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FEASIBILITY OF COMMERCIAL CARGO SHIPPING ALONG THE NORTHERN SEA ROUTE

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ABSTRACT

Feasibility of commercial cargo shipping along the Northern Sea Route

At least over the past two centuries, the Northern Sea Route (NSR), a link connecting the Pacific and Atlantic Oceans through Russian Arctic territorial waters, has attracted seafarers willing to test its potential for delivering shorter and faster voyages. Traditionally maritime activity along the NSR has been constrained by a harsh climate, including perennial ice-cover and sub-zero temperatures.

In recent decades, climate change has entailed improving climate conditions for shipping in the form of receding Arctic Sea ice-cover. This has turned the focus towards the Arctic region as a whole, mostly linked to its abundant reserves of natural resources. In many respects, climate change has reactivated interest in the NSR as a route for accessing natural resource riches and transcontinental shipping shortcuts between Europe and Asia.

Despite the significant multi-level attention focused on the NSR, an understanding of its feasibility is far from being conclusive, which has resulted in varying conclusions in the media and extant literature. This research aims to produce a holistic, fact-based and unbiased view on the feasibility of commercial cargo shipping along the NSR from the point-of-view of ship owners. The main research question investigates under what conditions commercial cargo shipping along the NSR could become feasible. It is divided into three separate research sub-questions, which focus on: i) economic viability; ii) infrastructure and related services; and iii) market potential.

The system-like characteristics of the phenomenon in question entail the positioning of the thesis in the categories of critical realism and pragmatism, with the emphasis on the former. The research approach has elements of constructive and system orientations, while the logic of inquiry relies on abductive reasoning with descriptive, normative and pragmatic features.

The thesis consists of five separate articles and the concluding summary, which contains new empirical data. The summary concludes with the findings of the appended papers and provides an overall synthesis with reference to the main research question and the more specific sub-questions.

This research employs quantitative research methods, including trend and capacity analysis as well as cost calculation and system dynamics modeling. Moreover, the widely used PESTEL framework is used in the concluding summary to describe the relevant external factors related to the political, economic, social, technological, environmental and legal preconditions affecting commercial cargo shipping along the NSR.

The subject of thesis is bound to the real world, which entails that the relevant research parameters are directly obtainable on a practical level. Accordingly, the primary research data comprises fleet and cost information from maritime consultancies, the data are then enhanced through the opinions of practitioners and those who have studied its potential.

The thesis contributes on three levels: managerial, theoretical and policy-making. On the managerial level, it contributes by providing normative tools, i.e. cost calculation and simulation models for ship owners in order to assess feasibility in a holistic manner. These tools provide guidance for the decision-making of ship owners and pertain to ship investment and management. A more pragmatic input is to participate in the general Arctic discussion, which tends to be based on unrealistic perceptions and misconceptions. This is valuable not only for business but also a wider audience.

The thesis also contributes on a theoretical level in terms of providing a typology for the Arctic shipping cost categorization and the generic profiles of the NSR ships. In addition, it provides a substantial contribution to the ongoing Arctic policy-making discussion in terms of the adoption of national strategies.

The conclusion of the thesis is that commercial cargo shipping along the NSR could be feasible under the right circumstances in the short-term, relating to particular shipping sectors in a favorable market and climate conditions. In particular, destinational traffic, i.e. traffic to or from the Russian Arctic along the NSR, most often associated with bulk shipping, may prove economically viable. However, the size of the market potential is limited, especially when taking into account the scant maritime infrastructure and dependency on macroeconomic drivers.

From the ship owner's decision-making point-of-view, the contemporary shipping economies in bulk shipping may be viewed as seizing market opportunities without a long-term commitment. On the other hand, more prominent involvement in shipping along the NSR would also require a number of fleet design considerations. In the long-term, the development of the NSR involves a high degree of uncertainty as its feasibility depends on a number of external factors relating mainly to climate, political and market issues.

Keywords: the Northern Sea Route, Arctic shipping, the Arctic, shipping market, market analysis, feasibility, system dynamics

TIIVISTELMÄ

Kauppamerenkulun toimintaedellytykset Pohjoisreitillä

Viime vuosisatojen aikana Pohjoisreitti, eli Atlantin ja Tyynen valtameren yhdistävä merireitti Venäjän arktisten merialueiden halki, on houkutellut merenkulkijoita testaamaan sen soveltuvuutta lyhempiin ja nopeampiin purjehduksiin. Ankara ilmasto – muun muassa erittäin alhaiset lämpötilat ja ympärivuotinen jääpeite – on kuitenkin merkittävästi rajoittanut perinteistä merenkulkua tällä reitillä.

Viimeisten vuosikymmenten aikana ilmaston lämpeneminen ja sen myötä ohentunut jääpeite on vähitellen muokannut olosuhteita suotuisammaksi merenkululle. Tämä on osaltaan lisännyt maailmanlaajuista mielenkiintoa arktista aluetta kohtaan muun muassa alueella sijaitsevien runsaiden luonnonvarojen sekä mannertenväliselle merenkululle avautuvien mahdollisuuksien vuoksi. Viimeaikaisesta mielenkiinnosta huolimatta ymmärrys Pohjoisreitin soveltuvuudesta kauppamerenkululle on vielä varsin puutteellinen, mikä käy ilmi tutkimuskirjallisuudessa ja mediassa esitetyistä johtopäätöksistä.

Tämä väitöskirjatutkimus pyrkii tuottamaan kokonaisvaltaisen, faktaperusteisen ja puolueettoman kuvan kauppamerenkulun toimintaedellytyksistä Pohjoisreitillä laivanvarustajan näkökulmasta. Tavoitteena on selvittää, millaisten reunaehtojen vallitessa Pohjoisreitillä voisi harjoittaa kannattavaa kauppamerenkulkua. Tavoitteeseen pyritään vastaamalla kolmeen alakysymykseen: i) mikä on reitin taloudellinen kannattavuus, ii) millainen merenkulun infrastruktuuri ja millaiset tukipalvelut reitillä on, sekä iii) mikä on reitin markkinapotentiaali.

Tutkimuksen kohteena olevan ilmiön systeemiset ominaispiirteet sijoittavat tämän tutkimuksen tieteenfilosofisessa mielessä kriittisen realismin ja pragmatismin luokkiin, jossa paino on vahvasti ensin mainitussa. Tutkimusotteessa on piirteitä konstruktiivisesta ja systeeminäkökulmista, kun taas tieteellisen päättelyn logiikka pohjautuu abduktiiviseen otteeseen kuvailevine, normatiivisine ja pragmaattisina ominaispiirteineen.

Väitöskirja koostuu viidestä erillisestä artikkelista ja johdanto-osasta, joka sisältää myös uutta empiiristä tietoa. Johdanto-osa kokoaa yhteen liitteenä olevien artikkelien tulokset, vastaa pää- ja alatutkimuskysymyksiin sekä esittää tutkimuksen synteesin. Tutkimuksen kvantitatiivisina tutkimusmenetelminä käytetään trendi- ja kapasiteettianalyysiä sekä kustannus- ja systeemidynamiikkamallinnusta. Johdanto-osassa on lisäksi käytetty ns. PESTEL-viitekehystä kuvaamaan niitä poliittisia, taloudellisia, sosiaalisia, teknologisia, ympäristöllisiä ja lainsäädännöllisiä reunaehtoja, jotka vaikuttavat kauppamerenkulun toimintaedellytyksiin Pohjoisreitillä.

Tutkimuksen kohteena on reaalimaailman ilmiö: Pohjoisreitin soveltuvuus kauppamerenkulkuun. Näin ollen työn keskeiset tutkimusparametrit sekä empiirinen aineisto perustuvat parhaaseen saatavilla olevaan käytännön tietoon. Pääasiallisen tutkimusaineisto muodostuu alus- ja kustannustiedoista, jotka on saatu maailman johtavilta merenkulun konsulttitoimistoilta. Näitä tietoja on täydennetty soveltuvin osin toimija- ja asiantuntijanäkemyksillä. Työssä on myös erittäin kattava aihepiiriä käsittelevän tutkimuskirjallisuuden katsaus.

Kokonaisuutena työn kontribuutio on osallistua yleiseen arktiseen aluetta ja sen potentiaalia koskevaan keskusteluun, ja tuoda tähän keskusteluun faktapohjaisia argumentteja aiempien osin epärealististen odotusten ja käsitysten vastapainoksi. Väitöskirjan kontribuutiot ulottuvat myös liikkeenjohtoon erityisesti varustamotoiminnan osalta, teoreettisesti merenkulkutalouden tutkimukseen sekä arktiseen alueeseen liittyvään poliittiseen päätöksentekoonkin.

Liikkeenjohdolle tutkimus tuottaa normatiivisia työkaluja erityisesti laivanvarustajille kustannuslaskenta- ja simulaatiomallien muodossa, jotka mahdollistavat kauppamerenkulun toimintaedellytysten kokonaisvaltaisen arvioinnin mm. alusinvestointien ja operatiivisen toiminnan suunnittelun osalta.

Väitöskirjan keskeinen teoreettinen kontribuutio liittyy arktisen merenkulun kustannusluokittelumallin rakentamiseen sekä yleisten kustannus- ja tuottoprofiilien luomiseen Pohjoisreitin aluksista. Lisäksi työ antaa merkittävän panoksen arktisen alueen poliittiseen päätöksentekoon niin kansallisella kuin kansainväliselläkin tasolla.

Tutkimuksen johtopäätöksenä on, että Pohjoisreitin kaupallisen merenkulun toimintaedellytykset voivat täyttyä lyhyellä tähtäimellä vain varsin tiukkojen reunaehtojen vallitessa. Näitä ovat mm. suotuisa markkinatilanne, sopivien lastien ja kuljetuskapasiteetin saatavuus sekä suosiolliset ilmasto-olosuhteet reitillä. Näidenkin edellytysten täyttyessä vain hyvin rajallinen osa maailman merenkulusta voi näitä mahdollisuuksia hyödyntää, ja reitin kaupallinen potentiaali erityisesti Euroopan ja Aasian välisessä kauttakulkuliikenteessä tullee olemaan marginaalinen vielä pitkään.

Sen sijaan liikenteellä Venäjän omiin arktisiin kohteisiin tai kohteista (ns. määränpääliikenne) on konkreettista potentiaalia erityisesti nestemäisen ja kuivan irtolastin merikuljetuksissa. Tämän markkinan koko on kuitenkin rajattu, mikä johtuu mm. alueen puutteellisesta infrastruktuurista (ml. riittämätön jäänmurtokapasiteetti) ja liikenteen kysynnän riippuvuudesta makroekonomisista tekijöistä.

Laivanvarustajan näkökulmasta Pohjoisreitin tämänhetkiset kauppamerenkulluliset mahdollisuudet eritoten irtolastien osalta perustuvat opportunistisiin lyhytaikaisiin markkinamahdollisuuksiin tarttumisiin ilman pidempiaikaista sitoutumista. Toisaalta reitin laajamittaisempi hyödyntäminen edellyttää myös alusteknisten näkökohtien entistä tarkempaa huomioimista.

Pidemmällä aikajänteellä Pohjoisreitin kauppamerenkulululliset toimintaedellytykset sisältävät suuren määrän epävarmuutta, koska ne ovat riippuvaisia useista ulkoisista tekijöistä, joista tärkeimmät ovat ilmaston kehitys sekä poliittiset ja markkinoilla tapahtuvat muutokset.

Avainsanat: Pohjoisreitti, arktinen merenkulku, arktinen alue, merenkulkumarkkinat, markkina-analyysi, taloudelliset toimintaedellytykset, systeemidynamiikka

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Turku, 2 November 2016

Tuomas Kiiski

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List of Abbreviations

AC	Arctic Council
ACIA	Arctic Climate Impact Assessment
AMSA	Arctic Marine Shipping Assessment
BDI	Baltic Dry Index
CEU	Car Equivalent Unit
DWT	Deadweight Tonnage
EEZ	Economic Exclusive Zone
FCC	Fully Cellular Containership
GDP	Gross Domestic Product
HFO	Heavy Fuel Oil
H&M	Hull and Machinery
IACS	International Association of Classification Societies
ILO	International Labor Organization
IMO	International Maritime Organization
INSROP	International Northern Sea Route Program
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MOPPR	Marine Oil Pollution Preparedness and Response
NM	Nautical mile
NSR	Northern Sea Route
PCC	Pure Car Carrier
PCR	Panama Canal Route
P&I	Protection and Indemnity
SAR	Search and Rescue
SCR	Suez Canal Route
SFOC	Specific Fuel Oil Consumption
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TSR	Trans-Siberian Railroad
TEU	Twenty foot equivalent unit
T/C	Time-Charter
UNCLOS	United Nations Convention on the Law of the Sea
USD	United States Dollar
USGS	United States Geological Survey
WMO	World Meteorological Organization
WTO	World Trade Organization

PART I: THE CONCLUDING SUMMARY

1 INTRODUCTION

1.1 Research context

1.1.1 The history of shipping along the Northern Sea Route until year 2000

One of the last frontiers of the world is located in the Polar Regions, where a hostile climate and perennial ice have traditionally constrained human activity. Throughout time, exploiting the shorter distances across the globe by sailing through the Arctic Sea has intrigued people in many ways. For mariners, fabled dreams of the Arctic Sea shortcuts have lived for centuries. However, it was not until the dawn of the 20th century, that scientific expeditions (led by the Finnish-Swedish Adolf Erik Nordenskiöld in 1878–1880 and then the Norwegian Roald Amundsen in 1903–1906) finally conquered the passages across the Arctic Sea (Mills 2003). However, owing to restricting climate conditions and technical deficiencies, the area north of the Arctic Circle, commonly known as the Arctic, passed into a phase in which human activity was scarce in the region.

In the 1930s, the Soviet Union, led by Josef Stalin, became actively engaged in the Arctic theatre by building a number of settlements in order to secure its northern frontiers and facilitate the extraction of natural resources (Emmerson 2011). In this respect, and largely owing to a lack of alternative modes of transportation, the need to organize the maritime system along the NSR became crucial. Accordingly, the large-scale development of a maritime route following the course of the Russian Arctic coast began. In Russian language the route called “Severnyi Morskoi Put”. In English it is the Northern Sea Route (NSR). A number of maritime infrastructure projects were embarked upon, including the establishment of the route’s administration and the construction of ports and icebreakers (Armstrong 1955).

