close to tanker sizes used in the NSR between 2011 and 2018.

Product carriers usually do not utilise their maximum capacity partly due to the low density of some oil products and partly due to smaller than the vessel's dwt parcel sizes (Stopford, 2009). Cargo sizes are presented in Table 5. These are based on average parcel sizes carried by ice class product tankers in 2011–2018 (CHNL, 2019). Capital costs refer to average newbuilding prices between 2011 and 2018[5], whilst operating costs to a daily average between 2014 and 2017. It is assumed that capital costs and installed power of the main engine for ice class 1A vessels are increased by 30.4% and 30.8% respectively (Solakivi et al., 2018). A shipowner conducting several product carrier voyages on the NSR provided the following premiums: maximum insurance premium at US$ 50,000, cost for books and charts at US$ 20,000 per voyage, daily crew costs are increased by 10%, and the rate for ice piloting at US$ 1,000 per day plus a fixed amount of US$ 5,000 for travel expenses (Tanker Company, 2019). Additional insurance premiums for piracy and armed guards when steaming off the Gulf of Aden are approximated at US$ 60,000 in 2011–2014 and US$ 24,000 in 2015, whereas these are estimated at US$ 10,500 per round voyage currently (2018). Increased repairs due to ice damage, if these occur, are estimated at US$ 200,000 per voyage including the cost of repairs, around three days off hire, bunkers and tugs in China – Shanghai region. The premiums are valid regardless of vessel size (Tanker Company, 2019). Moreover, a lump sum of US$ 190,000 owing to one-off ship to ship (STS) transfer operations for Suezmax/LR3 tankers is included when loading nearby the port of Vitino (Logistics Company, 2019)[6].

[4] The terms MR, LR1, LR2 and LR3 are used to denote oil product tanker sizes, which are equivalent to Handymax, Panamax, Aframax and Suezmax respectively for crude oil tankers (ICS, 2014, Platts, 2015).

[5] Data for LR2 newbuilding prices are only available for 2013–18 (Clarksons, 2019).

[6] STS transfer operations occur in the Barents Sea and used to occur in the White Sea due to port depth and other restrictions (Bambulyak and Frantzen, 2005, Bambulyak et al., 2015). The LR3 tanker Vladimir Tikhonov was loaded in such a manner for its NSR voyage in 2011.

Table 4. Operating and capital costs for non-ice class vessel (US$ per day)

	MR	LR1	LR2	LR3
Operating Costs	7,676	8,101	7,864	9,175
Capital Costs*	8,344	10,353	12,074	14,178

(*Sources:* Operating Costs: Moore Stephens, Interest Rates: Fed of St. Louis).
*capital recovery factor of 12.5% (2011-2018 average of 12-month USD Libor + 3%) over 10 years payment.

Table 5. Cargo sizes and draughts when loaded.

Ship Size	Tanker Size on NSR (DWT tonnes)[a]	Cargo Size on NSR (tonnes)[a]	Ship Size in this study (DWT tonnes)[b]	Cargo Size in this study (tonnes)	Draught when loaded (m)[c]
LR3	162,362	120,843	150,000	120,000	14.2
LR2	113,074	87,139	115,000	90,000	13
LR1	73,828	60,662	75,000	60,000	12.5
MR	47,327	35,943	50,000	35,000	10

Sources: [a]NSRA (2016), CHNL (2019), [b]from Table 3, [c]calculations based on TPC (Table 3).

3.2.3. Speed on ice

There exists high uncertainty regarding the operating speed on ice, which largely depends on sea ice thickness and concentration, and ice ridges amongst others (Löptien and Axell, 2014, Aksenov et al., 2017). Transit traffic data from the Northern Sea Route Authority (NSRA), the Centre for High North Logistics (CHNL), and ARCTIS Database were analysed to determine the speed on ice water during the summer/autumn navigation season. Of the transit years provided by these sources, speeds are reported only in 2012 and 2013 (ARCTIS, 2013; NSRA, 2016; CHNL, 2019). Speed data concerning 2011 were compiled from various sources to complement those from NSRA, CHNL and ARCTIS Database. In addition, the Bloomberg vessel movement platform was used to obtain the actual speeds of these transits in 2011–2018 summer/autumn seasons. Speeds obtained from Bloomberg were finally used in the analysis, as these are deemed as accurate and more detailed than those reported in the aforementioned sources (Bloomberg, 2019). The mean recorded speed of tankers in the range of MR-LR3 was 10.5 knots with a minimum of 5.8 and a maximum of 14.4 knots between 2011 and 2018 summer/autumn navigation seasons. Therefore, the average speed of 10.5 knots is used when a vessel operates on ice water. This average speed is close to speeds used by Wergeland (1992) and Mulherin et al. (1996) in their simulations, that is, 11.25 knots on average during the summer/autumn season. Moreover, studies, which modelled ship speed along the NSR based on ship speed-sea ice properties dependency, report values which are close to the real data. An average speed of 10 knots on the NSR (Kitagawa, 2001), with a minimum of 7.5 knots (von Boch und Polach et al., 2015) for LR2 tankers and a maximum of 13–14 knots during summer/autumn for vessels of LR1 size (Kitagawa, 2001, Faury and Cariou, 2016).

3.2.4. Ice breaking assistance and transit fees

Generally, an ice class 1A vessel is capable of sailing on first-year ice with a maximum thickness of 1.0m (MAN Diesel and Turbo, 2013b, Trafi, 2017a). Ice breaking assistance is not mandatory since 2012 and is solely determined on prevailing sea ice and climatic conditions on the NSR (Gritsenko and Kiiski, 2016). The long-term trend of sea ice extent and thickness in the Arctic exhibit anomalies of negative values (Parkinson and Comiso, 2013; Lindsay and Schweiger, 2015). However, there exists high inter-annual variability and uneven distribution of sea ice conditions in the Russian Arctic, especially in the Laptev, East-Siberian and eastern

Kara Seas in the medium-term (Stephenson et al., 2014). In addition, ship operators may be advised to use ice breaking assistance due to safety and for marine insurance reasons (Sarrabezoles et al., 2016).

For these reasons and although acknowledging the fact that unassisted transits may occur during favourable ice and climatic conditions as in 2015–2016 navigation seasons, ice breaking assistance is assumed when operating on the NSR. Discounted ice breaking fees are assumed to reflect practice during 2011–2014, whereas official fees are assumed from 2015 to 2018, following the introduction of new tariffs in 2014 (NSRA, 2014). The practice of negotiated tariffs is well documented in the literature (Lasserre, 2014, 2015; Gritsenko and Kiiski, 2016; Moe and Brigham, 2016) and is also confirmed by the industry (Falck, 2012; Tanker Company, 2019; Logistics Company, 2019). Besides, tariff rates during 2011–2014 as well as the latest ones (since 2014) are based on maximum rates, implying that these are negotiable (ARCTIS, 2019b; NSRA, 2014; Gritsenko and Kiiski, 2016; Moe and Brigham, 2016).

The ice breaking fees depend on ice class of a ship, gross tonnage, number of escorting zones and period of navigation (summer/ autumn, winter/spring), and are determined by Russian rouble exchange rates (NSRA, 2014). The Suez Canal fees depend on the type of vessel, routeing direction, Suez Canal Net Tonnage (SCNT), whether the ship is laden or ballast, draught, beam and are determined by the specific drawing rights (SDR) rates. The average Suez Canal tolls and SDR/US$ rates during the 2011–2018 NSR summer/ autumn seasons were used to calculate the Suez Canal tolls (IMF, 2019, Leth Agencies, 2019a). An online calculator from Leth agencies was used to calculate additional costs, such as tugs, disbursements, mooring and pilotage (Leth Agencies, 2019b). The assumptions and calculations of ice breaking fees and Suez Canal tolls are reported in Appendix B.

4. Analysis

4.1. Simulating the periods 2011–2014 and 2015–2017

4.1.1. Optimal ship speed and fuel prices

Here, the analysis focuses on the periods 2011–2014 and 2015–2017. The relationship between RFR and ship speed is illustrated in Fig. 4 by using the results of a LR1 tanker round voyage at the Yeosu-Rotterdam pair as an example. Similar results for other vessel sizes and ODs are reported in Appendix C. The left-hand side of Fig. 4 refers to the SCR and the right-hand side to the NSR. The vertical axis represents the minimum RFR in US$/t as a function of the optimal ship speed in knots (horizontal axis), with the solid curves in the graphs reflecting the period 2011–2014 and the dashed curves that of 2015–2017. The figure shows that when HFO/MGO fuel prices dropped from 600/900 US$/t in 2011–2014 to 260/450 US$/t in 2015–2017[7], the minimum RFR decreased from 41.5 and 38 US$/t to 32.5 and 33.8 US$/t for the SCR and NSR respectively. The SCR-NSR RFR differential at both high and low fuel price levels is illustrated by a shift of the curves downwards to the left. The differential was positive during 2011–2014 at 3.5 US$/t and negative during 2015–2017 at −1.3 US$/t, which shows that the NSR being a shorter route, is favoured at high fuel prices and discounted ice breaking fees.