In 1940, the first non-Soviet vessel to navigate through the NSR, a Nazi Germany auxiliary cruiser, *Komet*, transited the NSR from the Atlantic to the Pacific Ocean accompanied by Soviet icebreakers. A record time was set, as the voyage took only 21.5 days, including seven days of waiting for the icebreakers, something which was arguably due to political controversy (Lloyd 1950). The voyage constituted a milestone in terms of the NSR’s navigation. It suggested that the NSR could occasionally be accessible with reasonable speeds, provided that a sufficient amount of navigational support was given. However, use of the route was soon restricted to only Soviet vessels due to over half a century of political differences.

During the Cold War, the use of the NSR was confined behind the iron curtain and the Arctic Sea became a hotspot in the form of providing a playground for submarines and the shortest path for nuclear missile trajectories between the Soviet Union and the USA. For the Soviet Union, the NSR constituted a pivotal domestic transport corridor. Traffic flows along the NSR increased until they peaked in 1987, totaling around 6.6 million tonnes (Ragner 2000a). That same year, the Soviet Leader, Mikhail Gorbachev, gave a speech in Murmansk proposing, for the first time, the opening of the NSR to Western ships (Gorbachev 1987).

However, it took until the fall 1991, soon after the demise of the Soviet Union, for the NSR to be finally opened to international shipping. A French polar supply vessel, *MS L'Astrolabe*, was the first to turn a new page in the history of the NSR by conducting a transit voyage (Gritsenko and Kiiski 2016). In the 1990s, the feasibility of the NSR in an international context was tested, but, owing to the sizeable uncertainties pertaining to climate, political and economic issues, it was not able to sustain a large enough interest among the international shipping industry to be viable (Brubaker and Ragner 2010). In particular, concerns in relation to operational risks, reliability and regularity outweighed the nascent economic potential (Granberg 1998). Accordingly, international activity had seized up by the end of the decade and was also accompanied by a declining domestic activity along the NSR (Ragner 2000b).

The aforementioned historical occurrences provide the background and a starting point for the discussion of the present-day commercial cargo shipping potential of the NSR.

1.1.2 The increasing attraction of the Arctic and Northern Sea Route in the 21st century

By the turn of the 21st century, the Arctic was still far from global attention despite its unquestionable, but so far constrained, economic potential regarding natural resources and shipping. Economic activity was relatively limited in scope and predominantly focused on a few locations where shipping provided a means to supply Arctic settlements and to convey resources extracted from the region to the main markets. For example, in the late-1970s, the Norilsk nickel mine in the Western Siberia commenced year-round shipments (Ragner 2000b).

In the beginning of the new millennium, the situation changed rapidly owing to the dynamics of several external factors affecting the overall attractiveness of the region (Arbo et al. 2013). The shift in awareness was contributed to by scientific reports that provided empirical evidence of the unprecedented climate change occurring in the Arctic (IPCC 2001; 2007; ACIA 2004). The observed long term trends of warming temperatures and the consequent loss of the Arctic Sea ice indicated that the region will become more accessible in the foreseeable future. This meant that the region's vast natural resources, estimated by the United States Geological Survey in 2008 to account for about one third of the World's undiscovered oil and gas reserves (Bird et al. 2009), would be more easily obtainable. Furthermore, the prevailing market conditions back then also did their fair share to build up enthusiasm for commercial activity in the region; the price of oil was soaring and the global economy was in growth mode with an increasing demand for hydrocarbons. Additionally, the seemingly endless hunger for energy in Asian countries raised concerns over the depletion of existing hydrocarbon reserves, which the unexploited Arctic resources could relieve.

Thus, the dreams of the Arctic Sea voyages were revitalized as maritime transports provided a convenient method for conveying natural resources to the main markets. Hence, an increase in maritime activity was projected (Arctic Council 2009; Peters et al. 2011). This was encouraged by technological developments in the shipbuilding and icebreaking domains, enabling Arctic shipping ventures to shift from being solely an engineering challenge into more concrete business decisions.

As a result of the aforementioned developments, the Arctic became an object of multi-leveled aspirations. Blooming interest was seen throughout the Northern Hemisphere among governments, policymakers, academia, business, environmental organizations and media. At the same time, fundamental controversies unraveled due to conflicting ideologies in terms of how the Arctic should be developed. In many respects, owing to the multilevel underlying motives, the hype around the potential for the region was built on unrealistic perceptions rather than facts. A distinctive feature of the process was a high degree of uncertainty related to the development of the climate conditions, the commodity markets, the geopolitical atmosphere as well as changes in the infrastructural and regulatory environment.

Most of the Arctic Sea littoral states and some Asian countries, China in particular (Hong 2012), were actively involved, while others, namely the USA, adopted a "wait and see" policy (Offerdal 2014, 80). Different Arctic strategies have been drafted to signal national intentions. Some countries have adopted policies with an emphasis on asserting their sovereignty over the undivided Arctic areas. For example, Russia planted a flag on the seabed of the Arctic Sea in 2007 to justify its territorial claims to areas near the North Pole (Baev 2013).

In parallel, the still somewhat loose regulatory environment regarding Arctic shipping has been developed under auspices of the Arctic Council and the International Maritime Organization (IMO). A number of mandatory agreements have been introduced, in which the Polar Code, addresses the regulation of Arctic shipping, coming into force in 2017 (IMO 2016).

In academia, the Arctic has been a fertile area for all types of research. In particular climate change impacts have been studied in variety of ways and a growing number of studies have been devoted to assessing the economic viability of shipping ventures. In the long term, the overall economic implications of climate change are expected to be massive, causing the profound transformation and promotion of the position of the Arctic (Valsson and Ulfarsson 2011; Smith 2011).

During the past decade, an overwhelming enthusiasm has prevailed within the extractive industry regarding the exploitation of the Arctic's natural resources. A number of international cooperative ventures were signed between oil and gas companies in order to provide enough funds and expertise to manage the demands of ambitious extraction projects; the investments are estimated to reach up to USD 100 billion over the next decade (Emmerson and Lahn 2012). Also the shipping industry showed an interest in testing the conceived potential of the Arctic Sea routes, especially the NSR. In 2009, two vessels of the German-based Beluga Shipping sailed through the NSR from South Korea to the Netherlands. They have subsequently been followed by a number of other vessels over the last few years (NSRIO 2016a).

Arctic development has exacerbated a conflict of interests between business people and environmentalists. On the one hand, the business side seeks to exploit the economic potential, and on the other hand the environmentalists aim to preserve the pristine and vulnerable nature of the Arctic. In this regard, the exploitation of natural resources is viewed as causing environmental damages and an increasing maritime activity is expected to pose a number of ecological threats, such as oil spills and the spreading of invasive species. Accordingly, a number of protests and demonstrations have taken place throughout the Northern Hemisphere.

The media has also actively taken part in building up hype about the Arctic's prospects. As noted by Young (2010) the media has traditionally trumpeted a compelling picture of the unidirectional decline of the Arctic Sea ice and the imminent economic potential attached to it in terms of a rush to extract oil and gas reserves and to use the Arctic Sea routes. Some articles ostentatiously declared the advent of an Arctic shipping boom and a race to exploit the natural riches (Ibisonin 2007; Beary 2008; Murphy 2009).

1.1.3 Route-choice decisions in the nexus of the global shipping

Shipping, being a derivative of global economic activity, is a powerhouse of world trade in volume terms and one of the prime facilitators of globalisation (Kumar and Hoffmann 2002). Seaborne trade usually contributes about 80 per cent of the total volumes of global trade (UNCTAD 2015). A fairly constant share is largely attributed to the short-term inelastic nature of demand for maritime transport services owing to, among other things, the lack of substitutes (Button 2010).

Over the past decade, seaborne trade has evolved in terms of scale and direction. Expansion of seaborne trade has consecutively surpassed economic growth rate, implying that the volume could more than double from around 9 billion tonnes to between 19 and 24 billion tonnes by 2030 (Lloyd's Register et al. 2013; UNCTAD 2015). Trade is increasingly shifting away from the developed countries as Asia has established itself as a new center, coupled with the shifting economic balance from advanced to developing economies. The annual growth rate in Asian trade, by value, is expected to exceed 10 per cent between 2021 and 2030 (HSBC 2015). By 2030, China's position is expected to be emphasized by constituting the origin or destination of 17 out of the 25 main sea and air bilateral trade routes (PWC 2011). The process has already led to the increasing efficiency of maritime transport systems. In this respect, ships, ports and canals have already grown in size in order to sustain growth.

The shipping market comprises a number of sub-markets in terms of vessel size and specialization (Evans and Marlow 1990), constituting a place of transactions between the shippers and the ship owners. In other words, the demand for transportation per type of cargo meets the available supply of ships able to carry the cargo in question. Vessels are usually designed and optimized to trade in a particular region in terms of size and technology and the requirements of shippers and maritime authorities. Contemporary seaborne trade is organized in the form of shipping patterns, which reveal the density concentrations of maritime activity.

Shipping patterns are ultimately the results of the ship owners' routing decisions. Traditionally the role of ship owners in organizing the conveyance of the massive cargo loads has been viewed as exciting. To illustrate the realm of a ship owner, the famous Norwegian ship owner Erling Naess once stated:

> *"God must have been a ship owner. He placed the raw materials far from where they were needed and covered two thirds of the earth with water."* (Stopford 2009, 417).

However, the shipping market constitutes a turbulent business environment due to its dynamic connection with macroeconomic factors (e.g. Scarsi 2007). Traditionally the ability to foresee fluctuations in market development has been the key to success. Figure 1 shows the past market volatility in terms of the Baltic Dry Index (BDI) and Brent crude oil prices between 2000 and 2015. BDI indicates the combined daily freight rate of various sized dry bulk vessels.

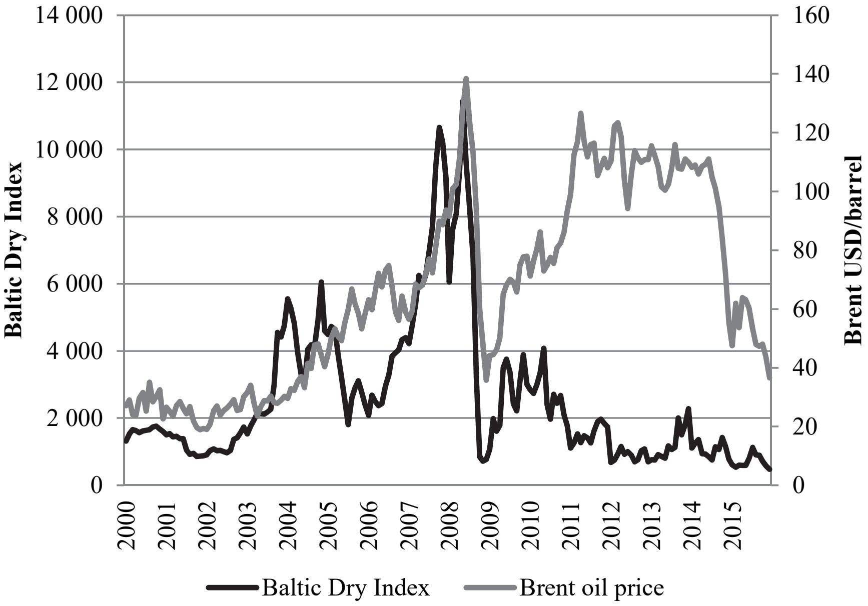

Figure 1 Baltic Dry Index and Brent oil price 2000 – 2015/2016 (EIA 2016; Bloomberg 2016)

The main objective of a ship owner or a shipping company, like any other entrepreneur, is to maximize the profits gained from their business activities. In order to sustain a competitive edge, they adopt strategies aimed at maximizing revenues or minimizing costs (Chen et al. 2010). Hence, the focus is constantly on examining a shipping network's design in search of cost efficiency, manageable risks and increased routing flexibility (Notteboom 2012). In this regard, the valued items commonly include freight rate and costs.

Freight rate is the price of a transport service at a given time. The actual rate level is set by the market and comprises part of the earnings potential, which guides the operational decisions of ship owners (Veenstra and Ludema 2006). High freight rates tend to induce ship owners to find ways to increase their fleet's performance, while low rates do the opposite (e.g. Cariou and Faury 2015). In this respect, fleet performance optimization decisions include, but are not limited to, vessel size, speed and routing (Cullinane and Khanna 2000; Maloni et al. 2013; Christiansen et al. 2013). The freight rate constitutes a reliable indicator of a ship owners' decisions, although rate discounts are occasionally used to gain more market share and are attributable to the elastic nature of demand for the service of an individual operator (Lim 1998).

Fluctuating costs influence operational practices, including route choices (Zelasney et al. 2011). High fuel prices advocate reducing a ship's performance in terms of the adoption of slower sailing speeds (e.g. Maloni et al. 2013). Similarly, increased canal tolls and insurance costs due to piracy have occasionally elevated the attractiveness of the Cape Route (e.g. Martinez-Zarzoso 2013). In the long term, costs are expected to increase due to fluctuating oil prices, growing congestion in ports and economic centers, as well as the adoption of public policies aimed at internalizing the external costs of transport (Tavasszy et al. 2011). In addition to the purely quantifiable and fiscal attributes, the criteria behind the making of route-choice decisions also includes qualitative aspects, like reliability, service-level and predictability (Notteboom 2006; Bergantino and Bolis 2008).

Traditionally, the landscape of shipping patterns has warranted a fertile platform for scholars. A number of studies have explored shipping pattern geography from two perspectives. First, the resiliency of an existing maritime network is tested owing to growing concerns related to its capacity, security and lead-times (Griffiths 1995; Mostafa 2004; Bendall 2010; Ungo and Sabonge 2012). Indeed, most trade is focused on a very few lanes that have limited capacities, such as the canals of the Suez and Panama, the former handling around 8 per cent (SCA 2015) of the seaborne trade and the latter 5 per cent (ACP 2015). Accordingly, the evaluation of the impacts of the closure of those key lanes is made a focal point of economic considerations (Fu et al. 2010; Qu and Meng 2012). Second, the opportunity cost comparisons of the alternatives not only involve sea options: the Cape Route (Notteboom 2012); the Nicaragua Canal (Yip and Wong 2015); the Northern Sea Route (Liu and Kronbak 2010); and the Northwest Passage (Somanathan et al. 2007, 2009), but also land connections, like the Trans-Siberian Railroad (Verny and Grigentin 2009; Moon et al. 2015).