[7] The analysis is based on average annual fuel prices in Rotterdam (Clarksons, 2019). It is assumed that HFO is used for the period 2011–2014 in both ECA and non-ECA legs and that MGO is used from 2015, after the implementation of the 0.1% sulphur limit for fuels within ECAs (IMO, 2018).

The optimal speed gives the minimum RFR for each route, which is lower than that when a ship steams at design speed. The U-shaped curves demonstrate the trade-off between fixed and variable costs with any departure from the optimal speed being cost-wise inefficient, always subject to constraints. At speeds lower that the optimal one, fuel costs decrease non-linearly whereas capital and operating costs increase with additional days per round voyage and vice versa. The optimal speed increased from 12.6 and 11.6 knots in 2011-2014 to 15.7 and 13.5 knots in 2015–2017 on the SCR and NSR respectively. This confirms that speed optimisation and slow steaming practices can be mainly adopted at a high fuel price environment, whereas ships operate close to design speed or even faster when fuel prices are very low. Another point is that optimal laden speeds are lower by 0.9-1.6 knots than optimal ballast speeds due to higher resistance and fuel consumption when a vessel is fully laden. The lower optimal speeds on NSR is the result of the effect of speed on ice at 10.5 knots regardless of the fuel price levels.

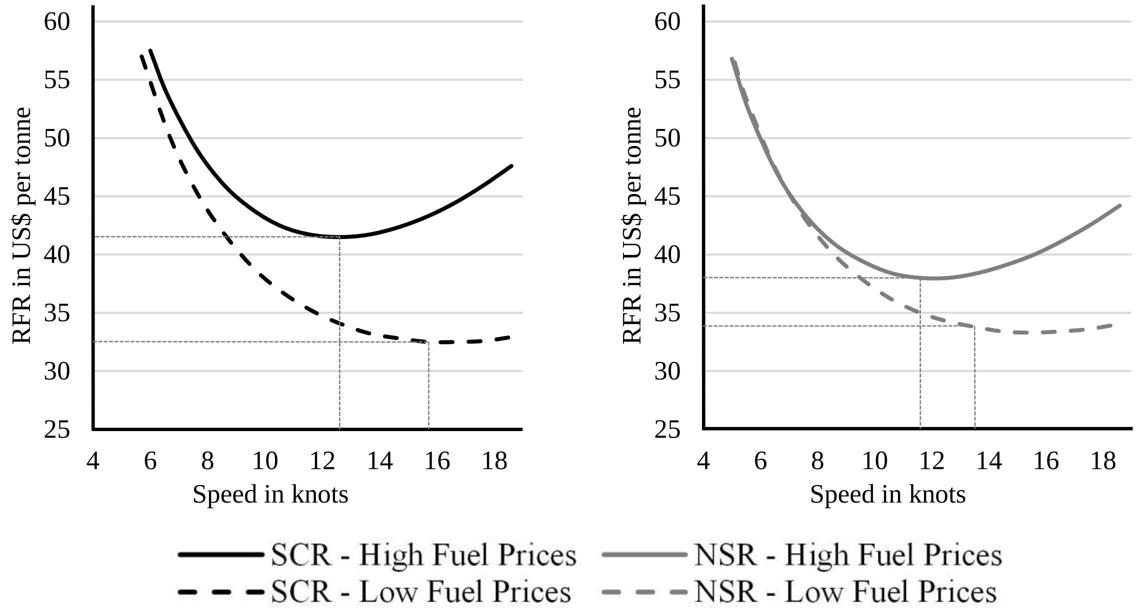


Figure 4. Relationship between optimal speed and minimum RFR for LR1 Yeosu-Rotterdam at high (2011-2014) and low (2015-2017) fuel prices.

4.1.2. Ship size, fuel prices and distance

The relationship between minimum RFR and ship size across all OD pairs is depicted in Fig. 5, with numerical results reported in Appendix C. Here, using the NSR as a basis of comparison, the Yeosu-Rotterdam pair is considered as a long-haul, whereas the Vitino-Daesan pair a short-haul, with the Mongstad-Mizushima pair in between these two being a medium-haul. Distance savings increase gradually moving from the long to the short-haul when using the NSR between Northwest Europe/Baltic/Arctic to Northeast Asia. The results are based on the optimal speed, which minimises the RFR at a given OD and vessel size. As in Fig. 4, there is a distinction between 2011–2014 and 2015–2017 with a high and low fuel price environment reflected in solid and dashed curves for each route respectively. According to a shipowner with extensive experience in the NSR, operators factor in the cost of repairs when assessing alternatives to take into account the risk of severe ice damages to the hull of a ship (Tanker Company, 2019). To distinguish between cases where repairs are materialised, results are shown separately in Fig. 5. On the right-hand side, results for SCR are kept constant, whereas those of NSR are adjusted accordingly.

Several observations can be made concerning the relationship between minimum RFR and ship size as well as the influence of geography on route competitiveness. First, the results show that there is always an advantage of using big vessels across every OD and route alternative, for these give a lower RFR than small vessels, all else being equal. Second, the economies of scale derived from bigger ship sizes in absolute terms decline when moving towards the shortest OD for a given route alternative. This means that scale economies are bigger for the NSR on the Yeosu-Rotterdam pair and smaller on the Vitino-Daesan pair, whereas the opposite holds true for the SCR. Moreover, the use of a LR3 tanker on the short-haul is less competitive than on the medium-haul due to STS transfer operation costs outside the port of Vitino. Fig. 6 shows this relationship with the long-haul curve for each route alternative being steeper than the short-haul. Not only do costs fall with the increase in ship size, but also this decline is bigger in absolute terms at higher fuel prices for a given OD and route alternative. Third, the differential between SCR and NSR widens as we move from the long to the short-haul both with and without repairs. The SCR-RFR is gradually increased, whereas the NSR-RFR is decreased across all ship sizes.

The lowest RFR for the SCR route was achieved with an LR3 tanker on the Yeosu-Rotterdam pair at 22 US$/t. For the NSR, this was given by an LR3 tanker on the Mongstad-Mizushima pair at 23.6 US$/t, whereas this would be 25.3 US$/t if repairs were included. These RFRs were actualised at low fuel prices (2015–2017), whereas they rose by 5.8 and 2.5 US$/t at high fuel prices (2011–2014) for the SCR and NSR respectively. Fig. 5 shows that the NSR was more competitive than the SCR at all ODs at high (2011–2014) fuel prices and discounted fees. However, the SCR-NSR RFR differential was negative on the Yeosu-Rotterdam pair between -2 (MR) and -3 (LR3) US$/t and on the Mongstad-Mizushima pair for a LR3 tanker (-0.4 US$/t) at low fuel prices and official fees, which were relatively low owing to the depreciation of the rouble in 2015, but still higher than the discounted ones. When including ice damage repairs in the model, the differential on the Yeosu-Rotterdam pair was also negative at low fuel prices as well as at high fuel prices for LR2 and LR3 tankers. It also narrowed significantly or became negative on the Mongstad-Mizushima pair between 9/−1.7 (MR) and 1.5/−2.1 US$/t (LR3) at high/low fuel prices. On the other hand, the Vitino-Daesan pair was less impacted in case repairs were needed for MR-LR2 tankers regardless of the fuel price levels. However, the differential narrowed significantly for LR3 tankers at low fuel prices and became negative when repairs were included. This is largely attributed to the STS transfer operation costs for a LR3 tanker outside the port of Vitino.