1.2 Key concepts

1.2.1 The Arctic

The Arctic is an abstract concept with multiple definitions grounded on various geographical, physical, ecological and contractual criteria (Figure 2). A common definition, also used henceforth in this thesis, refers to the Arctic as the area above the Arctic Circle at 66 degrees 32 minutes North (Arctic Council 2009).

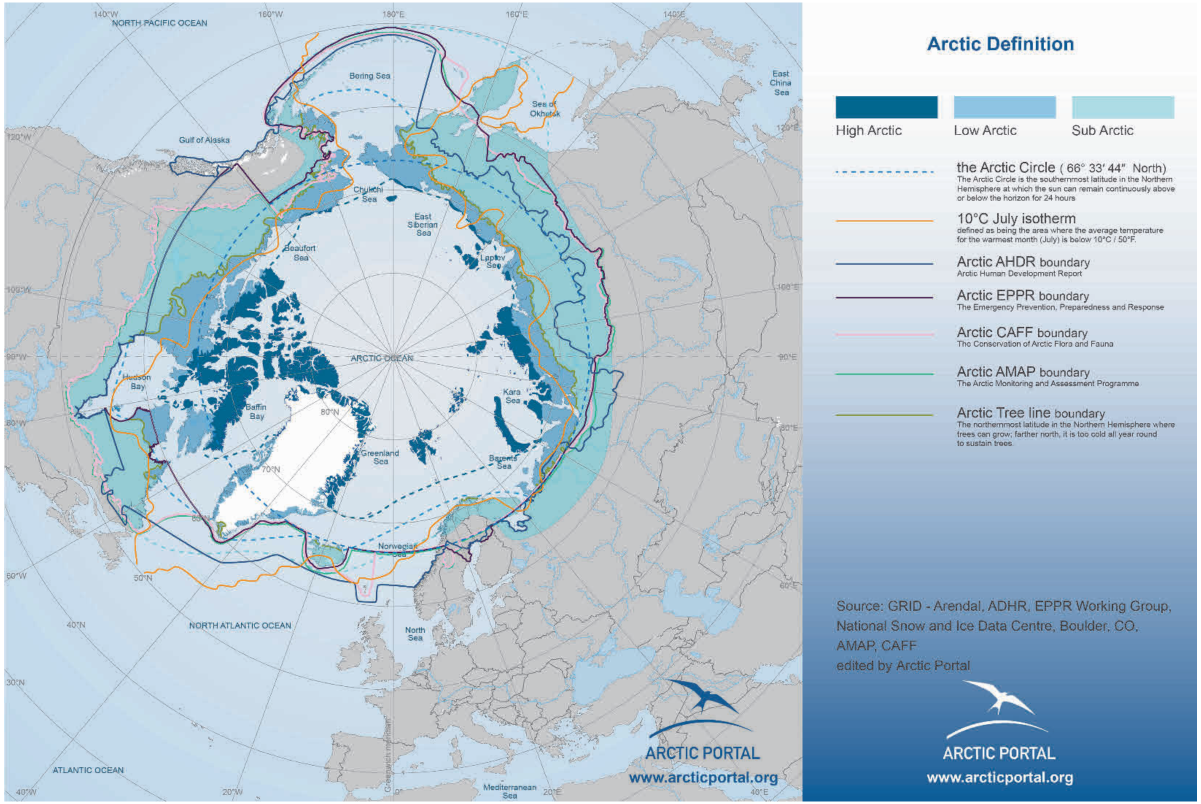

Figure 2 The main Arctic definitions (Arctic Portal 2015 reproduced with permission)

1.2.2 Arctic shipping

Arctic shipping can be defined through multiple criteria. The most commonly used is linked to the definition by the International Maritime Organization (IMO 2010a), which delineates Arctic waters based on sea-ice concentrations posing structural risks to ships (Figure 3).

Figure 3 The IMO Arctic waters definition (IMO 2010a)

Unless otherwise stated, Arctic shipping in this thesis refers hereafter to all types of shipping activity within the Arctic waters as defined by the IMO.

1.2.3 The Northern Sea Route and the Northeast Passage

The Northern Sea Route (NSR) and the Northeast Passage (NEP) are two concepts that are often mixed in extant literature. The "Northern Sea Route" is derived directly from the Russian "Severnyi Morskoi Put", while the NEP has a historic origin as the fabled goal of ancient navigators on quests to find a passage between the Atlantic and the Pacific Oceans. The NSR refers to the water area in the Russian territorial waters between the Novaya Zemlya and Bering Strait defined by Russian law (Russian Federation 2012). The Northeast Passage (NEP), in turn, denotes shipping activity from the Atlantic Ocean to the Pacific Ocean, of which the NSR is an integral part (Figure 4). Hereafter in this thesis, the NEP is incorporated into the concept of the NSR.

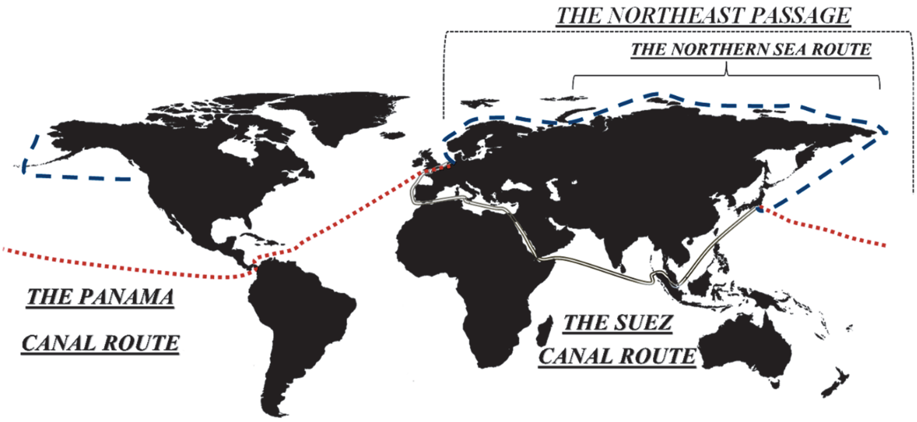

Figure 4 Visualization of the Northern Sea Route, the Northeast Passage and the Suez and the Panama Canal routes

1.2.4 The Suez Canal and the Panama Canal routes

Two of the World's principal maritime routes follow the Equator passing through either the Suez Canal or the Panama Canal. The Suez Canal is an artificial waterway through the Isthmus of Suez, a link between the Mediterranean and the Red Sea, enabling a shortcut between the Atlantic and the Indian Oceans. The Panama Canal is similarly an artificial passage through the Isthmus of Panama, connecting the Atlantic and the Pacific Oceans (Figure 4).

1.2.5 The Northwest Passage and the Transpolar Passage

The Northwest Passage (NWP) encompasses the coast of the North American Arctic region from the Atlantic to the Pacific through the archipelago of the Canadian Arctic, allowing seven different routing options (Pharand 2007). The Transpolar Passage (TPP) spans the Arctic Sea through the North Pole and offers the shortest path across the Arctic Sea (Humpert and Raspotnik 2012). Figure 5 presents these routes.

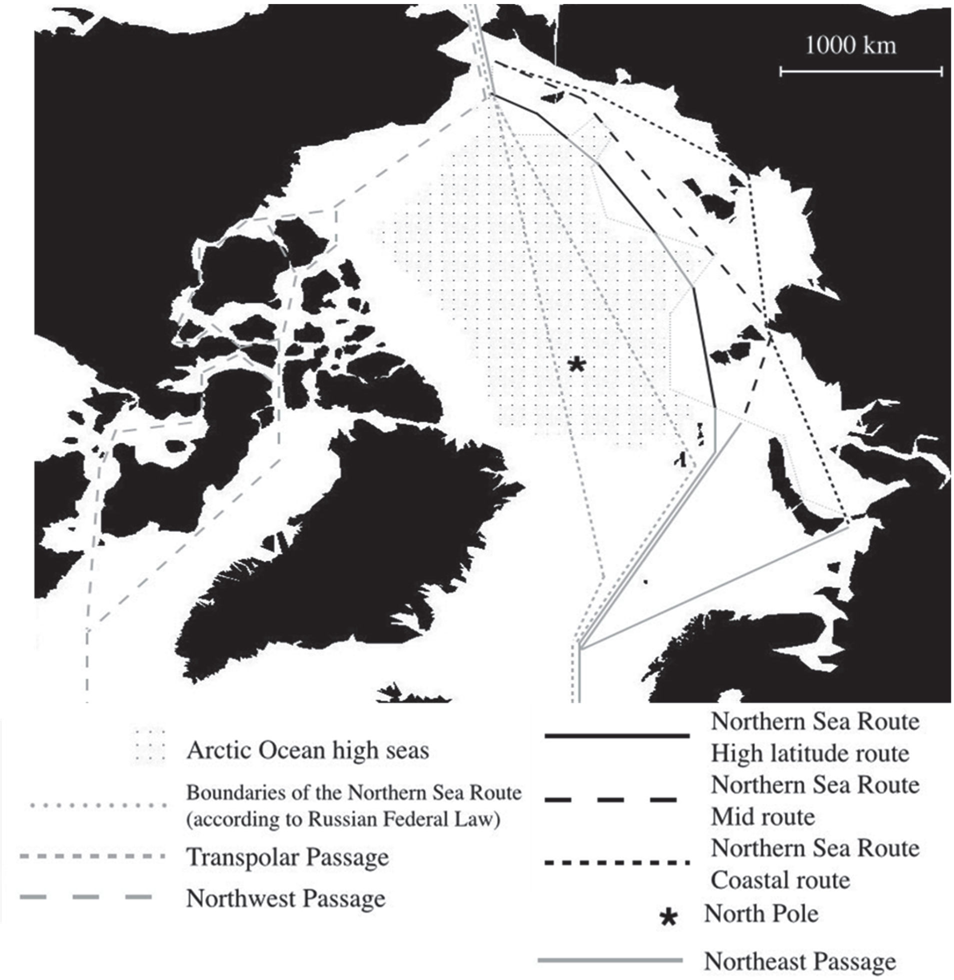

Figure 5 The Arctic Sea routes: the Northern Sea Route, the Northwest Passage and the Transpolar Passage

1.2.6 The concept of feasibility

In research literature, the concept of feasibility is elusive, discourse-dependent and lacks a systematic definition (Graaskamp 1972; Gilabert and Lawford-Smith 2012). It may also be used with various prefixes relating to political, economic and social contexts. The simplest approach accounts just for cost and value in terms of determining the economic feasibility (Young 1970).

Graaskamp (1972, 515) defines the feasibility as an indicator of

> *"… a reasonable likelihood of satisfying explicit objectives when a selected course of action is tested for fit to a context of specific constraints and limited resources".*

According to Gilabert and Lawford-Smith (2012), feasibility has two primary functions: 1) it rules out proposals that cannot be executed in practice; 2) it enables comparative evaluations of various proposals.

Majone (1975, 50) argues that feasibility is a realistic aim for policy analysis. It should be defined in terms of the relevant social, political, administrative, institutional, technical and economic constraints.

A similarly elusive concept is viability, which has connotations for ecology in determining whether the survival rate of population over a certain period of time exceeds losses (Baumgärtner and Quaas 2009). In economics discourse, viability is usually used to describe the actions or endeavors that continuously generate cashflows that exceed threshold values (Lin 2003), while profitability is an accounting term reflecting the balance of realized costs and revenues over a fiscal year.

In this thesis, the concept of feasibility refers to reasoning whether commercial cargo shipping along the NSR would be a sound decision for a ship owner when taking into account the key underlying constraints (Figure 6). Here, these macro-level key constraints are denoted with the suffix "viability" in accordance with the PESTEL framework pertaining to "Political", "Economic", "Social", "Environmental" and "Legal" issues (See Chapter 3).

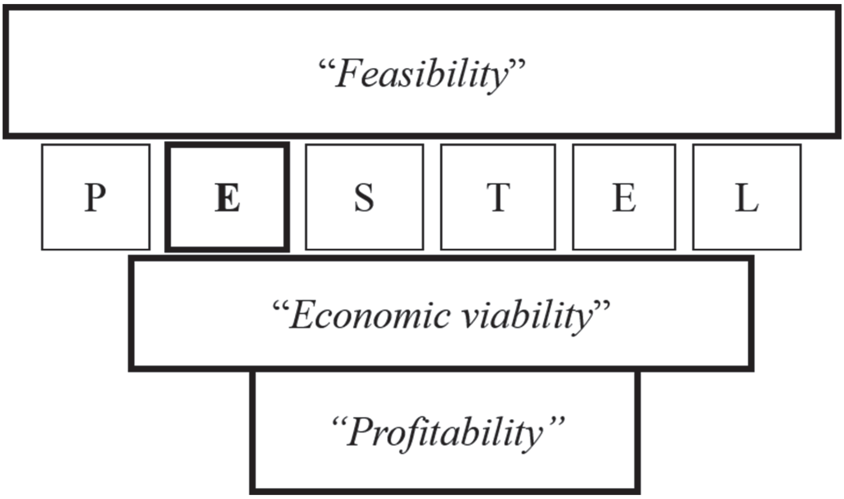

Figure 6 Key concepts and the PESTEL framework

In this respect, the thesis analyzes the economic viability of commercial cargo shipping along the NSR, which is assessed partly from an industry level (meso-level) perspective. In the more detailed (micro-level) treatment, the profitability of a ship owner operating in the NSR is assessed through operational cashflow stemming from estimated yet realistic revenues and costs.

1.2.7 Navigational season

Previous studies have defined the NSR navigational season as the number of days per year with a defined threshold of ice-cover, ranging usually from lower than 15 per cent up to 50 per cent (ACIA 2004; Khon et al. 2010; Lei et al. 2014). In this thesis a more pragmatic approach is adopted, referring to the aggregated annual period of ice-free and icebreaker assisted activity along the NSR.