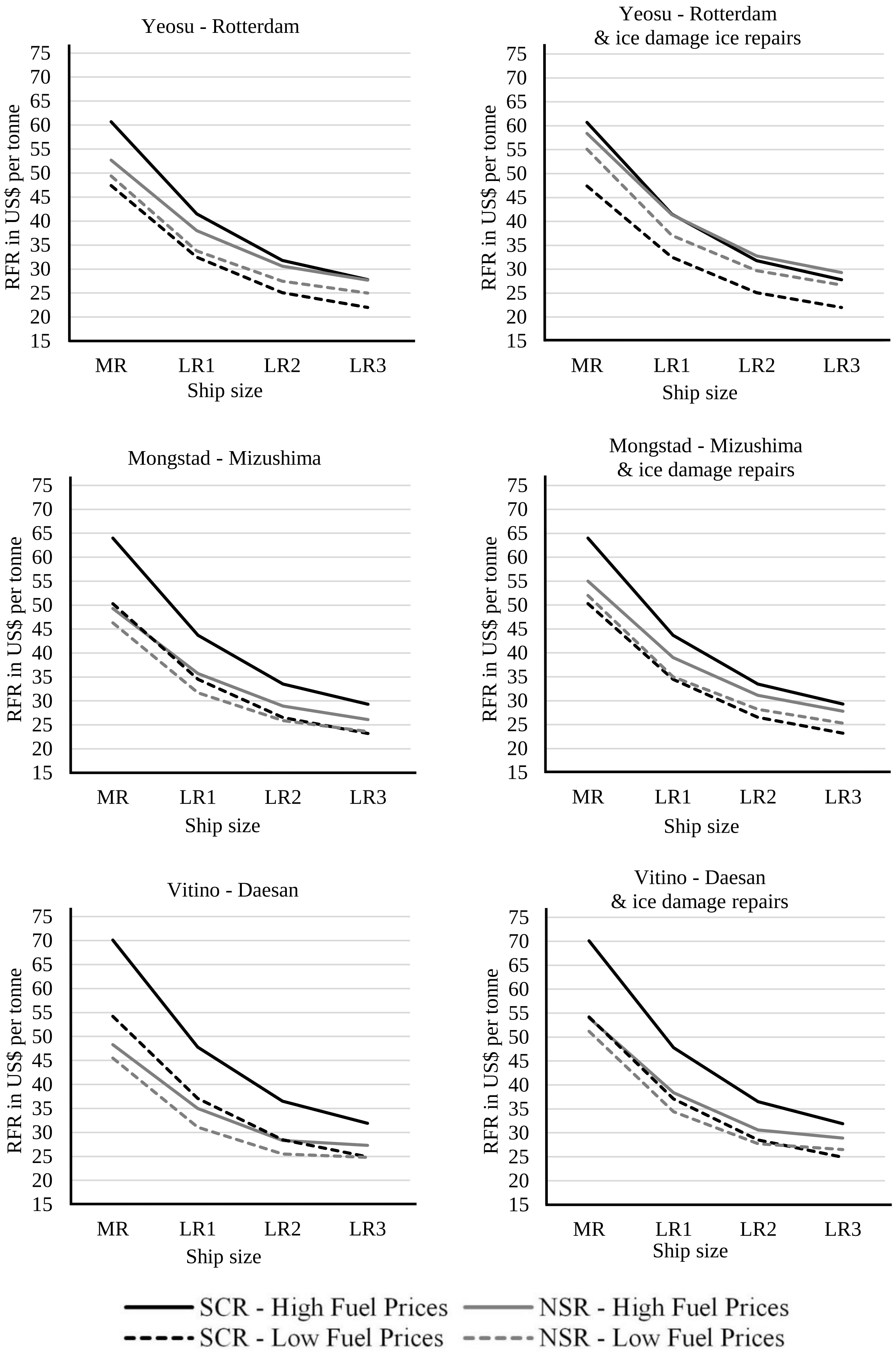


Figure 5. Relationship between ship size and minimum RFR at a given OD at high (2011-2014) and low (2015-2017) fuel prices, with and without ice damage repairs.

The differential on the long-haul would be lower if MGO was used in ECAs prior to 2015, due to a longer ECA leg for the NSR. On the other hand, the differential on the medium-haul would be higher due to a significantly shorter ECA leg for the NSR compared to the SCR.

It should be mentioned that if the path north of the New Siberian Islands is not accessible, then the Sannikov Strait sets the upper boundary with regards to ship size or dwt utilisation. The draught restriction of 13m means that the SCR becomes more competitive at a given OD pair when using tankers bigger than a MR size (50,000 dwt) but this also depends on parcel sizes and dwt utilisation.

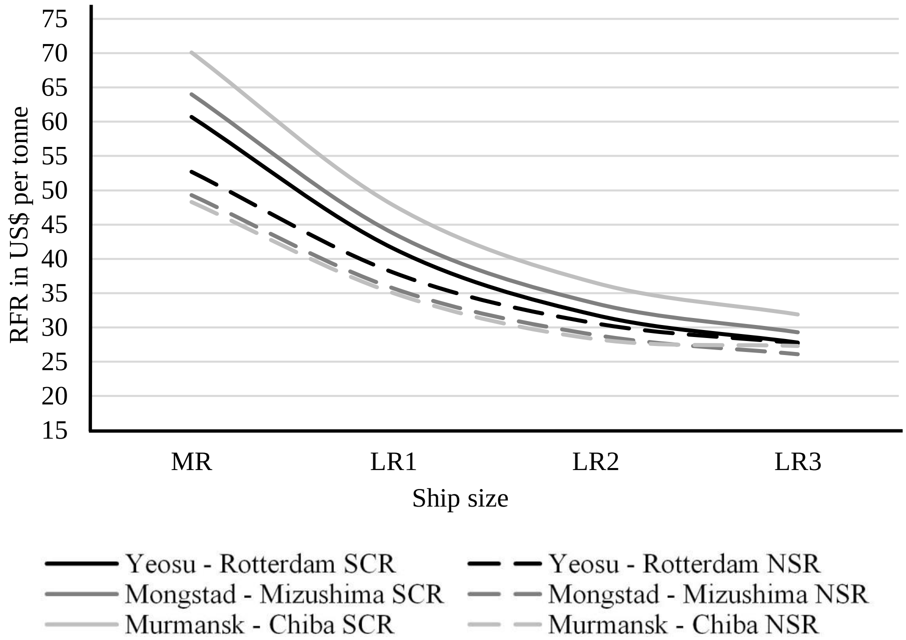


Figure 6. Relationship between ship size and minimum RFR at a given distance at high (2011-2014) fuel prices.

4.2. Current situation and environmental policy implications after 2020

4.2.1. Optimal ship speed and alternative operational modes

In this section, the NSR competitiveness against the SCR is investigated currently (2018). Three operational modes are assumed, including options to comply with the IMO 2020 sulphur limit. First, the use of HFO/MGO when operating outside and inside ECAs respectively, to reflect the period 2018–2019. Second, the use of MGO, and third, the installation of a scrubber to allow the use of HFO for operations after 2020. These two options also mean that the same fuel is used on all voyage legs. The relationship between minimum RFR and ship speed is graphically presented in Fig. 7. As in Section 4.1.1, results of a LR1 tanker round voyage on the Yeosu-Rotterdam pair are presented, whereas similar results for other ship sizes and ODs are reported in Appendix D. The left-hand side refers to the SCR and the right-hand side to the NSR. The average fuel prices in Rotterdam during 2018 are assumed, which were approximately 400 US$/t for HFO and 600 US$/t for MGO (Clarksons, 2019). Fig. 7 shows that currently, the round voyage optimal speed on the SCR is 14.3 knots at a RFR of 36.3 US$/t.

The use of a scrubber increases the optimal speed by 0.3 to 14.6 knots at a RFR of 37 US$/t. On the other hand, the option to use MGO, lowers the optimal speed at 12.3 knots and gives a

RFR of 41.1 US$/t. For the NSR, currently the round voyage optimal speed stands at 12.5 knots and gives a RFR of 36 US$/t, whereas the HFO-scrubber option slightly increases the optimal speed at 12.8 knots and gives a RFR of 36.2 US$/t. The MGO option lowers the optimal speed at 11.4 knots and increases the RFR at 39.6 US$/t. The increase in optimal speed when using a scrubber at a given fuel price is due to additional capital and operating costs that this option entails, which become more important than fuel costs. On the other hand, the use of the more expensive MGO fuel results in the lowering of the optimal speed, which becomes more important than other costs. Both the MGO and HFO-scrubber options shift the RFR curves upwards to the right, with the first having a bigger magnitude on the SCR-NSR RFR differential. As in 4.1.1, the trade-off between fixed and variable costs is reflected in the U-shaped nature of the curves. Optimal laden speeds are lower by 0.9–1.7 knots than optimal ballast ones, whilst optimal speeds on ECA legs are around 0.8 (NSR) −2.1 (SCR) knots lower than on non-ECA legs.