1.2.8 Maritime infrastructure

The concept of maritime infrastructure in this thesis accords with the Arctic Council (2009, 157) definition, and refers to the following:

> *"… all major aspects of marine shipping, including vessels and crews, the systems needed to gather and supply accurate and timely information for safe navigation and operations, the personnel and resources needed to respond to a variety of potential emergencies, port reception facilities for ship-generated waste and the shoreside facilities needed to provide supplies and logistics in support of marine shipping and emergency response".*

1.3 Literature review

Studying the feasibility of Arctic shipping is not a new research field. During the past two decades several international research endeavors have focused on the issue, especially the NSR (Table 1). The topic gained popularity well ahead of the current climate change inspired discussion. Soon after the demise of the Soviet Union and the subsequent opening of the NSR, the first international research project saw daylight.

Between 1993 and 1999, the International Northern Sea Route Program (INSROP), a pioneering multidisciplinary research project focusing on the commercial shipping aspects, was conducted (Brubaker and Ragner 2010). INSROP's results, among others, concluded that operations with purpose-built NSR vessels could not be economically viable relative to the Suez Canal route (e.g. Ragner

2000b). This was largely attributable to the then contemporary navigational conditions, which set the building cost of a specialized fleet so high that any economic gains were lost.

Table 1 International research programmes dedicated to Arctic shipping (Lasserre 2014)

Research program	Time period	Focal area(s)	Funder(s)
INSROP – International Northern Sea Route Program	1993–1999	Economics of the Northern Sea Route	Japan, Norway and Russia
Ice Routes – The Application of Advanced Technologies to the Routing of Ships through Sea Ice	1997–1998	Barents and Kara Seas, Baltic Sea and Greenland waters	EU
ARCDEV – Arctic Demonstration and Exploratory Voyages	1997–1999	Western Russian Arctic seas	EU
ARCOP – Arctic Operational Platform	2002–2006	Northern Sea Route	EU
Northern Maritime Corridor	2002–2005	North, Barents and Kara Seas	EU, Norway and Russia
JANSROP (Japan Northern Sea Route Program)	2002–2005	Northern Sea Route	Japan
Canadian Arctic Shipping Assessment	2006–2008	Canadian Arctic waters	Canada
Arctic Marine Shipping Assessment	2006–2008	Arctic	Arctic Council

INSROP set the expectations for the future research, while simultaneously establishing the NSR as a valid subject for wider academic interests. A stream of studies, focusing extensively on the region, subsequently followed due to the increasing awareness of the impacts of climate change.

1.3.1 Economic viability

A comprehensive literature review was conducted in order to investigate the findings in extant literature pertaining to the economic viability of the Arctic shipping. The review included digital library search which was followed by backward snowballing that refers to a process of iterative tracing of the references of the initial findings (e.g. Spanos and Angelis 2016). A sample of 44 studies, published during the 16-year period of 1999–2015, was analysed[1]. The selection criteria for the studies were that they contained either their own or a replicated economic viability analysis focusing on some of the Arctic Sea routes (Table 2). The sample is not exhaustive because some historic and North American studies were not at the author's disposal.

At first glance, the subject seems especially topical as 70 per cent of the studies were made during the 2010–2015 period. The mediums of the publications consisted of 20 peer-reviewed academic journal papers and conference proceedings (45 per cent), two Master's thesis (5 per cent), seven book chapters (16 per cent), and the remainder were 15 miscellaneous industry publications (34 per cent).

In line with the overall perception of the Arctic Sea route potential (e.g. Østreng et al. 2013), the NSR appears the most widely studied of the Arctic Sea routes, with a share of 82 per cent. The NWP accounts for 14 per cent and the TPP only 4 per cent. The distribution of the studies may also be seen as reflecting the level of present-day activity as well as the predicted developments in climate change (e.g. Stephenson et al. 2013).

In a shipping mode comparison, container shipping is by far the most common subject (64 per cent), which is followed by bulk shipping (23 per cent) and general cargo (7 per cent). LNG and Pure Car Carriers (PCC) have the lowest shares accounting for 4 per cent and 2 per cent, respectively.

The focus of the analysed papers is mostly concentrated on seasonal Arctic activity (73 per cent) while year-round operations are investigated by 27 per cent of the studies. This is consistent with the expected seasonal nature of shipping activity within this century (e.g. Guy and Lasserre 2016). The physical constraints of the routes (e.g. Ragner 2000b) have arguably been accounted for in terms of the smaller vessel sizes applied in the models: containerships have around 5,000 TEU; PCCs 6,500 CEU; and the remainders 78,000 DWT, including bulkers, general cargo ships and LNG-carriers.

The division of the ice-classes of the vessels used in the models follows a twofold pattern: roughly half conform to the requirements equivalent to Baltic Sea conditions and the rest apply purely Arctic dedicated ice-classes. This may be attributable to the different intended operational periods of the vessels: year-round or seasonal. The time perspective of the studies is concentrated on the present-day as 70 per cent are explicitly or implicitly positioned in the current period, while the rest (30 per cent) address an undisclosed period in the future.

The conclusions of the studies are notably diverse given that the share of economic viability findings account for around two thirds of the studies (61 per cent), while roughly one third (34 per cent) rules out the economic viability proposition

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[1] One research/publication may account for several studies depending on the chosen methodology. For example, a book chapter by Wergeland (2013) investigated the economic viability of the NSR, the NWP and the TPP for general cargo and containerships, thus comprising six studies in total.

(Table 3). In addition, two studies (5 per cent) did not explicitly express their conclusions but focused on analysing the sensitivities of the parameters (Lu et al. 2014; Hua and Dong 2014).

In a more detailed analysis per shipping mode, the findings with respect to container shipping were ambivalent as 54 per cent of the studies found economic viability, while 39 per cent found the opposite; the remaining 7 per cent did not comment one way or another. Similarly, bulk shipping was deemed economically viable in 60 per cent of the studies while 40 per cent did not see it as viable. However, several authors could identify marginal profits but did not find them sufficient to provide a viable business case relative to the principal canal routes (e.g. Pruyn 2016). These remarks are consistent with the findings of an earlier literature review by Lasserre (2014).

All three general cargo shipping studies found economic viability (Wergeland 2013). However, since the basis of the studies was a single book chapter, the finding should be considered with caution. The same argument may also be applicable to LNG-carriers and PCCs given that the former were found economically viable by just two studies and the latter by only one study.

The parameters included in the models vary considerably. Not surprisingly, the bunker costs and sailing speeds were used in all of the studies. A total of 20 studies (45 per cent) considered bunker costs as a key profitability factor (e.g. Liu and Kronbak 2010). This finding corresponds with the overall significance of bunker costs in shipping (e.g. Notteboom and Vernimmen 2009). A derivative of bunker costs in terms of vessel fuel consumption, i.e. sailing speeds, was considered instrumental by six studies (e.g. Way et al. 2015).

A total of ten studies, mostly concerned with time-chartered bulk vessels, used freight rates in their models, and the majority of them (six studies) viewed their levels as an important factor for economic viability (e.g. Cariou and Faury 2015). Insurance costs and icebreaking fees were adopted in most of the studies (89 per cent). In both accounts, a considerable variation on the actual parameter values was detected.

The competitors' actions, namely the pricing of the Suez Canal was considered by 77 per cent of the publications, but none of them considered it critical to the economic viability of the NSR. The capital costs, which are the costs of the amortization of a vessel's building expenses, were explicitly accounted for in 70 per cent of the studies. In this regard, some included the extra ice-class building cost premiums (e.g. Liu and Kronbak 2010) while others excluded them (e.g. Xu et al. 2011). Surprisingly, only 55 per cent explicitly mentioned the impact of climate conditions on economic viability. That may be partly attributable to the built-in assumptions of the models with respect to the thawing of the Arctic Sea.

To sum up, the different methodological approaches adopted in the studies were arguably the primary reason for the variety of conclusions. In this respect, the differences largely arise from how the NSR distance advantage is expected to deliver savings. Most of the studies seem to assume that the NSR distance advantage at given speeds is directly equivalent to savings in costs and time. This unidirectional approach (e.g. Falck 2012; Chang et al. 2015) seems to provide compelling results favouring the NSR relative to the SCR. However, it fails to include issues related to ambient conditions. For example, a smooth sailing presumption removes delays from the models (e.g. Pruyn (2016), which appears a disingenuous assumption given the previous experiences of NSR sailings (e.g. Lee and Kim 2015). In addition, vessel fuel economy is likely to be impaired owing to the use of a specialized fleet and the impact of ice (Lasserre 2014).

Table 2 The methodological choices of studies[2] on the economic viability of Arctic shipping

		#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Author			Sørstrand 2012	Omre 2012	Furuichi and Otsuka 2013	Furuichi and Otsuka 2014	Furuichi and Otsuka 2015	Verny and Grigentin 2009	Way et al. 2015	Liu and Kronbak 2010	Lasserre 2014	Cho 2012	Wergeland 2013	Xu et al. 2011	Eide et al. 2010	Niini et al. 2006	Kamesaki et al. 1999	Kamesaki et al. 1999	PWC 2009	Niini et al. 2006	Hua and Dong 2014	PWC 2009	Eide et al. 2010	Khon et al. 2010
Arctic Sea route		NSR/NEP	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		NWP																						
		TPP																						
Mode of shipping		Container	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		LNG																						
		Bulk																						
		General cargo																						
		Cars																						
Operation period		Seasonal	X	X	X	X	X	X	X	X	X	X	X	X	X									
		Year-round														X	X	X	X	X	X	X	X	X
Ship parameters	**Size (1000)**	DWT															25	40						
		TEU	3.8		4.0				4.3		4.5	8.5	4.3	10.0	6.5	0.75	1.4	1.7	5.0		10.0	12.0	5.0	n.a.
		CEU																						
	Ice -class		IC– IAS		IA	n/a	IA	n/a	IB		IAS	n/a		no	PC4	DAS+LU7	DAS+IAS		DAS	DAS+LU9	n/a	DAS		n/a
Period of analysis		Present	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X		
		by 2030													X								X	
		by 2050													X								X	
		undisclosed											X	X										X

		#	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Author			Cariou and Faury 2015	Schøyen and Bråthen 2011	Falck 2012	von Bock und Polach et al. 2014	Cho 2012	Chang et al. 2015	Kamesaki et al. 1999	Pruyn 2016	Juurmaa 2006	Juurmaa 2006	Raza and Schøyen 2014	Falck 2012	Wergeland 2013	Furuichi and Otsuka 2014	Griffiths 2005	Wergeland 2013	Somanathan et al. 2009	Somanathan et al. 2007	Lu et al. 2014	Wergeland 2013	Wergeland 2013	Wergeland 2013
Arctic Sea route		NSR/NEP	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
		NWP															X	X	X	X	X	X		
		TPP																					X	X
Mode of shipping		Container															X	X	X	X	X		X	
		LNG											X	X										
		Bulk	X	X	X	X	X	X	X	X	X	X												
		General cargo													X							X		X
		Cars														X								
Operation period		Seasonal	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
		Year-round								X	X	X												
Ship parameters	**Size (1000)**	DWT	40		75	90	320		50		60–120		85		12.7							12.7		12.7
		TEU															2.4	4.3	4.5		4.5 – 15		4.3	
		CEU														6.5								
	Ice -class		IA			ARC4/5+DAT	n/a	n/a	IAS	IA/IAS	DAT	no	IA		n/a		no	n/a	CAC3		n/a			
Period of analysis		Present	X	X	X	X	X	X	X		X	X	X	X		X			X	X				
		by 2030																						
		by 2050																						
		undisclosed								X					X		X	X			X	X	X	X

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[2] One research/publication may account for several studies depending on the chosen methodology. For example, a book chapter by Wergeland (2013) investigated the economic viability of the NSR, the NWP and the TPP for general cargo and containerships, thus comprising six studies in total.

Table 3 A compilation of the conclusions and arguments in extant research literature regarding the economic viability of Arctic shipping (O= excluded from the analysis; X=included in the analysis; I= identified as a key factor; blank = not explicitly mentioned)

		#	28	34	25	1	2	10	27	24	39	40	5	36	4	3	11	35	19	22	31	32	41	38	42	43	44	12	13	18	33	23	26	30	7	9	21	8	6	17	20	14	29	15	#	37
		Author	Chang et al. 2015	Falck 2012	Falck 2012	Sørstrand 2012	Omre 2012	Cho 2012	Cho 2012	Schøyen and Bråthen 2011	Somanathan et al. 2009	Somanathan et al. 2007	Furuichi and Otsuka 2015	Furuichi and Otsuka 2014	Furuichi and Otsuka 2014	Furuichi and Otsuka 2013	Wergeland 2013	Wergeland 2013	Hua and Dong 2014	Khon et al. 2010	Juurmaa 2006	Juurmaa 2006	Lu et al. 2014	Wergeland 2013	Wergeland 2013	Wergeland 2013	Wergeland 2013	Xu et al. 2011	Eide et al. 2010	Niini et al. 2006	Raza and Schøyen 2014	Cariou and Faury 2015	von Bock und Polach et al. 2014	Pruyn 2016	Way et al. 2015	Lasserre 2014	Eide et al. 2010	Liu and Kronbak 2010	Verny and Crigentin 2009	PWC 2009	PWC 2009	Niini et al. 2006	Kamesaki et al. 1999	Kamesaki et al. 1999	Kamesaki et al. 1999	Griffiths 2005
Arctic Sea routes found economically viable		Yes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	?	X	X	X	?	X	X	X	X	X	X	X	X															
		No																														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Shipping mode			B	LNG	B	C	C	C	B	B	C	C	C	PCC	C	C	C	GC	C	C	B	B	C	C	GC	C	GC	C	C	C	LNG	B	B	B	C	C	C	C	C	C	C	C	B	C	C	C
Profitability factors	**Market-based**	Bunker cost	X	I	I	I	X	I	I	X	X	X	I	I	I	I	I	I	X	X	X	X	X	I	I	I	I	I	X	I	X	X	I	X	X	X	X	I	X	X	X	I	X	X	X	X
		Icebreaking fees	X	X	X	X	X			X			X	X	X	X	O	O	X	X	X	X	I	O	O	O	O	O	O	O	X	X	X	X	X	X	O	I	I	O	O	X	X	X	X	
		Freight rates	I	I	I					I										X			X								I	I		X				X								
		Insurance cost	O	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
		Load factors				X	X					X	X	X			X							X		X				X					X	X		X	X			X				
		Capital cost				X	X				X	X	X	X	X	X			X	X	X	X					X	O	X	X		X	X	X	X	X	X	X	X	I	I	X	I	I	I	X
		Competitor actions		X	X	X	X			X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X			X	X	X	X	X	X	X		X	X	X	X
		Sailing speed	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	I	X	X	X	X	X	X	X	X	X	X	X	X	I	I	I	I	I	X	X	X	X	X	X	X	X	X	X
	Environmental	Ship emissions				X	X	X	X	X			X	X	X	X	O	O						O	O	O	O		X			X					X									
	Climatic conditions		X			I	I				X	X	X	X	X	X			X	I								I	X	X			X	X		X	I	X				X	X	X	X	X
	Technology					X													X											I			X									I	I	I	I	
	Distance		I							X	I	I																	X							X	X									
	Delays																																	I				X								

1.3.2 *Maritime infrastructure and related services*

A total of 16 studies, published between 1998 and 2015, were investigated in order to compile their insights on the infrastructural constraints of the NSR (Table 4). The majority of them (14) were published in peer-reviewed academic journals or equivalent policy papers. The availability of both icebreakers and ice-classed ships was the most frequently cited (81 per cent) critical issue. The inadequate port infrastructure was second place on 63 per cent, followed by Search and Rescue (SAR) and Administrational deficits accounting for 56 per cent. Infrastructural issues relating to the navigational aids and crews were considered the least critical with shares of 44 and 31 per cent, respectively.

Table 4 A compilation of the infrastructural constraints of the NSR in extant literature in chronological order

Author		Granberg 1998	Ragner 2000a; 2000b	Arctic Council 2009	Ho 2010	Moe and Jensen 2010	Lasserre and Pelletier 2011	Erikstad and Ehlers 2012	Sakhuja 2013	Sakhuja 2014	Klimenko 2014	Moe 2014	Buixadé Farré et al. 2014	Marken et al. 2015	Lee and Kim 2015	Hill et al. 2015
Infrastructural constraints	Icebreakers	X	X	X	X	X		X			X	X	X	X	X	X
	Ports	X		X		X	X	X	X		X		X		X	X
	Search & Rescue			X	X	X		X	X	X			X	X		X
	Ice-class fleet	X	X	X	X	X	X	X	X	X		X			X	X
	Navigational aids			X	X	X			X	X			X			X
	Administration		X	X	X	X	X	X				X			X	
	Crews			X	X				X	X					X	

The body of literature calls for investments in the NSR's infrastructure before large-scale activity along it can commence (e.g. Ho 2010). The existing infrastructure descends largely from the Soviet era, and thus has a limited capacity. Granberg (1998) estimated that the infrastructure could accommodate only 2–3 million tonnes of additional volumes.

In the main, there is a clear interdependency between the economic viability of the NSR and its infrastructure. A critical mass is needed in order for the NSR to establish an adequate infrastructure and to sustain it at a sufficiently high level. It has been estimated that at least 40 million tonnes of cargo is needed annually to finance the services, while simultaneously maintaining commercial attractiveness

(AMSA 2009, 117). Additionally, Moe and Jensen (2010) argue that the infrastructural problems translate directly into higher operational costs, namely insurance, thus reducing the economic viability of the NSR.

1.3.3 Market potential

The sparsely populated and practically non-industrialised Russian Arctic seemingly offers little potential to produce or absorb containerized cargo or to import large volumes of bulk cargo. Intuitively, the transport potential of the NSR could emerge from either exporting the bulk cargoes related to natural resources or by providing shortcuts for the transcontinental shipping.

The NSR has attracted several estimates with regards to its cargo potential. Table 5 shows a total of 20 estimates[3], published between the years 1994–2015, indicating the market potential of the NSR according to various traffic types. Almost half of the estimates are published in peer-reviewed academic journals or other outlets, the remainders being mainly articles published in the mass media.

The range of the estimates varies considerably as does the time perspective. Three of the estimates are focused on the year 2020, while the majority concentrates on 2030 and a few on 2050. This may signal that most of the studies use established climate scenarios, often ending by 2030, as the basis for their estimates. Half of the estimates focus on transit traffic, while about a third concern destinational traffic. Only two accounts focus on internal traffic whereas the remainders analyse an undisclosed traffic category. The distribution of the estimates is in line with the body of literature focusing on the economic viability of container shipping, which can be categorized as transit traffic. On the other hand, the lower number of estimates relative to the economic viability analysis (See Chapter 1.3.1) suggests an inferior market interest and therefore a limited potential.

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[3] One research/publication may account for several studies depending on its contents. For example, an industry publication by Eide et al. (2010) provided estimates for both transit and destinational traffic in two different timeframes, thus comprising four studies in total.

Table 5 Estimates of the Northern Sea Route's cargo potential in million tonnes (MT) or million TEUs (MTEU) in extant literature

	Traffic type					**Annual volume of traffic**				
Author	Transit	Destinational	Internal	Unspecified	**Time period by**	Containers (MTEU)	Bulk (MT)	Cars (MT)	Unspecified (MT)	**Estimate description**
Chinese estimate after Doyle 2013 *)	X				2020	8–24				5–15 % of China's foreign trade
Peters et al. 2011	X				2030	1.4				8 % of the projected Europe-Asia trade
Russian Ministry of Transport 2015 after Barents Observer 2015	X				2030				5	
Eide et al. 2010	X				2030	3.9				
Peters et al. 2011	X				2050	2.5				10 % of the projected Europe-Asia trade
Eide et al. 2010	X				2050	5.6				
Tavasszy et al. 2011	X				n.a.	3.3				1.5 % of the global containerized trade
Furuichi and Otsuka 2014 **)	X				n.a.			2.5		2.5 million automobiles
Laulajainen 2009 ***)	X				n.a.	7.9	30			1 % of global bulk and 20–25 % of containerized trade
Arpiainen 1994	X				n.a.	0.2	4–5	1–2		
Ruksha 2014		X			2020		26			16.7 MT LNG; 8 MT oil; 1.3 MT nickel and supplies
Arctic Council 2009		X			2020		40			Oil and gas from the Western NSR
Laulajainen 2009		X			2030		55–60			Coal, pulp wood, oil and gas
Eide et al. 2010		X			2030		87			Oil and gas
Gunnarson 2016		X			2030		104			34.1 MT LNG; 60.8 MT oil; 1.3 MT non-ferrous metals and coal 5–10 MT
Eide et al. 2010		X			2050		199			Oil and gas
Russian Ministry of Transport 2015 after Barents Observer 2015		X	X		2030		83			Ore concentrate, supplies for industrial projects, oil and gas
Laulajainen 2009			X		2030				5–10	
Bekkers et al. 2015 ****)				X	2030				551	2/3 of Suez Canal volumes
Stamatopoulou and Psaraftis 2013 ****)				X	n.a.				50.1	6 % of Suez Canal volumes

*) In 2013, value of China's foreign trade was around 3,159 billion USD (WTO 2014), postulated value per TEU USD 20,000
**) Average car weight one tonne
***) Includes all Arctic Sea routes in ice-free conditions. Container volume is calculated by using 14 tonne nominal TEU weight.
****) Suez Canal cargo volume 835 MT in 2014 (SCA 2015)

The high magnitude of the destinational traffic estimates (between 40 and 199 million tonnes), consisting mostly of bulk shipping, supports the dominant perception that regards it as the category with the highest potential in the foreseeable future (e.g. Buixadé Farré et al. 2014; Lasserre 2014). In this respect, the oil and gas, cited by every destinational traffic estimate have arguably the highest potential. To some degree, the remoteness of the NSR might be beneficial for certain cargo types, for example, transporting nuclear waste materials (Sawhill and Ragner 2002).

When comparing the estimates to the actual figures of the global seaborne trade, it may be concluded that the transit traffic potential accounts for around 23 per cent of the 2014 Europe–Asia container trade on average. If the extremely high estimates of Doyle (2013) and Laulajainen (2009) are excluded, the figure is 13 per cent, which seems more reasonable in light of the reported lack of shipping industry interest (Lasserre and Pelletier 2011). Similarly, the scale of the destinational traffic potential relative to the Suez Canal averages from 9 to 14 per cent depending on the estimates, namely whether the figures of Bekkers et al. (2015) or Stamatopoulou and Psaraftis (2013) are included.

The methodologies behind the estimates differ substantially. Some, perhaps more politically oriented, are based on production capacities of the proposed energy projects (e.g. Barents Observer 2015; Gunnarson 2016), while others derive their figures directly from actual trade indicators like GDP growth (e.g. Corbett et al. 2010) or seaborne trade (e.g. Laulajainen 2009). To some extent, more sophisticated methods have been employed: strategic network choice models (Tavasszy et al. 2011), multinomial logit function (Stamatopoulou and Psaraftis 2013) or gravitation models (Bekkers et al. 2015).

The proposed market potential of the NSR, if ever materialized, could impact on the Europe–Asia shipping network up to the Malacca Straits (Abdul Rahman et al. 2014). Button et al. (2015) concluded that the NSR may decrease the attractiveness of the Southern Adriatic ports up to 9 per cent.

1.4 Research objective and questions

Despite the large number of studies that analyse the feasibility of the NSR from different positions, there is far from being conclusive understanding of it. Although the majority of studies on the NSR indicate economic viability (e.g. Furuichi and Otsuka 2015), the current practical level activity along the NSR is marginal (e.g. NSRIO 2016a) and ship owner's interest modest (Lasserre and Pelletier 2011). To add to the confusion, the media and various pundits have continuously created images of substantial economic gains and a rapid growth in Arctic Sea voyages (see e.g. Ibisonin 2007; Borgerson 2008, 2013).

The divergent opinions may be attributed to a number of factors. The political agendas connected with security, economic and power-related motives may have implicitly contributed to building a vision for the popular imagination. For example, the diversified market potential estimates indicate the presence of political-level aspirations and strategies (see for example Doyle 2013). Next to that, an ambiguous terminology is a commonplace in the discourse of the Arctic. Especially relevant is the notion of “ice-free”, which tends to be interpreted differently. According to Lindstad et al. (2016) ice-free refers to absence of continuous sea ice cover, but part of the voyage will still go through the areas with broken ice cover of varying density which may require strengthened hulls and icebreaker assistance to ensure a safe passage. This approach differs considerably from the layman’s point of view, where ice-free actually means open-water conditions (see also IMO 2016).

The models in extant literature used to analyse the economic viability of the NSR employ various methodologies and assumptions (e.g. Lasserre 2014). From the methodological point of view, analyzing the economic viability of the NSR in conditions where ice does not exist is a fairly simple procedure. In this approach the distance advantage related to economic gains dominate, resulting in extremely compelling outcomes. In contrast, adding an ice variable complicates the calculations, influencing, among other things, on vessel economies and transit times.

The rigid cost comparisons may provide knowledge about the NSR’s relative cost competitiveness, but miss the revenue dynamics. On top of that, the evaluation of the actual costs is complicated as the data is scattered and largely based on industry estimates (e.g. Pruyn 2016). Uncertainty makes the analysis even more complex, which is exacerbated in the Arctic where macroeconomic factors influence development (e.g. Arbo et al. 2013).

In order to tackle the aforementioned uncertainties and complexity, this thesis aims to increase knowledge by bridging the gap between the perceived and the realistic feasibility of the NSR. The research strives to produce a fact-based and unbiased view on the relevant factors affecting maritime development in the NSR. A call for valid knowledge on the NSR is imminent, as noted by Marken et al. (2015), because the lack of information constitutes a key constraint when ship owners want to consider using it. The motivation of this study is to build a novel holistic understanding of the feasibility of commercial cargo shipping; mainly from the point-of-view of ship owners.

The main research question (MRQ) of the thesis is formulated as follows:

MRQ: Could commercial cargo shipping along the NSR become feasible?

In order to answer to the main research question, the research problem has been divided into three interrelated research sub-questions (RQ1 through RQ3) under three respective themes pertaining to the NSR: 1) Economic viability; 2) Maritime infrastructure and related services; and 3) Market potential.

RQ1) Theme: The economic viability of the NSR

The economic viability of commercial cargo shipping along the NSR has been suggested as being dependent on the mode of shipping (e.g. Schøyen and Bråthen 2011; Lasserre 2014). Hence, the first sub-question focuses on the economics of the main shipping sectors, such as containerships, car carriers, dry bulkers and tankers. The research sub-question RQ1 is formulated as follows:

RQ1: How does the cost of shipping along the NSR relate to shipping markets?

RQ2) Theme: Maritime infrastructure and related services along the NSR

It is argued that the level of the NSR maritime infrastructure and the related services will not only create the preconditions for activity but influence the economic viability of commercial cargo shipping (e.g. Ragner 2000b; Moe and Jensen 2010). The second sub-question assesses the present and future NSR maritime transport infrastructure capacity and its determinants. Research sub-question RQ2 is:

RQ2: What are the main infrastructural constraints and the theoretical throughput capacity of the NSR?

RQ3) Theme: Market potential of the NSR

The estimates of the NSR's market potential show notable variation in extant literature (e.g. Laulajainen 2009; Tavasszy et al. 2011). The third sub-question evaluates the scope and scale of the NSR's market potential. Research sub-question RQ3 is:

RQ3: What is the level of the market potential for commercial cargo shipping along the NSR?

The "market potential" in RQ3 refers mainly to the volume of cargo and, to a lesser extent, to the number of ship passages in timeframes that extend to year 2030 and 2050.

Figure 7 shows how the research questions relate to the key concepts (feasibility, economic viability and profitability), the PESTEL framework and the levels of analysis (macro, meso, micro).