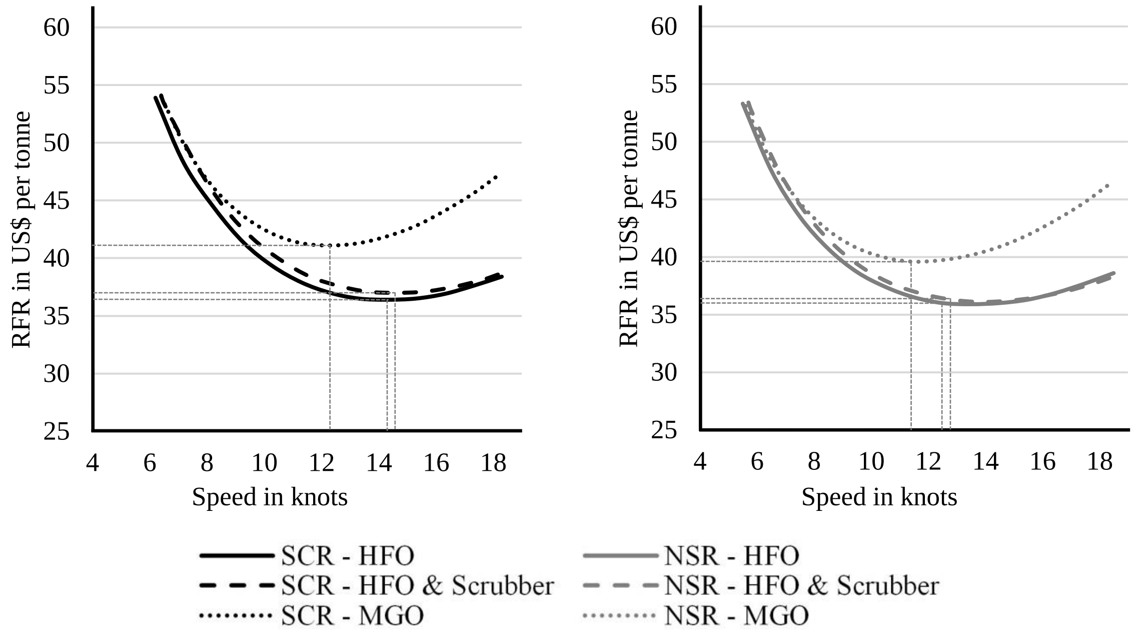
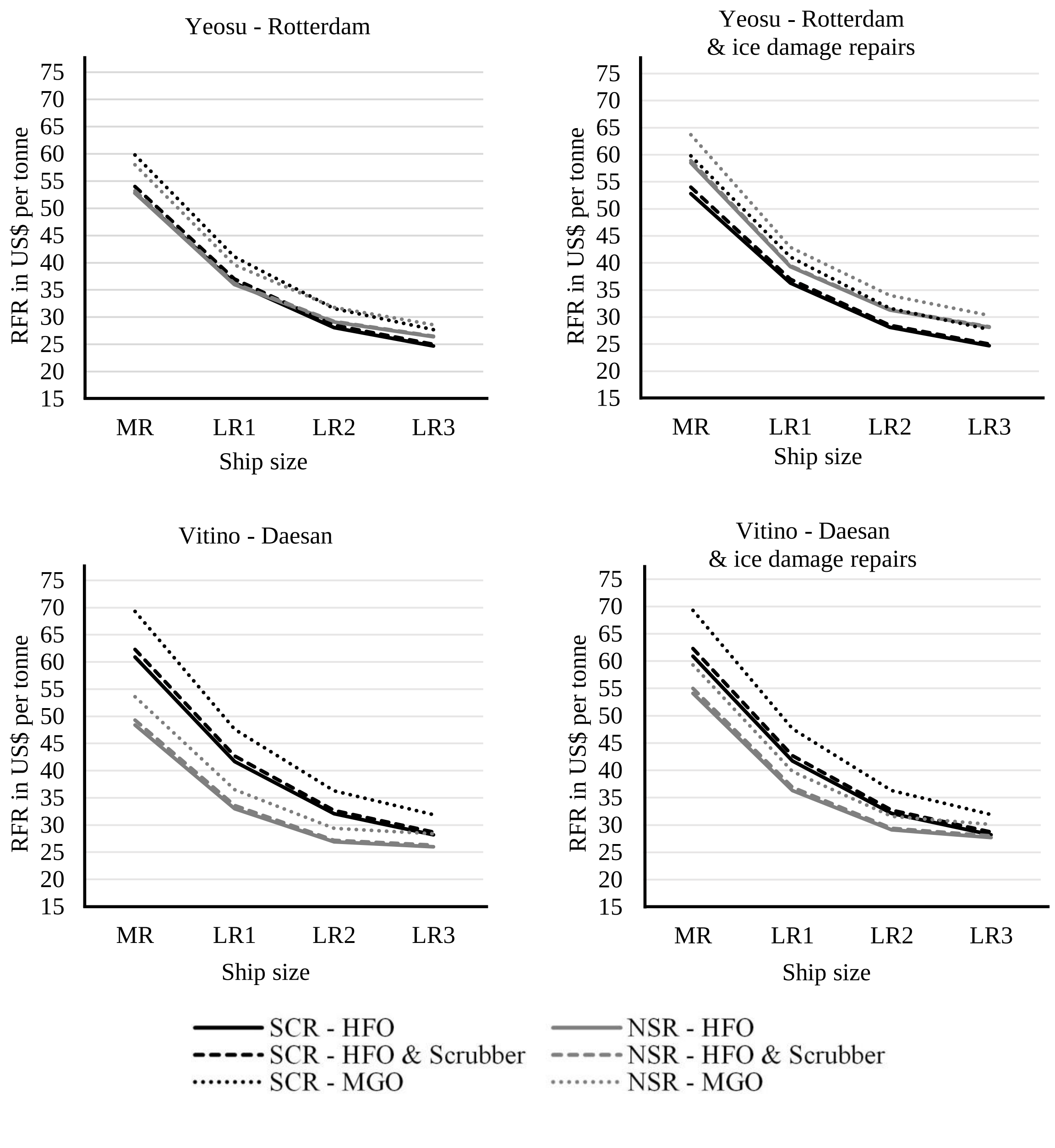


Figure 7. Relationship between optimal speed and minimum RFR for LR1 Mongstad-Mizushima at three alternative operational modes currently (2018) and following IMO 2020.

4.2.2. Ship size, alternative operational modes and distance

Fig. 8 shows the relationship between minimum RFR at the optimal speed and ship size currently. The NSR is used as a basis of comparison, and results are reported for the Yeosu-Rotterdam and Vitino-Daesan pairs. The results for Mongstad-Mizushima are included in Appendix D. The lowest RFR for the SCR route is achieved when using an LR3 tanker on the long-haul at 24.7 US$/t. For the NSR, this is given by an LR3 tanker on the medium-haul at 24.8 US$/t, whereas this becomes 26.5 US$/t if ice damage repairs are included. These RFRs refer to the HFO/MGO mode, whereas they rise by 3 and 2.4 US$/t at the MGO mode for the SCR and NSR respectively. As can be seen, the NSR is the most competitive alternative for all ship sizes on the short-haul at any operational mode, whereas the SCR-NSR RFR differential narrows significantly on the long-haul, and becomes negative for LR2 and LR3 tankers at any operational mode. The differential at the HFO/MGO option is found between 0 (MR) and −1.7 (LR3) US$/t. The MGO option raises the difference between 1.8 (MR) and −0.9 (LR3) US$/t. The differential on the short-haul at the HFO/MGO option is between 12.5 (MR) and 2.2 (LR3) US$/t, and is further increased at the MGO option between 15.7 (MR) and 3.5 (LR3) US$/t. When including ice damage repairs, it becomes negative on the Yeosu-Rotterdam pair, regardless of the operational mode, whereas that on the short-haul is less affected. Results for the Mongstad-Mizushima pair are found in between the long and short-haul. However, the use of a LR3 tanker on the medium-haul is more competitive than on the short-haul due to STS transfer operation costs. The differential at the HFO/MGO option is found between 6.8 (MR) and 1.3 (LR3) US$/t and is increased between 8.6 (MR) and 1.9 (LR3) US$/t at the MGO option. Clearly, the MGO option mostly benefits the NSR, followed by the HFO-scrubber and HFO/MGO options across all ship sizes and ODs[8]. The same observations can be made regarding scale economies as in Section 4.1.2.



[8] An exception in this paper is the Mongstad-Mizushima pair, where the HFO/MGO mode gives slightly higher RFR differentials than the HFO-scrubber mode due to the disproportionately higher ECA leg on the SCR than on the NSR. This gives NSR a big advantage under the HFO/MGO mode.

Figure 8. Relationship between ship size and minimum RFR at a given OD at three alternative operational modes currently (2018) and following IMO 2020.

Table 6 presents a breakdown of the results in the form of fixed and variable costs across all ODs at the HFO/MGO mode. It can be seen that scale economies exist in every cost factor by using bigger ships. For the NSR, these are more prominent on the long-haul, whereas for the SCR are found to be greater on the short-haul. For the SCR, capital costs is the most important factor, followed by fuel and operating costs, and Suez Canal tolls. Exceptions are LR3, and LR2 and LR3 tankers on the medium and long-haul respectively, where tolls become the third important cost factor followed by operating costs. For the NSR, capital costs and ice breaking fees are the primary cost factors for MR and LR1 sizes on the long-haul. Ice breaking fees become the largest cost factor for LR2 and LR3 sizes, followed by capital costs on the long-haul. Ice breaking fees is the primary cost factor for both medium and short-haul, followed by capital, operating and fuel costs, and repairs across all vessel sizes.

Table 6. Total cost analysis in US$/t between SCR and NSR currently (2018).