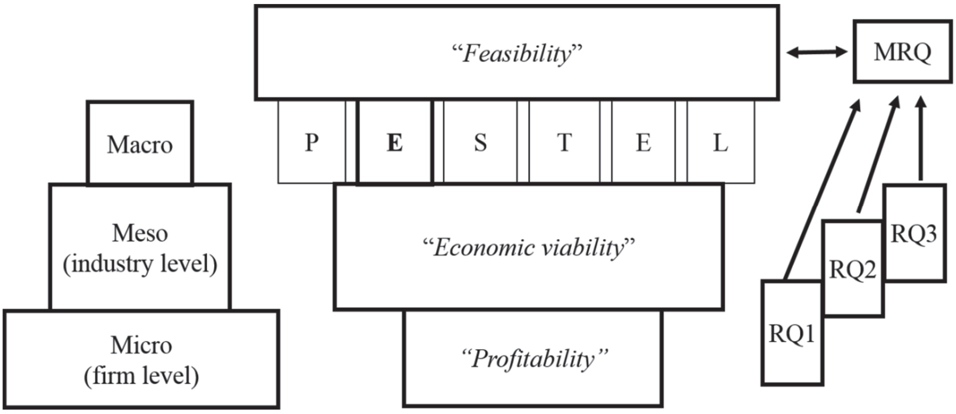


Figure 7 The conceptualization of the connections and the hierarchy between the key concepts, the levels of analysis and the research questions

With respect to the specific definitions of the key concepts and their connections to the research setting, see Chapter 1.2.6. This thesis uses the Economic dimension of the PESTEL framework (highlighted in the Figure 7) as the main lens for approaching the meso-level research questions that refer to the industry and/or market perspective. At the bottom of the figure is the micro-level that refers to the individual ship and/or firm level analysis.

1.5 Research scope and focus

The scope of the thesis is confined to commercial cargo shipping along the NSR up to the year 2050. The analysis is geographically limited to the shipping activities taking place within the boundaries of the NSR as defined by the Russian law – the water areas between the Novaya Zemlya in the West and the Bering Strait in the East (Russian Federation 2012). In this thesis, the strict definition of the NSR is extended to also include the adjoining waterways towards the Atlantic and Pacific Oceans in order to assure conformity with international shipping.

The NSR is part of a larger thematic concept, Arctic shipping, which is used to describe the activity that also includes other Arctic Sea routes. In this respect, the maritime activity within the Northern Hemisphere along the principal canal routes (primarily the Suez Canal and to some extent the Panama Canal) is used as a point of reference.

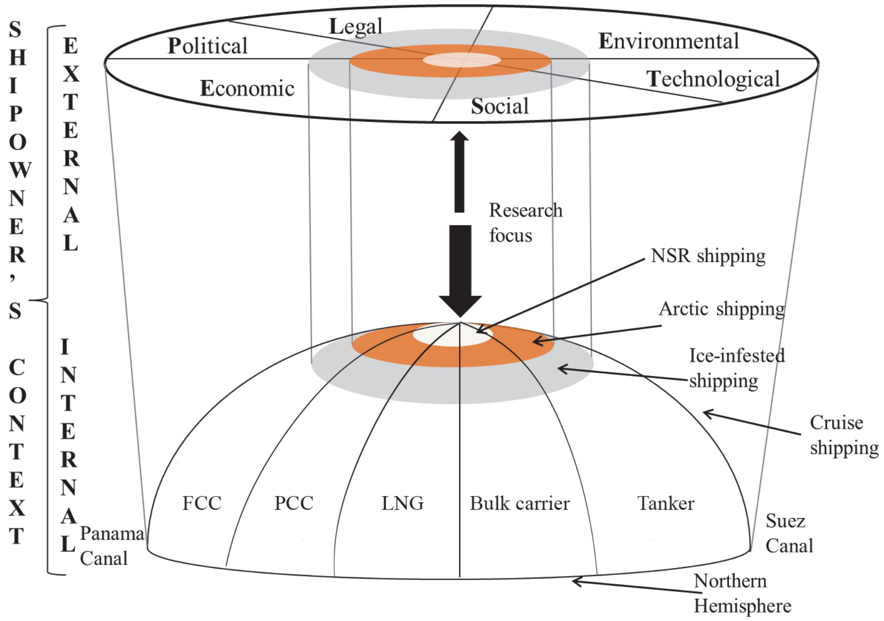


Figure 8 The scope and focus of the research (FCC= Fully Cellular Containership, PCC= Pure Car Carrier, LNG = Liquefied Natural Gas carrier)

There are several rationales grounded on extant literature that support the chosen approach for studying the NSR (see e.g. Bird et al. 2008; Arctic Council 2009; Østreng et al. 2013; Stephenson et al. 2013; Baev 2013):

- It is a clearly definable entity (both geographically, legally and on practical grounds)
- Existing, but rudimental, maritime infrastructure along the route
- Proven track-record of maritime activity; precedents for analysis
- Substantial natural resources located within the geographical vicinity
- Prevailing climate conditions, already the most favorable out of the Arctic Sea routes, and expected to change dramatically within the chosen timeframe
- Russia constitutes a state-level champion for advocating development

The analysis is set to micro/meso levels in order to focus on the subject from the ship owner's and the shipping industry's perspective. This perspective incorporates both internal and external contexts in order to comprise a holistic point of view. The internal context includes the economics issues regarding shipping, while the external involves macroeconomic factors that are viewed through the lens of the PESTEL framework (Figure 8).

1.6 Structure of the thesis

This doctoral thesis contains two parts: 1) the concluding summary and 2) the appended research Articles (see Figure 9). The concluding summary consists of eight Chapters, which have the following content.

- Chapter one describes the research context, elaborates the key concepts and contains literature review.
- Chapter two describes the applied research framework, entailing the positioning of the thesis in terms of the philosophy of science approaches.
- Chapter three describes the PESTEL framework and the exogenous factors that are involved in shaping the prerequisites for shipping along the NSR.
- Chapter four elaborates on the characteristics of the NSR as a shipping route and a maritime system.
- Chapter five scrutinizes shipping economics in the NSR by describing the generic revenue and cost profiles of the NSR ships and analyzing the sensitivity of the parameters.
- Chapter six employs the PESTEL framework to compare the level of risks involved in shipping along the three Arctic Sea routes.
- Chapter seven summarizes the results and synthetizes the conclusions in terms of the research questions.
- Chapter eight concludes the thesis by presenting its contributions and outlining avenues of discussion for further research.

In addition to the concluding summary, the thesis contains five peer-reviewed research Articles that tackle the feasibility of the NSR from different angles.

-

- Article I “Viability of Slow Steaming in container shipping along the NSR” and Article III “The economic viability of Northern Sea Route as a seasonal supplement for container shipping between Europe and Asia” focus on the shipping economics.
- Article II “The Dynamics of World Ice-Classed Bulk and Containership Fleet in view of Arctic Shipping” is involved with the supply development aspects.
- Article IV “Supply and Demand of Transit Cargo Along the Northern Sea Route” is similarly concerned with the supply aspects while also incorporating the demand issues. Article V “Long-term dynamics of shipping and icebreaker capacity along the Northern Sea Route” concentrates in the supply dynamics.

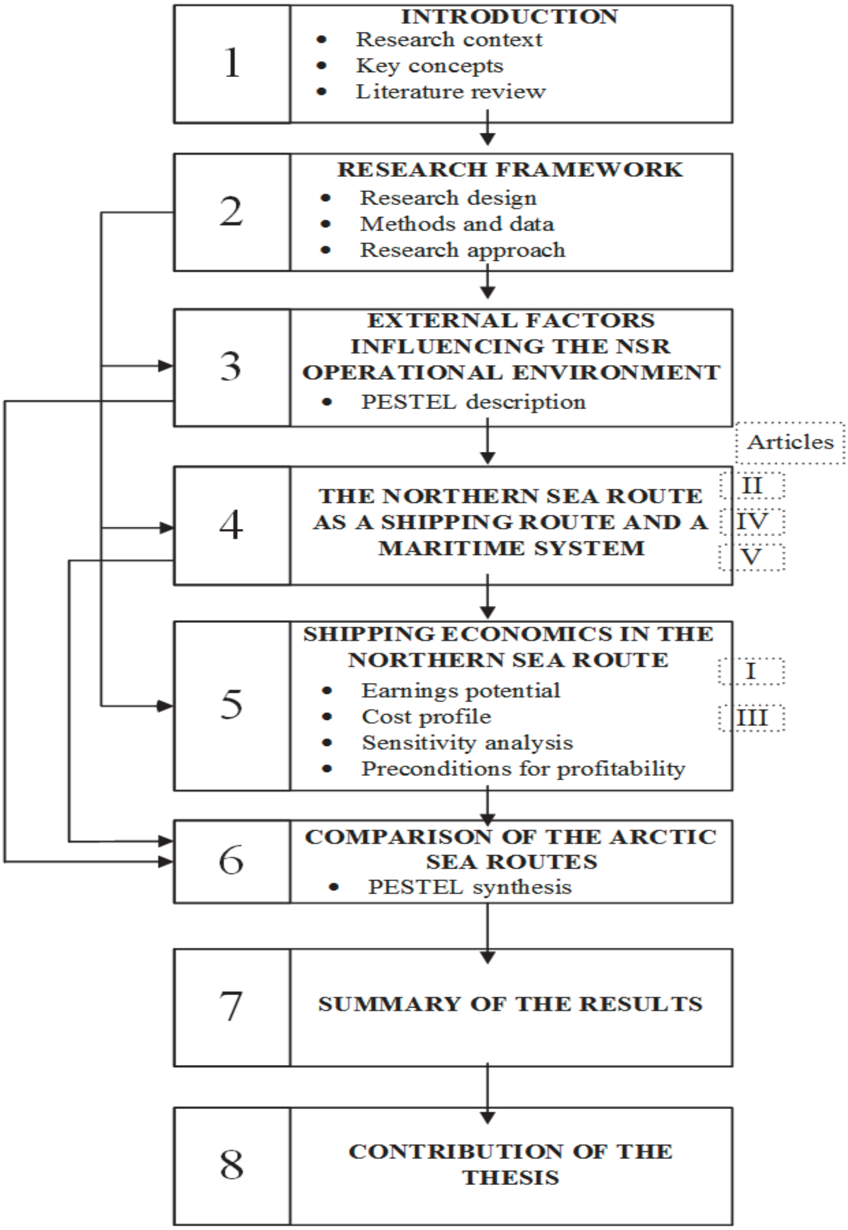
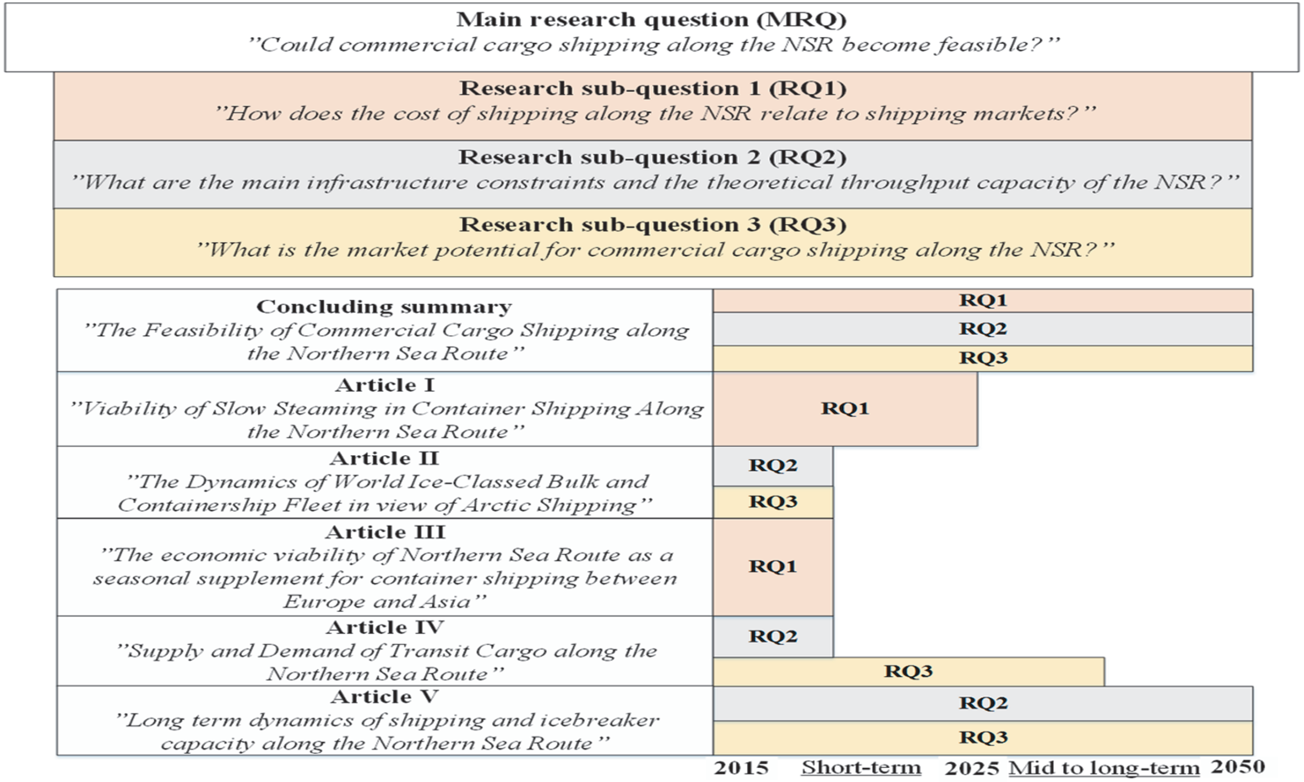


Figure 9 The contents of the thesis and linkages between Chapters and appended Articles

The concluding summary not only concludes with the findings of the five appended Articles but also provides a synthesis with respect to the main research question and the more specific sub-questions (Figure 10).


Main research question (MRQ)
"Could commercial cargo shipping along the NSR become feasible?"

Research sub-question 1 (RQ1)
"How does the cost of shipping along the NSR relate to shipping markets?"

Research sub-question 2 (RQ2)
"What are the main infrastructure constraints and the theoretical throughput capacity of the NSR?"

Research sub-question 3 (RQ3)
"What is the market potential for commercial cargo shipping along the NSR?"

Concluding summary
"The Feasibility of Commercial Cargo Shipping along the Northern Sea Route"

Article I
"Viability of Slow Steaming in Container Shipping Along the Northern Sea Route"

Article II
"The Dynamics of World Ice-Classed Bulk and Containership Fleet in view of Arctic Shipping"

Article III
"The economic viability of Northern Sea Route as a seasonal supplement for container shipping between Europe and Asia"

Article IV
"Supply and Demand of Transit Cargo along the Northern Sea Route"

Article V
"Long term dynamics of shipping and icebreaker capacity along the Northern Sea Route"

Figure 10 The linkage between the specific research questions and Articles, and their indicative temporal coverage from short to long-term developments

2 RESEARCH FRAMEWORK

Manuals on scientific inquiry and discussion in the philosophy of science are typically overwhelmed with parallel concepts and jargon (See e.g. Vafidis 2007). This tends to alienate modern logisticians from its important aspects, something which is arguably shown by the decline in the number of Nordic PhD thesis containing a philosophy of science discussion (Rajkumar et al. 2016). That said, this Chapter aims to provide a thorough but concise description on the position taken and the decisions made with regard to the thesis. The content reflects the author's viewpoint on the issues while taking the liberty to streamline the equivocal nature of the terminology.

2.1 Research design

The logical structure of the research, embedded with the connections to philosophy, underlying theories, a research approach and specific methods is often used as a definition of the research design (e.g. Creswell 2009). Yin (1994) describes the concept as a rational sequence that connects the data to the initial research questions and conclusions.

2.1.1 Philosophical considerations

The role of the philosophy of science is to question common beliefs and ways of thinking, and elucidate ambiguous and implicit concepts by making them more understandable and specific (Niiniluoto 1984). A research work is positioned within an existing scientific discipline, paradigm (Arbnor and Bjerke 1997) or worldview (Creswell 2009) and is based on its underlying assumptions regarding the philosophical issues relating to ontology, epistemology and methodology (Burrell and Morgan 1979).

Ontology describes the essence of the phenomenon upon which a theory will be based (Grix 2002). More specifically, the ontological assumptions are related to what we believe comprises social reality (Blaikie 2000). In the social sciences, an ontological discussion usually revolves around the dichotomy between the nominalism and realism (Burrell and Morgan 1979). Nominalism postulates the researcher's subjective cognition on the phenomenon, while realism is based on objective perception. In this thesis, the phenomenon in question, the NSR, falls under the realism category as a real world phenomenon that has clear boundaries and which exists outside the researcher's cognition.

Epistemology is a theory of knowledge that has an emphasis on how knowledge is accumulated, which methods are used and how valid they are (Grix 2002). Blaikie (2000) refers to epistemology as assertions about how what is assumed to exist can be known.

Assumptions about ontology and epistemology tend to advocate a research position that favors particular methodologies (Burrell and Morgan 1979; Danermark 2002). Methodology, as such, is concerned with the logic of scientific inquiry, especially the strengths and limitations of particular methods (Grix 2002). On a pragmatic level its contents are often associated with the notion of a research approach.

The NSR consists of a complex set of mechanisms, such as a fleet of ships, infrastructure and crews, which combined together, determine the performance of the entity. This setting, embedded with interdependencies, fulfills the notion of a system. According to Merriam-Webster dictionary a system is *"a regularly interacting or interdependent group of items forming a unified whole"*. In addition, the NSR is part of the larger system of Arctic shipping, which subsequently forms part of the global shipping market. The whole shipping ecosystem is subject to multi-level and latent factors.

With the above in mind, the research at hand contains elements of at least two philosophies. In some respects, pragmatism may be pinpointed as the research is heavily grounded on real world problems and it makes ad hoc choices regarding the research methods (Creswell 2009). Pragmatism originates from the work of Charles Peirce (1960). It approaches the problem from the practical perspective of trying to find reasons behind particular actions in order to master the complex world (Bromley 2008). The relevant question is whether the ideas are helpful in comprehending the facts and events in the world (Bromley 2008).

The second and perhaps more dominant approach in this thesis is critical realism. It is a school of thought in the philosophy of science that developed from the epistemological point of view; one which is suitable for studying research questions that involve understanding complexity (Clark 2008). Roy Bhaskar (1979) can be considered the founder of the critical realism. His idea relied on, among other things, stratification where, on the first layer, three ontological realms of reality exist: i) empirical experiences; ii) real objects and mechanisms; and iii) actual events (Modell 2009). The empirical domain, gained through the experiences of individuals or scientific inquiry, consists of all the mechanisms that have been activated and observed (Gorski 2013). The real domain consists of all the mechanisms that exist. The actual domain refers to all the mechanisms activated, but not necessarily observed.

On the second layer, reality consists of hierarchically ordered levels where a lower level creates the conditions for a higher level (Danermark 2002). This means that each level has its generative mechanism without direct hierarchical dependence on another level. To sum up, critical realism simultaneously identifies knowledge free of humans and also the socially embedded and fallible nature of the scientific inquiry (Clark 2008). In terms of this thesis, the aforementioned philosophical structure conforms to the multiple levels that comprise the real world system of the NSR and its latent underlying macroeconomic factors.

2.1.2 Theoretical frame of reference

A theory is an interrelated set of constructs formed into propositions that specify the relationships among the variables (Creswell 2009). The adopted philosophical approaches in the thesis guide us towards the appropriate theories to be used as points of reference. For example, there is a strong link between critical realism and systems theory (Clark 2008).

The general systems theory, introduced by Ludvig von Bertalanffy (1969), is by definition well-suited to analysing systems. It is the transdisciplinary study of the abstract organization of phenomena, independent of substance, type, or spatial or temporal scale of existence. It investigates both the principles common to all complex entities and the (usually mathematical) models which can be used to describe them (Heylighen and Joslyn 1992). The background of system theory, which is often interchangeably used with a systems approach, comes from physics and more specifically the open and closed systems used in thermodynamics (von Bertalanffy 1969). Closed systems, e.g. the universe, must eventually attain an equilibrium state, while open systems, like business, interact with their environment and remain in a constant state (Vafidis 2007). Systems theory has connections to cybernetics (Ashby 1956), while also providing a platform for a separate application called system dynamics (e.g. Forrester 1961).

As the main objective of the thesis is to analyse the feasibility within the shipping market context, the relevant theoretical foundation needs to include the principles of transport and maritime economics (e.g. Evans and Marlow 1990; Stopford 1988; 2009). Owing to the lack of a unified cost categorization model in shipping, Stopford's (2009) cashflow model has been used as a guideline for the construction of cost calculation models. The principles of the system dynamics have been adopted from Forrester (1961) and Sterman (2000) which are incorporated with Stopford's (1988, 2009) shipping market model (Figure 11). The shipping market system consists of four closely intertwined sub-markets; 1) the freight market, 2) the newbuilding market, 3) the second-hand market and 4) the scrapping market.

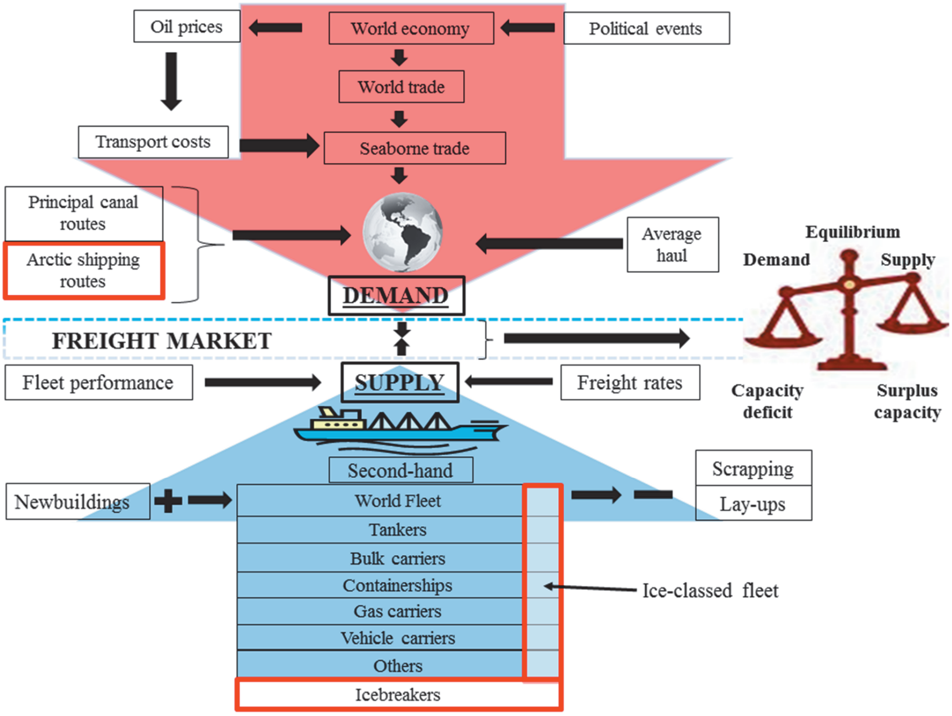


Figure 11 The Arctic shipping market model (inspired by Stopford 1988, 2009)

The global shipping market works in a highly dynamic environment as a derivative from world economic activity and is subject to random shocks, such as political turmoil and wars. The cyclicality, which is a characteristic feature of the market, is attributed to imbalances at a given time between rigid supply and the volatile demand. The mechanism of the freight rates is based upon the balance between supply and demand; when supply exceeds demand the rates are depressed and vice versa. The freight rates guide the decision-making of the ship owners. High freight rates induce the ship owners to increase supply and reduce it in times of depressed rates. Supply is usually increased by ordering new or second-hand ships but also by increasing fleet productivity through, for example, route-choice decisions.

2.1.3 Research approach

The typology of Arbnor and Bjerke (1997) is commonly used to categorize research based on its approach and has a special emphasis on ontological and epistemological characteristics (e.g. Vafidis 2007). It consists of three separate approaches: analytical, systems and actors. The analytical approach seeks causal relations to create knowledge, but it is dependent on social constructs in the actors' approach. This thesis can be positioned in the systems plot, because knowledge is dependent on the entire system and parts of the system cannot be analysed separately.

The NSR constitutes a classic example of a system where each individual part of the ecosystem can influence the performance of the entity and every member is thus dependent on others. The ecosystem, or the maritime environment, of the NSR consists of the actual water area; technical elements including ports, navigational aids, icebreakers and the ice-classed fleet; and the human element in the form of the personnel needed. The performance of the system can be measured in terms of its feasibility, which is the main objective of this research. The NSR can also be viewed as a set of subsystems which provide a more detailed view of the processes involved. In this thesis, the perspective has been adhered to in terms of the five Articles (I-V) and the concluding summary, all of which analyze separate parts of the system (see also Figure 9 and Figure 10). Finally, the findings are synthetized in order to draw the conclusions of the thesis.

A second categorization model by Neilimö and Näsi (1980) is more involved in methodological issues than Arbnor and Bjerke’s (1997) model (See e.g. Vafidis 2007).

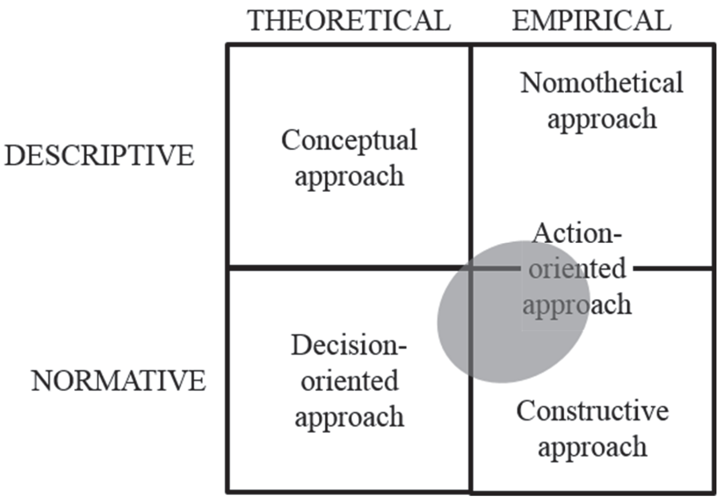


Figure 12 The positioning of the thesis (shaded area) based on the research approach categorisation framework by Neilimö and Näsi 1980; Lukka 1991; Kasanen et al. 1993

To some extent, the research in question fits the characteristics of Neilimö and Näsi’s (1980) action-oriented research as it is based on empirical data and aims to understand the research object and not to explain it as such. Similarly, but to a lesser degree, the research includes features of the decision-oriented approach, given that its aim is to build models – in this case cost calculation and system dynamics models – for decision-making – in order to solve certain types of problems in certain conditions. In many respects, most of the elements of the thesis fit the constructive approach (Kasanen et al. 1993). The objective of the thesis adheres to the aim of building practical-level solutions which incorporate both theoretical knowledge and insights that can be used to answer managerial problems. Examples of issues that this thesis aims to deliver answers include decisions over when and what type of fleet to use along the NSR (Figure 12).

2.2 Research methods and data

This research employed multiple quantitative research methods, including trend, freight potential and capacity analysis as well as cost calculation and system dynamics modeling. While critical realism is usually associated with qualitative methods, the use of quantitative methods is not dismissed (Downward et al. 2002). In fact, it endorses a relatively wide range of research methods provided that they fulfil the purposes of the study and its objectives (Sayer 2000). Quantitative research is particularly well-suited in cases like this thesis; when the research problem requires the identification of factors that influence an outcome and the understanding of the drivers behind them (Creswell 2009).

Several types of models were used to comprehensively study the complex entity in question. According to Casti (1989) the good models include elements that directly correspond to the real world, while simultaneously being the simplest way to explain the data and still leave some room for the model, or theory, to grow. The models, as abstractions of reality, force us to consider the underlying structural and dynamic assumptions behind the phenomenon in question (Ruth and Hannon 2012).

Cost calculation modeling was used in Articles I and III to analyse the cost competitiveness of the NSR compared to Suez Canal in various conditions. Article II used comparative trend analysis to investigate changes in the ice-class fleet composition between certain time points. Article IV applied a descriptive capacity and freight potential analysis to study the demand and supply components of the NSR. Article V employed system dynamics modeling to scrutinize the supply dynamics of the icebreaker and ice-class fleet capacity along the NSR.

Finally, the concluding summary employed the PESTEL framework, which originates from the work of Aguilar (1967). PESTEL is a widely used (e.g. Abdul Rahman et al. 2014) managerial-level analytical tool for scanning the relevant external factors related to the Political, Economic, Social, Technological, Environment and Legal preconditions affecting the present and future operating environment (e.g. Johnson et al. 2011).

Validity, reliability and generalizability are key issues determining whether the research will stand up to external scrutiny. All of them are guided by the philosophical positioning and subsequent research approach of the thesis.