Ship Size (DWT tonnes)	SCR Fuel Cost	Transit Fees	Operating Cost	Capital Cost	RFR	NSR Fuel Cost	Transit Fees	Operating Cost	Capital Cost	Repairs	RFR
Yeosu - Rotterdam											
MR	14.3	9.6	14.0	14.9	52.8	10.1	14.5	13.2	15.0	5.7	52.8
LR1	9.7	7.0	8.7	10.9	36.3	6.9	10.1	8.1	10.9	3.3	36.0
LR2	7.3	6.2	5.8	8.8	28.1	5.3	9.8	5.3	8.7	2.2	29.1
LR3	6.3	5.6	5.1	7.7	24.7	4.6	9.6	4.6	7.6	1.7	26.4
Mongstad - Mizushima											
MR	15.4	9.6	15.1	16.1	56.2	9.0	14.5	12.2	13.7	5.7	49.4
LR1	10.5	7.0	9.4	11.8	38.7	6.2	10.1	7.5	10	3.3	33.8
LR2	7.8	6.2	6.3	9.4	29.7	4.7	9.8	4.9	7.9	2.2	27.3
LR3	6.8	5.6	5.4	8.3	26.1	4.1	9.6	4.2	6.9	1.7	24.8
Vitino - Daesan											
MR	17.0	9.6	16.6	17.7	60.9	8.7	14.5	11.9	13.3	5.7	48.4
LR1	11.5	7.0	10.3	12.9	41.7	5.9	10.1	7.3	9.7	3.3	33.0
LR2	8.6	6.2	6.9	10.4	32.1	4.6	9.8	4.8	7.7	2.2	26.9
LR3	7.5	5.6	6.0	9.1	28.2	4.0	9.6	4.1	6.7	1.7	26.0

Fig. 9 illustrates results when considering a global fuel tax (Cariou and Faury, 2015; Lindstad and Eskeland, 2015), and a future ban on the use of HFO in the Arctic. The dashed curves denote the HFO-scrubber option for both route alternatives on the long and short-haul, where a global fuel tax is imposed on HFO. The results for Mongstad-Mizushima are included in Appendix D. A fuel tax of 100 US$/t raises the current price of HFO from 400 to 711.4 US$/t. The results indicate that the NSR, being a shorter alternative, benefits from this. The NSR appears to be more competitive in all ODs except for LR3 tankers on the Yeosu-Rotterdam pair and when repairs are included on this OD pair.

The introduction of a ban on the use of HFO in the Arctic is also investigated. Under such a scenario, the MGO option or any other distillate or fuel type would be the only options for the NSR, whereas the HFO-scrubber option would be the cheapest alternative on the SCR. In Fig. 9, black solid curves denote a HFO-scrubber option for the SCR and grey solid curves the use of MGO on the NSR. Under this scenario, the NSR is mainly competitive on the Vitino-Daesan pair. On the other hand, the SCR-NSR RFR differential is negative on the Yeosu-Rotterdam pair, either when including repairs or not. For the Mongstad-Mizushima pair, the differential is between 2.3 (MR) and -0.9 (LR3) US$/t, whereas the RFR is negative across all vessel sizes when repairs are included. Clearly, such a policy significantly reduces the potential of the NSR over that of the SCR.

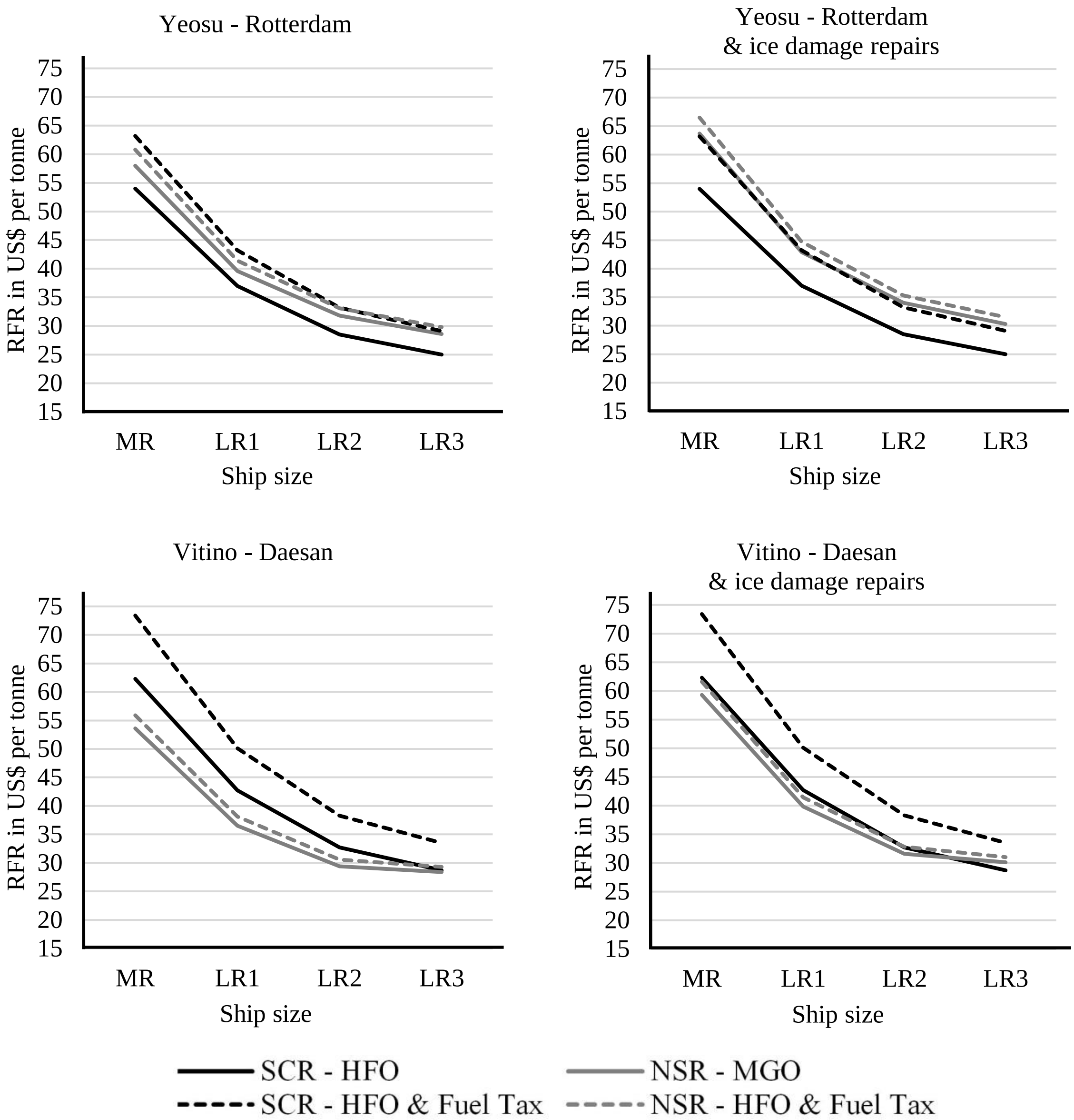


Figure 9. Relationship between ship size and RFR at a given OD with environmental costs currently (2018) and following IMO 2020.

4.3. Sensitivity analysis

In this section, the results are tested against important cost and operational factors that affect the competitiveness of a route alternative. The base case refers to the operational period after the implementation of the IMO 2020 sulphur limit (either HFO-scrubber or MGO modes), using the results of 2018 as a reference. Both official and discounted fees are included in the analysis to take into account of the dependence between oil prices, fuel prices and the USD/RUB exchange rates (Beckmann and Czudaj, 2013; Yang et al., 2017; Chuffart and Hooper, 2019). It is assumed, drawing on historic data, that a high USD/RUB rate of 62.99 corresponds at low fuel prices (200, 400 US$/t for HFO, and 300, 600 US/t for MGO) and a low USD/RUB rate of 33.21 at high fuel prices (600 US$/t for HFO and 900 US$/t for MGO) (Bloomberg, 2019, Clarksons, 2019). Table 7 reports the SCR-NSR RFR differential, including repairs on the NSR, by using results of a LR1 tanker on the long and shorthauls as an example. The base case is compared to that of independent navigation, assuming relatively easy ice conditions and therefore no ice breaking assistance. A drop of the speed on ice by 50%, that is 5.3 knots, is also included to take into account of uncertainty due to delays arising when a ship operates independently. It is shown that using the official ice breaking fees, the NSR is less competitive on both OD pairs not only at low fuel prices, but also at high fuel prices due to a low USD/RUB rate, which dramatically increases ice breaking fees. The results also reflect that should the NSRA used the official fees before 2014, the NSR would be never competitive, although fuel prices were at historic highs at that time. On the other hand, fuel prices become more influential with a more competitive NSR fee policy at high fuel prices and vice versa.

Table 7. Sensitivity of ice breaking fees and speed on ice for LR1 tanker RFR in US$/t from 2020.

		Yeosu – Rotterdam				Vitino – Daesan			
HFO & Scrubber and MGO modes for both SCR and NSR									
Fuel Type	Fuel Price	Base Case & Official Fees	Base Case & Discounted Fees	Independent navigation	Independent navigation & speed on ice -50%	Base Case & Official Fees	Base Case & Discounted Fees	Independent navigation	Independent navigation & speed on ice -50%
HFO	200	-4.5	-3.0	5.7	1.5	2.3	3.7	12.4	8.1
	400	-3.0	-1.6	7.1	4.0	5.2	6.7	15.3	12.1
	600	-11.2	-0.7	7.9	5.4	-1.7	8.8	17.5	14.8
MGO	300	-3.7	-2.2	6.4	3.3	3.8	5.3	13.9	10.6
	600	-2.3	-0.8	7.8	5.6	7.2	8.6	17.3	14.8
	900	-10.5	0.0	8.7	7.0	0.4	10.9	19.6	17.7
SCR – HFO & Scrubber and NSR – MGO									
HFO/MGO	200/300	-6.5	-5.0	3.6	0.5	0.5	2.0	10.6	7.3
	400/600	-6.4	-4.9	3.7	1.5	2.3	3.7	12.4	9.9
	600/900	-15.2	-4.7	4.0	2.3	-5.2	5.3	14.0	12.1

The NSR is always more competitive than the SCR when independent navigation is assumed, even on the long-haul and across all fuel types and prices. The short-haul benefits mostly as is expected. A 50% drop of the speed on ice affects the RFR differential at a high degree but retains the competitiveness of the NSR, especially under high fuel prices. When it comes to the use of MGO only on the NSR, the differential becomes negative on the long-haul either using the official or discounted fees at any fuel price levels. It also becomes negative on the short-haul when using the official fees at high fuel prices and a low USD/RUB rate. On the other hand, the NSR is always more competitive than the SCR when independent navigation and/or a 50% drop of the speed on ice is assumed on both OD pairs.

5. Discussion and conclusions

Fuel price movements along with a competitive ice breaking fees policy, and high piracy insurance premiums in a lesser extent explain the competitiveness of the NSR against the longer SCR during the period 2011–2014. Moreover, distance savings, which increase when moving towards the short-haul, also mean a wider RFR differential between SCR and NSR. Bigger ships achieve a lower RFR across every OD and route alternative, all else being equal. Moreover, cost savings increase in absolute terms at higher fuel prices for a given OD pair and route alternative, assuming discounted ice breaking fees. The majority of clean product tanker voyages (20 out of 32) occurred between the Murmansk area and Northeast Asia. The results for the Vitino-Daesan pair clearly reflects this, since it is the most competitive OD. On the other hand, seven voyages occurred from Mongstad to Japan (1), and S. Korea to the Rotterdam area (6) (CHNL, 2019; Bloomberg, 2019). Although more voyages occurred between Northwest Europe and Northeast Asia than between Mongstad to destinations in Northeast Asia, this could be explained by other factors, such as the commodities shipped at each itinerary and their market characteristics during that period. The NSR was still more competitive than the SCR during 2014 across all ODs and ship sizes examined in this paper, assuming discounted fees and no repairs[9]. However, it was only used by Russian-flagged tankers. A re-direction of condensate and naphtha flows from the Barents and White Seas to Baltic terminals (Bambulyak et al., 2015; Tanker Company, 2019; Logistics Company, 2019), and diplomatic tensions between Russia and the west had a negative impact on the use of the NSR amongst others (Reuters, 2015, Platts, 2016). Further, a drop in crude oil prices by 46% between 2014 and 2015 resulted in a decline of 41 and 50% in MGO and HFO prices[10] respectively. The results show that the NSR was only competitive in the short-haul and marginally competitive in the medium-haul for MR, LR1 and LR2 tankers, but not competitive when repairs are included in the analysis. However, with no petroleum products flows from the White Sea, and due to the western sanctions, there was no interest on the route. In addition, oil-related commodity prices and piracy insurance premiums became lower, meaning that lead times and piracy risks were not deemed as critical as in 2011–2014. Another important factor is the provision for ice damage repairs. When these repairs are factored in the model, they increase the NSR-RFR by 1.7 (LR3) and 5.7 (MR) US$/t.

Fuel prices in 2018 – HFO/MGO at 400/600 US$ per tonne – and a high USD/RUB rate of 65.78 (Bloomberg, 2019) following the rouble depreciation since 2015, indicate that the NSR is a competitive alternative for voyages originating from Vitino to destinations in South Korea,

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[9] Following the introduction of new tariffs in 2014, these were still prohibitive during that year for all OD pairs owing to a USD/RUB rate of 38.73 (Bloomberg, 2019). Therefore, discounted fees are assumed for that year too.

[10] The crude oil price refers to Brent crude, and both HFO and MGO to annual mean prices in Rotterdam (Clarksons, 2019).

but marginally competitive from Mongstad to Japan when repairs are included. On the other hand, the RFR differential between SCR and NSR is marginal for voyages between the Rotterdam area and S. Korea, and becomes negative when repairs are included in the calculations. The results show that shipowners who will opt for the use of the expensive MGO following the IMO 2020 sulphur limit, will benefit from using the NSR. The HFO-scrubber option comes second, since it is in between the HFO/MGO and MGO-only option.

The sensitivity analysis indicates that ice breaking fees is a crucial factor, which considerably affects the competitiveness of the NSR at any OD and ship size. High fuel prices are important but cannot determine the competitiveness of the NSR alone. It is shown that considerably high official fees due to a low USD/RUB rate outweigh any benefit that the use of the NSR gives at high fuel prices. This largely explains the practice of negotiated or discounted fees before 2014, when fees were determined by the USD/RUB rate and a maximum fee of 530 roubles per tonne of liquid cargo (ARCTIS, 2019b). It should also be noted that discounted fees varied from case to case (Falck, 2012). According to Tanker Company (2019) and Moe and Brigham (2016), regular users of the route could be granted even lower discounted fees than those mentioned by Atomflot and used in this paper (in Gritsenko and Kiiski, 2016; Falck, 2012). This explains why certain voyages from Vitino or Mongstad to destinations such as in Thailand, Taiwan, Singapore and Malaysia were conducted at that time, since the tankers were either owned or chartered by companies which conducted 24 of the 32 product tanker voyages. Further, the relatively smaller or sometimes negative SCR-NSR RFR differential for LR2 and LR3 tankers than for MR and LR1 across all cases and scenarios can be partly explained by the fact that ice breaking fees increase proportionally more than Suez Canal tolls with vessel size.

The results show that a combination of high fuel prices and independent navigation considerably widens the SCR-NSR RFR differential. Furthermore, a 50% reduction in speed through ice significantly reduces the potential of the NSR, especially on the long-haul. These findings are in line with Wergeland (1992), Liu and Kronbak (2010), Lu et al (2014), and Xu et al. (2018). Lasserre (2014, 2015) argues that fuel cost savings alone cannot determine the competitiveness of the NSR. In addition, the inverse relationship between fuel prices and official ice breaking fees is also in line with Shibashaki et al. (2018). Moreover, if ships are not able to use the path north of the New Siberian Islands, then the SCR is always more competitive when using big tankers at any OD regardless of any other factors. However, this also depends on parcel sizes, which for oil product trades they could be around 22% lower than the maximum ship capacity (Stopford, 2009), and could enable e.g. LR2/Aframax tankers to go through the Sannikov Strait. Not only are economies of scale and/or high dwt utilisation important for the cost-competitiveness of the NSR (Wergeland, 1992; Lasserre, 2014, 2015; Furuichi and Otsuka, 2015; Zhang et al., 2016; Xu et al., 2018), but also these contribute to lower environmental costs (Zhu et al., 2018). The results also show that the consideration of environmental costs leads to opposing outcomes. A future environmental policy which aims to ban the use and carriage of HFO in the Arctic over concerns for accidents and potential oil spills in this sensitive environment (Roy and Comer, 2017), significantly reduces the potential of the NSR. In particular, the NSR is only competitive on the Vitino-Daesan pair, and marginally or even uncompetitive on the Mongstad-Mizushima and Yeosu-Rotterdam pairs. On the other hand, it was found that a (theoretical) tax on HFO globally, favours low speeds and the use of the shorter Arctic routes. These results agree with Cariou and Faury (2015) who also considered environmental costs in the form of a CO_2 tax and with Wan et al. (2018), who conclude that a ban of HFO in the Arctic lowers the economic potential of the NSR. This paper investigates the feasibility of the NSR for product tanker trades at the tactical/operational level for round voyages at the summer/autumn season. It contributes to the literature in several ways. The main factors examined are distance, ship size, fuel types and prices, and ice breaking fees. Whilst ship sizes, distances, fuel prices and ice breaking fees have been widely explored in the literature concerning liner operations on NSR (Theocharis et al., 2018), there is a limited understanding as to how they affect tanker operations (Zhang et al., 2016). Further, this is the first study to investigate the impact of the IMO Sulphur 2020 limit, and alternative operational modes concerning fuel types and technologies in the context of Arctic shipping. The impact of a ban on HFO in the Arctic is also explored for the first time for tanker trades. Furthermore, the optimal speed which minimises the RFR constitutes a decision variable. It is dynamically adjusted as theory suggests (Alderton, 1981; Psaraftis and Kontovas, 2013) with respect to the factors that affect it such as displacement and payload, capital, operating and fuel costs. Although Cariou and Faury (2015) also attempted to optimise speed with respect to freight rates and fuel prices, they used a range of optimal speeds assuming equal transit times in both SCR and NSR and at a constant fuel price level. In addition, the relationship between fuel prices and ice breaking fees is investigated by considering both official and discounted fees.

The results of this study are based on up to date secondary data, and most importantly on primary data related to Arctic-specific cost factors which might change over time. The complexity of Arctic maritime operations and the relatively small ice class fleet globally (Solakivi et al., 2018; Tseng and Cullinane, 2018), increase the variability of estimates and underline the difficulty of obtaining reliable parameters (Lasserre, 2014). For example, the shipowner who provided the primary data for this paper, highlighted that the price for an ice-class vessel can be negotiable and sometimes not so higher than that of an ordinary vessel. Ice breaking fees depend on the number of escorting zones amongst others. The number of zones used depend on the ice class of the ship, navigation season and local climatic and ice conditions (Faury and Cariou, 2016). On the other hand, the uncertainty of the NSRA tariff policy underlines that fees vary depending on political and economic factors (Gritsenko and Kiiski, 2016; Moe and Brigham, 2016). It could be argued that ice breaking assistance of ships larger than a LR1 tanker may require the use of more than one ice breakers due to their wide beams, which may have a direct impact on costs and entail diseconomies of scale. Besides, there have been cases were tankers with beams smaller than those of the ice breakers were assisted by two or more ice breakers as well as large tankers which were assisted by one ice breaker (Bambulyak et al., 2015; NSRA, 2016). In addition, all LR2 tanker voyages in 2013 were assisted by one rather than two ice breakers (NSRA, 2016). This implies that local ice and climatic conditions play an important role independent of the ship size. In this paper it is assumed that the use of more than one ice breakers is factored in the official fees, following the logic of the official NSRA fees (NSRA, 2014) as well as the estimations that the online calculator of NSRA provides for large vessels (NSRA, 2019). Future research could shed light on this issue i.e. whether ice breaking fees are charged on the basis of the service provided at the respective fee for a certain tanker size (NSRA, 2014) or are based on the number of ice breakers used per se. Moreover, transit voyages on the NSR are still exploratory in nature not least because of the uncertainty related to climatic and ice conditions, transit times, minimal infrastructure, remoteness and safety (Farré et al., 2014; Faury and Cariou, 2016; Aksenov et al., 2017; Fedi et al., 2018; Tseng and Cullinane, 2018). Exceptions include ships serving specific projects or are under the ownership of industrial carriers, such as the Yamal LNG tankers or the fleet of Norilsk Nickel. Geopolitical issues may also affect petroleum flows, even if a route is a viable alternative. This is clearly shown with the re-direction of flows from the Murmansk/White Sea region to the Baltic since 2014. Besides, gas condensate flows from the Russian Arctic to Northeast Asia have recently re-emerged owing to the new Yamal/Sabetta condensate grade (Platts, 2018). In addition, 68% of the global ice class fleet is more than 10 years old, meaning that increased repairs and maintenance costs may restrict the use of this tonnage in more conventional trades (Gibson, 2018). Future research could focus on new technologies, other fuel types and operational modes, as well as future emissions and environmental regulation. The recent voyage of the LNG-powered Aframax tanker Lomonosov Prospect between South Korea and West Europe confirmed the viability of such voyages (MarEx, 2018). Wider geographical implications, commodity prices and cargo value could complement the transport cost analysis for tanker or other trades.

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Appendix A

Port	Tanker Terminals	Berths	Max DWT	Max LOA (m)	Max draught (m)
Yeosu	GS Galtex Crude Oil Terminal	No. 1 (Crude oil & Clean Products)	255,000	330	20.5
	GS Galtex Product Terminal	No. 3/5	35,000/50,000	183/195	11.3/12
	LPG & E-1 Gas Terminal	LPG Terminal (LPG, Chemicals & Clean Products)	65,200	249.8	12.6
	Sapo Terminal No. 1	Tank Terminal Quay	100,000	280	N.A.
	KNOC Terminal	No. 1/2/3	80,000/120,000/320,000	340/380/440	13.9/15.5/17.7
Rotterdam*	20 Terminals		50,000-355,000	185-366	11-16.1
Mongstad	Mongstad Refinery (Equinor, former Statoil)	Crude Oil Jetty No.1 (Crude & Clean Products)	380,000	350	23
		Jetty No. 14 (STS)	440,000	380	25
	Product Jetty	No. 2/8/9	90,000/60,000/50,802	240/235/235	14.5/16.4/16.4
Mizushima	Nippon Petroleum	No .5/6	114,106/314,026	250/340	16
	Japan Energy	No. 1	114,106	250	N.A.
Vitino	Vitino Terminal	No. 3/4	116,000/80,000	249/230	15.4/10.9
Daesan	Seetec Terminal	MDH-21/23/ MDK-15/16	100,000/50,000/ 100,000/45,000	280/219/ 280/200	12.5/12.7/ 14.9/12
		Samsung Petrochemical MDS-31	100,000	270	14
		KNOC	325,000	330	23

Source: IHS Maritime, 2015. Ports and Terminals Guide 2015-2016. *20 terminals/berths were identified, which explicitly refer to clean oil products.

Appendix B

Ship Size	Suez Canal Tolls in US$			NSR Ice Breaking Fees in US$		
	2011-2014[a]	2015-2017[b]	2018[c]	2011-2014[d]	2015-2017[e]	2018[f]
LR3	684,083	627,420	669,212	1,038,750	1,188,021	1,120,836
LR2	574,683	526,985	559,965	786,375	910,816	859,308
LR1	434,711	398,355	419,343	519,375	615,611	580,797
MR	352,166	322,756	335,210	321,250	509,771	480,942

[a]SDR=1.53 US$ & 2011-2014 tariffs, [b]SDR=1.40 US$ & 2015-2017 tariffs, [c]SDR=1.40 US$ & current tariffs (2018), (IMF, 2019, Leth agencies, 2019a), [d]5 US$/t of cargo & 2.5 US$/displacement tonne (Gritsenko and Kiiski, 2015, Lasserre, 2015, Falck, 2012, Tanker Company, 2019, Logistics Company, 2019), [e]For Arc4 (1A) ice class ships and 6/7 escorting zones during the summer/autumn season: 536.21 Roubles/GT for a MR tanker, 446.84 Roubles/GT for LR1,LR2, LR3 tankers at USD/RUB exchange rate of 62.06 (2015-2017 average), [f]same as [e] at a USD/RUB exchange rate of 65.78 (2018 average) (NSRA, 2014), (Bloomberg, 2019).

Appendix C. Results for the periods 2011-2014 and 2015-2017.

Yeosu – Rotterdam

	SCR		NSR			Differential (US$/t)	Differential incl. ice damage repairs (US$/t)
Ship Size	Speed (knots)	RFR (US$/t)	Speed (knots)	RFR (US$/t)	RFR incl. ice damage repairs (US$/t)		
HFO = 600 US$ per tonne							
MR	12.7	60.7	11.6	52.7	58.4	8.0	2.3
LR1	12.6	41.5	11.6	38.0	41.4	3.5	0.1
LR2	12.2	31.8	11.3	30.6	32.8	1.2	-1.0
LR3	12.2	27.8	11.4	27.7	29.3	0.1	-1.5
HFO = 260 & MGO = 450 US$ per tonne							
MR	15.9	47.4	13.6	49.4	55.1	-2.0	-7.7
LR1	15.7	32.5	13.5	33.8	37.1	-1.3	-4.6
LR2	15.5	25.1	13.3	27.5	29.7	-2.4	-4.6
LR3	15.5	22.0	13.3	25.0	26.7	-3.0	-4.7

Mongstad – Mizushima

	SCR		NSR			Differential (US$/t)	Differential incl. ice damage repairs (US$/t)
Ship Size	Speed (knots)	RFR (US$/t)	Speed (knots)	RFR (US$/t)	RFR incl. ice damage repairs (US$/t)		
HFO = 600 US$ per tonne							
MR	12.7	64.0	11.6	49.3	55.0	14.7	9.0
LR1	12.6	43.7	11.5	35.7	39.0	8.0	4.7
LR2	12.2	33.5	11.3	28.9	31.1	4.6	2.4
LR3	12.2	29.3	11.3	26.1	27.8	3.2	1.5
HFO = 260 & MGO = 450 US$ per tonne							
MR	15.8	50.3	13.6	46.3	52.0	4.0	-1.7
LR1	15.6	34.5	13.5	31.7	35.0	2.8	-0.5
LR2	15.3	26.5	13.4	25.9	28.2	0.6	-1.7
LR3	15.4	23.2	13.4	23.6	25.3	-0.4	-2.1

Vitino – Daesan

	SCR		NSR			Differential (US$/t)	Differential incl. ice damage repairs (US$/t)
Ship Size	Speed (knots)	RFR (US$/t)	Speed (knots)	RFR (US$/t)	RFR incl. ice damage repairs (US$/t)		
HFO = 600 US$ per tonne							
MR	12.7	70.1	11.6	48.3	54.0	21.8	16.1
LR1	12.6	47.8	11.5	35.0	38.4	12.8	9.4
LR2	12.2	36.5	11.3	28.3	30.6	8.2	5.9
LR3	12.2	31.9	11.3	27.3	28.9	4.6	3.0
HFO = 260 & MGO = 450 US$ per tonne							
MR	16.0	54.2	13.6	45.5	51.2	8.7	3.0
LR1	15.8	37.1	13.5	31.1	34.4	6.0	2.7
LR2	15.6	28.5	13.3	25.5	27.7	3.0	0.8
LR3	15.6	24.9	13.3	24.8	26.5	0.1	-1.6

Appendix D. Results for 2018 including environmental costs.

Yeosu – Rotterdam

	SCR						NSR							Differential (US$/t)	Differential incl. repairs (US$/t)
Ship Size	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	RFR incl. repairs (US$/t)		
HFO = 400 US$/t															
MR	14.5	14.3	9.6	14	14.9	52.8	12.6	10.1	14.5	13.2	15.0	52.8	58.5	0.0	-5.7
LR1	14.3	9.7	7	8.7	10.9	36.3	12.5	6.9	10.1	8.1	10.9	36.0	39.3	0.3	-3.0
LR2	13.8	7.3	6.2	5.8	8.8	28.1	12.3	5.3	9.8	5.3	8.7	29.1	31.3	-1.0	-3.2
LR3	13.9	6.3	5.6	5.1	7.7	24.7	12.3	4.6	9.6	4.6	7.6	26.4	28.1	-1.7	-3.4
HFO & Scrubber at 400 US$/t															
MR	14.7	14.7	9.6	13.8	15.9	54.0	12.8	10.1	14.5	12.9	15.7	53.2	58.9	0.8	-4.9
LR1	14.6	9.9	7.0	8.6	11.5	37.0	12.8	6.9	10.1	7.9	11.3	36.2	39.5	0.8	-2.5
LR2	14.1	7.4	6.2	5.7	9.2	28.5	12.5	5.3	9.8	5.2	8.9	29.2	31.4	-0.7	-2.9
LR3	14.2	6.4	5.6	5.0	8.0	25.0	12.5	4.6	9.6	4.5	7.8	26.5	28.2	-1.5	-3.2
MGO = 600 US$/t															
MR	12.5	16.6	9.6	16.3	17.3	59.8	11.5	12.8	14.5	14.3	16.4	58.0	63.7	1.8	-3.9
LR1	12.3	11.3	7.0	10.1	12.7	41.1	11.4	8.8	10.1	8.7	12.0	39.6	42.9	1.5	-1.8
LR2	11.9	8.4	6.2	6.8	10.2	31.6	11.2	6.7	9.8	5.8	9.5	31.8	34.0	-0.2	-2.4
LR3	12.0	7.3	5.6	5.9	8.9	27.7	11.2	5.8	9.6	4.9	8.3	28.6	30.3	-0.9	-2.6
HFO = 400US$/t +100 US$/t CO2 Tax = 711.4 US$/t															
MR	12.2	17.8	9.6	16.6	19.2	63.2	11.3	13.9	14.5	14.5	17.9	60.8	66.5	2.4	-3.3
LR1	12.0	12.0	7.0	10.3	13.9	43.2	11.2	9.5	10.1	8.9	12.9	41.4	44.7	1.8	-1.5
LR2	11.6	9.0	6.2	6.9	11.1	33.2	11.0	7.2	9.8	5.9	10.2	33.1	35.3	0.1	-2.1
LR3	11.7	7.8	5.6	6.0	9.7	29.1	11.0	6.3	9.6	5.0	8.9	29.8	31.5	-0.7	-2.4

Mongstad – Mizushima

	SCR						NSR							Differential (US$/t)	Differential incl. repairs (US$/t)
Ship Size	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	RFR incl. repairs (US$/t)		
HFO = 400 US$/t															
MR	14.4	15.4	9.6	15.1	16.1	56.2	12.6	9.0	14.5	12.2	13.7	49.4	55.1	6.8	1.1
LR1	14.2	10.5	7	9.4	11.8	38.7	12.6	6.2	10.1	7.5	10.0	33.8	37.1	4.9	1.6
LR2	13.7	7.8	6.2	6.3	9.4	29.7	12.3	4.7	9.8	4.9	7.9	27.3	29.5	2.4	0.2
LR3	13.8	6.8	5.6	5.4	8.3	26.1	12.3	4.1	9.6	4.2	6.9	24.8	26.5	1.3	-0.4
HFO & Scrubber at 400 US$/t															
MR	14.7	15.7	9.6	14.7	16.9	56.9	12.7	9.1	14.5	12.1	14.5	50.2	55.9	6.7	1.0
LR1	14.6	10.6	7.0	9.1	12.2	38.9	12.7	6.2	10.1	7.4	10.4	34.1	37.4	4.8	1.5
LR2	14.1	7.9	6.2	6.1	9.8	30.0	12.4	4.8	9.8	4.9	8.2	27.7	29.9	2.3	0.1
LR3	14.2	6.9	5.6	5.3	8.5	26.3	12.4	4.2	9.6	4.2	7.2	25.2	26.9	1.1	-0.6
MGO = 600 US$/t															
MR	12.5	17.8	9.6	17.3	18.5	63.2	11.4	11.7	14.5	13.3	15.1	54.6	60.3	8.6	2.9
LR1	12.3	12.1	7.0	10.8	13.5	43.4	11.4	8.0	10.1	8.1	11.0	37.2	40.5	6.2	2.9
LR2	11.9	9.0	6.2	7.2	10.9	33.3	11.2	6.1	9.8	5.4	8.7	30.0	32.2	3.3	1.1
LR3	12.0	7.8	5.6	6.2	9.5	29.1	11.2	5.3	9.6	4.6	7.7	27.2	28.9	1.9	0.2
HFO = 400US$/t +100 US$/t CO2 Tax = 711.4 US$/t															
MR	12.2	19.0	9.6	17.7	20.5	66.8	11.2	12.6	14.5	13.4	16.4	56.9	62.6	9.9	4.2
LR1	12.0	12.8	7.0	11.0	14.8	45.6	11.2	8.6	10.1	8.2	11.8	38.7	42.0	6.9	3.6
LR2	11.6	9.6	6.2	7.4	11.9	35.1	11.0	6.6	9.8	5.4	9.3	31.1	33.3	4.0	1.8
LR3	11.7	8.3	5.6	6.4	10.3	30.6	11.0	5.8	9.6	4.7	8.2	28.3	30.0	2.3	0.6

Vitino – Daesan

	SCR						NSR							Differential (US$/t)	Differential incl. repairs (US$/t)
Ship Size	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	Speed (knots)	Fuel Cost (US$/t)	Transit Fees (US$/t)	Operating Cost (US$/t)	Capital Cost (US$/t)	RFR (US$/t)	RFR incl. repairs (US$/t)		
HFO = 400 US$/t															
MR	14.5	17.0	9.6	16.6	17.7	60.9	12.6	8.7	14.5	11.9	13.3	48.4	54.1	12.5	6.8
LR1	14.4	11.5	7.0	10.3	12.9	41.7	12.6	5.9	10.1	7.3	9.7	33.0	36.3	8.7	5.4
LR2	13.9	8.6	6.2	6.9	10.4	32.1	12.3	4.6	9.8	4.8	7.7	26.9	29.1	5.2	3.0
LR3	14.0	7.5	5.6	6.0	9.1	28.2	12.3	4.0	9.6	4.1	6.7	26.0	27.7	2.2	0.5
HFO & Scrubber at 400 US$/t															
MR	14.7	17.5	9.6	16.3	18.9	62.3	12.7	8.8	14.5	11.9	14.1	49.3	55.0	13.0	7.3
LR1	14.6	11.8	7.0	10.2	13.7	42.7	12.6	6.0	10.1	7.3	10.2	33.6	36.9	9.1	5.8
LR2	14.1	8.8	6.2	6.8	10.9	32.7	12.4	4.6	9.8	4.8	8.0	27.2	29.4	5.5	3.3
LR3	14.2	7.7	5.6	5.9	9.5	28.7	12.4	4.0	9.6	4.1	7.0	26.3	28.0	2.4	0.7
MGO = 600 US$/t															
MR	12.5	19.8	9.6	19.3	20.6	69.3	11.4	11.4	14.5	13.0	14.7	53.6	59.3	15.7	10.0
LR1	12.3	13.5	7.0	12.0	15.1	47.6	11.4	7.8	10.1	7.9	10.7	36.5	39.8	11.1	7.8
LR2	11.9	10.0	6.2	8.0	12.1	36.3	11.1	5.9	9.8	5.2	8.5	29.4	31.6	6.9	4.7
LR3	12.0	8.7	5.6	7.0	10.6	31.9	11.2	5.2	9.6	4.5	7.5	28.4	30.1	3.5	1.8
HFO = 400US$/t +100 US$/t CO2 Tax = 711.4 US$/t															
MR	12.2	21.2	9.6	19.7	22.9	73.4	11.2	12.3	14.5	13.1	16.0	55.9	61.6	17.5	11.8
LR1	12.0	14.3	7.0	12.3	16.5	50.1	11.2	8.4	10.1	8.1	11.5	38.1	41.4	12.0	8.7
LR2	11.6	10.7	6.2	8.2	13.2	38.3	11.0	6.4	9.8	5.3	9.1	30.6	32.8	7.7	5.5
LR3	11.7	9.3	5.6	7.1	11.5	33.5	11.0	5.6	9.6	4.6	7.9	29.3	31.0	4.2	2.5

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