Validity is concerned with the meaningfulness of the research components (Drost 2011). External validity is a key criterion in quantitative research as it determines whether general conclusions can be drawn on the basis of the applied model and used data, and whether the results may be generalized (Ryan et al. 2002). Internal validity is concerned with the validity of the research itself (Drost 2011).

As this thesis relies heavily on the systems approach, the validity issue is considered in accordance with it. By and large, generality and absoluteness have a lower bearing on systems theory, allowing looser connections between the theory, definitions and reality (Arbnor and Bjerke 1997). Accordingly, the definitions must be relevant, the measurements have to reflect the real system and most of all the results must be reasonable and correct from the researcher’s perspective, which may be further verified by using external experts (Arbnor and Bjerke 1997).

With these aspects in mind, the subject of the thesis is bound to real world phenomena, thus the relevant parameters are derived directly from the actual pragmatic-level. Accordingly, the research data used are largely based on the comprehensive databases of ship operating costs and the fleet parameters obtained from two distinguished international maritime consultancies: Drewry Shipping Consultants (Drewry 2012) and Clarkson Research Services Limited (CRSL 2015).

Reliability generally refers to the extent to which a variable or set of variables is consistent with what it is intended to measure (Bollen 1989). Reliability defines the extent to which the measurements are repeatable on different occasions, conditions or instruments (Drost 2011). In this thesis, reliability has been ensured by using well-established methods in the field of maritime economics and system dynamics, following the logic of e.g. Marlow and Evans (1990), Stopford (2009) and Sterman (2000). Additionally, the reliability of the results and parameters are tested by verifying them with expert and practitioner experience.

2.3 Research process and the logic of the scientific inquiry

This research endeavor officially began in February 2013 when the author was nominated as a doctoral candidate in the discipline of Operations and Supply Chain Management (Figure 13). The de facto foundations of the doctoral thesis stem from the author’s Master’s thesis finished in June 2012 (Kiiski 2012). After starting working as a full-time post graduate student, the first paper idea was rather straightforwardly put into paper. The most influential contributing factors at that time were author's working experience as a freight forwarder and then the prevailing high fuel prices, which called for special operational measures.

Article I "The viability of slow steaming along the Northern Sea Route" was written during the summer and published in September 2013 in the Proceedings of the Hamburg International Conference of Logistics (HICL) 2013, held in Hamburg, Germany. The article contributes to the analysis of the economic viability of the NSR for container shipping over a mid-term perspective. In short, it uses a best-case scenario in terms of the NSR's potential by employing ice-free conditions, favorable distance advantage and similarly sized vessels in order to study the impact of speed on total shipping costs. In many respects, the approach follows a commonly used methodology, while also adding new perspectives in terms of the speed analysis.

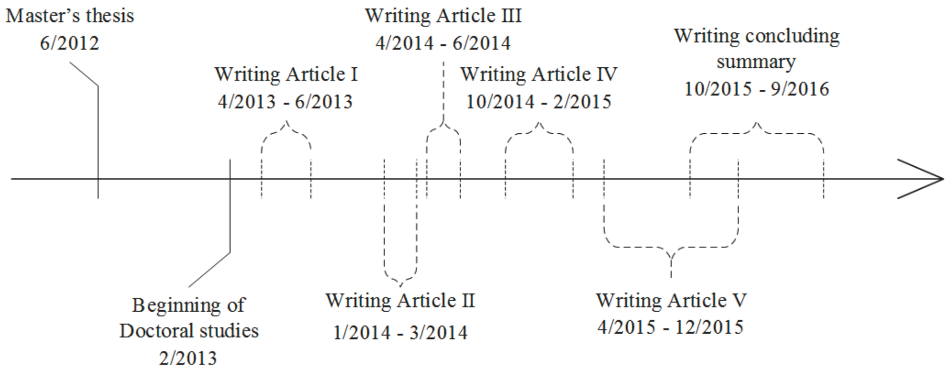


Figure 13 Timeline of the research process indicating the timing of the main effort of the work (excl. the time for subsequent revision rounds)

The lessons learnt from Article I in terms of the observation of the inadequate availability of data with regard to ship parameters provided the grounds for Article II. In addition, it was also inspired by the author's personal interest in fleet statistics. In this respect, external funding was requested in order to gain access to the costly fleet database. This resulted a time-lag of several months but finally, when external funding was obtained, the writing process of Article II "The Dynamics of World Ice-Classed Bulk and Containership Fleet in view of Arctic Shipping" began in January 2014.

Article II was subsequently published in June 2014 in the Proceedings of Nordic Logistics Research Network (NOFOMA) Conference 2014, held in Copenhagen, Denmark. It contributes to the discussion on the contemporary supply capacity of the NSR by deriving observations from the ice-class fleet development and evaluating its conceived market potential from the shipping industry's perspective. Article II aims to provide an update on a topic that has been previously studied.

Immediately after finishing Article II, work began on Article III "The economic viability of the Northern Sea Route as a seasonal supplement for container shipping between Europe and Asia". The article was inspired by the results of Article I and their inconsistency relative to actual activity along the NSR. Article III was published in June 2014 in the Proceedings of the 6th International Conference on Maritime Transport, held in Barcelona, Spain. It contributes to the analysis of the economic viability of the NSR regarding container shipping over a short-term perspective. More specifically, it incorporates the effects of varying conditions and a seasonal network routing itinerary, a setup which has not been much studied thus far.

After writing the two cost-related papers and having discussions with the users of the NSR, it become evident that factors other than mere costs were necessary to consider. This observation became the inspiration for Article IV "Supply and Demand of Transit cargo along the Northern Sea Route". That was written in late 2014 and published in June 2015 in the Proceedings of the 11th International Conference on Maritime Navigation of Sea Transportation, (TransNav 2015), held in Gdynia, Poland. Article IV contributes to the analysis of the contemporary supply capacity and market potential of the NSR in the short to mid-term perspective. The latter has been studied in the previous literature quite extensively while the former has not.

Article V "Long-term dynamics of shipping and icebreaker capacity along the Northern Sea Route" is a continuation of Article IV as it uses the results as a starting point for building a system dynamics model. The model is created with Stella, a system dynamics software with a graphical interface. The writing of Article V began in April 2015 and was finished just before the Christmas 2015. It was subsequently submitted to a journal and after a few rounds of revision was eventually accepted for publication in Maritime Economics & Logistics in Autumn 2016.

Article V provides a contribution to the discussion of the infrastructural constraints of the NSR over a short to long-term perspective. This approach is pioneering in its field since it combines system dynamics and analysis of the supply capacity of the NSR. In a nutshell, the system dynamics model is created to study supply dynamics of the NSR over a 50 year period.

In this model demand is assumed to be an exogenous factor, which follows three pre-determined patterns. Each of these patterns initiate at a cargo volume of 3.7 MT in 2015, which grows linearly until 10 MT, 30 MT or 50 MT towards the end of the simulation period according to the three scenarios, respectively. The model consists of two basic pillars in terms of the stock of fleets that illustrate the contemporary maritime infrastructure[4] along the NSR. First, the ice-classed fleet, consisting of IA and IAS ice-classed dry bulkers, LNG carriers and tankers is based on details as per January 2015. Second, the active fleet of Russian nuclear-powered icebreakers is used as a starting point. The capacities of both of these stocks are needed for the NSR to function. This mechanism follows a basic supply and demand interaction. In other words, if enough supply capacity is available, then demand is fulfilled and cargo is transported through the NSR. In case adequate capacity is not available, missed cargo demand initiates a newbuilding process that will increase the supply capacity of either ice-classed ships or icebreakers. The time-lag for this process to be completed is two years for ice-classed vessels and five years for icebreakers.

Furthermore, as the vessel stocks are based on actual data on the vessel age, ageing constitutes a factor that depletes the stocks. In case there is excess supply capacity, market exits decrease the capacity of the ice-classed fleet, while icebreakers are being scrapped. Climate conditions constitute a variable that influence fleet productivity of ice-classed fleet and icebreakers. Climate conditions follow three different linearly progressing patterns: (1) constant baseline, (2) melting and (3) freezing. The changing conditions influence fleet productivity in terms of the number of escorted ships, their sailing speeds, the length of the icebreaker escorted area, waiting times needed and to the length of annual navigational season.

The concluding summary “Feasibility of commercial cargo shipping along the Northern Sea Route” provides new empirical evidence while also summarizing the findings of the five appended Articles. It produces an overall synthesis by providing a novel and holistic understanding of the feasibility of commercial cargo shipping along the NSR. The writing of the summary began in autumn of 2015 and was finalized in September 2016. Table 6 sums up the contributions of each Article and the concluding summary.

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[4] According to the definition Arctic Marine Shipping Assessment, which includes both the fixed physical infrastructure and the fleet, among others (Arctic Council 2009).

Table 6 Contents of the thesis and its contribution

Thesis section	Title	Contribution	Level of observation	Method
Concluding summary	Feasibility of commercial cargo shipping along the Northern Sea Route	Novel holistic understanding on feasibility	Micro & Meso & Macro	PESTEL framework
Article I	Viability of Slow Steaming in Container Shipping Along the Northern Sea Route	Economic viability analysis with a mid-term perspective incorporating ideal conditions and the effects of varying sailing speeds	Micro & Meso	Cost calculation modeling
Article II	The Dynamics of World Ice-Classed Bulk and Containership Fleet in view of Arctic Shipping	Contemporary supply capacity analysis and market potential insights from the industry perspective	Meso	Trend analysis
Article III	The economic viability of Northern Sea Route as a seasonal supplement for container shipping between Europe and Asia	Economic viability analysis with a short-term perspective incorporating a network setting and the effects of varying sailing conditions	Micro & Meso	Cost calculation modeling
Article IV	Supply and Demand of Transit Cargo Along the Northern Sea Route	Contemporary supply capacity and market potential analysis in the short to mid-term	Meso	Capacity modeling and cargo analysis
Article V	Long term dynamics of shipping and icebreaker capacity along the Northern Sea Route	Dynamic supply capacity analysis in the short to long-term	Meso	System dynamics modeling

Unlike the bulk of the research on logistics, which concentrate on deductive reasoning (e.g. Arlbjørn and Halldórsson 2002), this thesis is largely inspired by the abductive approach. Originally the concept of abduction was introduced by Aristoteles but in practice it was brought to public awareness by American Charles Peirce in late-19th century (e.g. Hintikka 1998). Abduction is mostly viewed as an inference from effect to cause or explanation (e.g. Spens and Kovacs 2006). The conceptualization by Kovacs and Spens (2005) shows the abductive research process as usually entailing the creation of new theory (Figure 14).

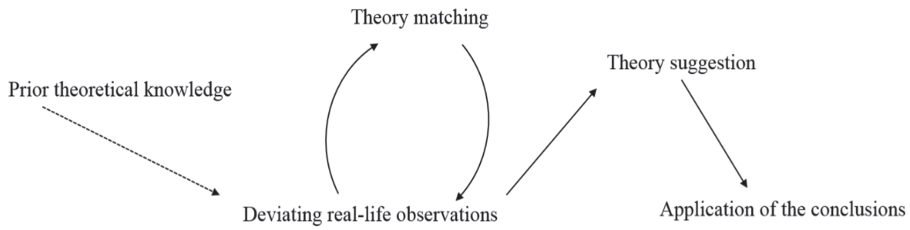

Figure 14 The abductive research process (Kovacs and Spens 2005)

In contrast to the usual application of abductive reasoning, this research process has features of normative, descriptive and pragmatic approaches, and thus does not aim to create a new theory as such. Descriptive research is an exploration of the existing phenomena and aims to provide a better understanding of the current situation, which, in this case is also extended to provide future insights in a normative fashion. The objective of the study is grounded on the practical-level needs of a ship owner who considers shipping along the NSR. Henceforth, the term theory is replaced by the term knowledge, which conforms to the objective of the thesis with regard to providing practical and normative understanding.

At the starting point of the research process, the researcher had to some extent preconceptions and theoretical knowledge on the subject, namely the basic principles and theories of maritime economics due to the antecedent Master’s thesis (Kiiski 2012). Soon after the publication of Article I it became evident that the existing knowledge was inconclusive in terms of describing the level of actual activity along the NSR (Dubois and Gadde 2002).

Consequently, an iterative process took place in which the results of each Article (I–V) were firstly used as a frame of reference to explain the observations made on the phenomenon and then to adjust the cumulative knowledge accordingly. The conclusions of this thesis contain the refined outcome of the aforementioned knowledge iteration process, which may be applied on a practical level.

3 EXTERNAL FACTORS INFLUENCING THE OPERATIONAL ENVIRONMENT OF THE NORTHERN SEA ROUTE

In this Chapter, a PESTEL framework is employed to identify and analyze the exogenous factors influencing the operational environment of the NSR. PESTEL refers to an approach, where the Political, Economic, Social, Technological, Environmental, and Legal issues of a given phenomenon or object of analysis are each studied in a systematic manner.

In this respect, Political relates to the issues that influence business conditions on a geopolitical level. Economic refers mainly to macroeconomic issues, such as global economic growth influencing the demand for shipping in the region. Social is a rather complex notion, thus it mainly focuses on the human element of shipping, such as labor issues. Technological is mainly concerned with the items in shipbuilding and navigation equipment domains. Environmental issues are linked with the ambient conditions that provide the operational environment for shipping. Legal means the framework of governance that regulates the activity.

3.1 Political issues

As part of a larger thematic concept, the NSR needs to be evaluated together with the overall Arctic discourse, as these two are essentially inseparable. Political aspirations of various kinds are present in the Arctic. Most of the countries in the Northern Hemisphere, including Finland, have adopted national policies that manifest strategies to reach desired outcomes regarding the Arctic (e.g. Finland’s Prime Minister’s Office 2013).

In general, opposing strategies usually tend to cause of conflicts (Brosnan et al. 2011), but in the case of the Arctic, this has not been the case thus far. On the contrary, during the recent decades, the Arctic region has been a place of positive international cooperation. The process has been facilitated by regional bodies such as the Arctic Council, which have managed to put some of the political agendas aside. Here, multilateral cooperation has concentrated on issues related to shipping, research and the environment, while sovereignty and resources are typically considered as to be bilateral questions (Brosnan et al. 2011).

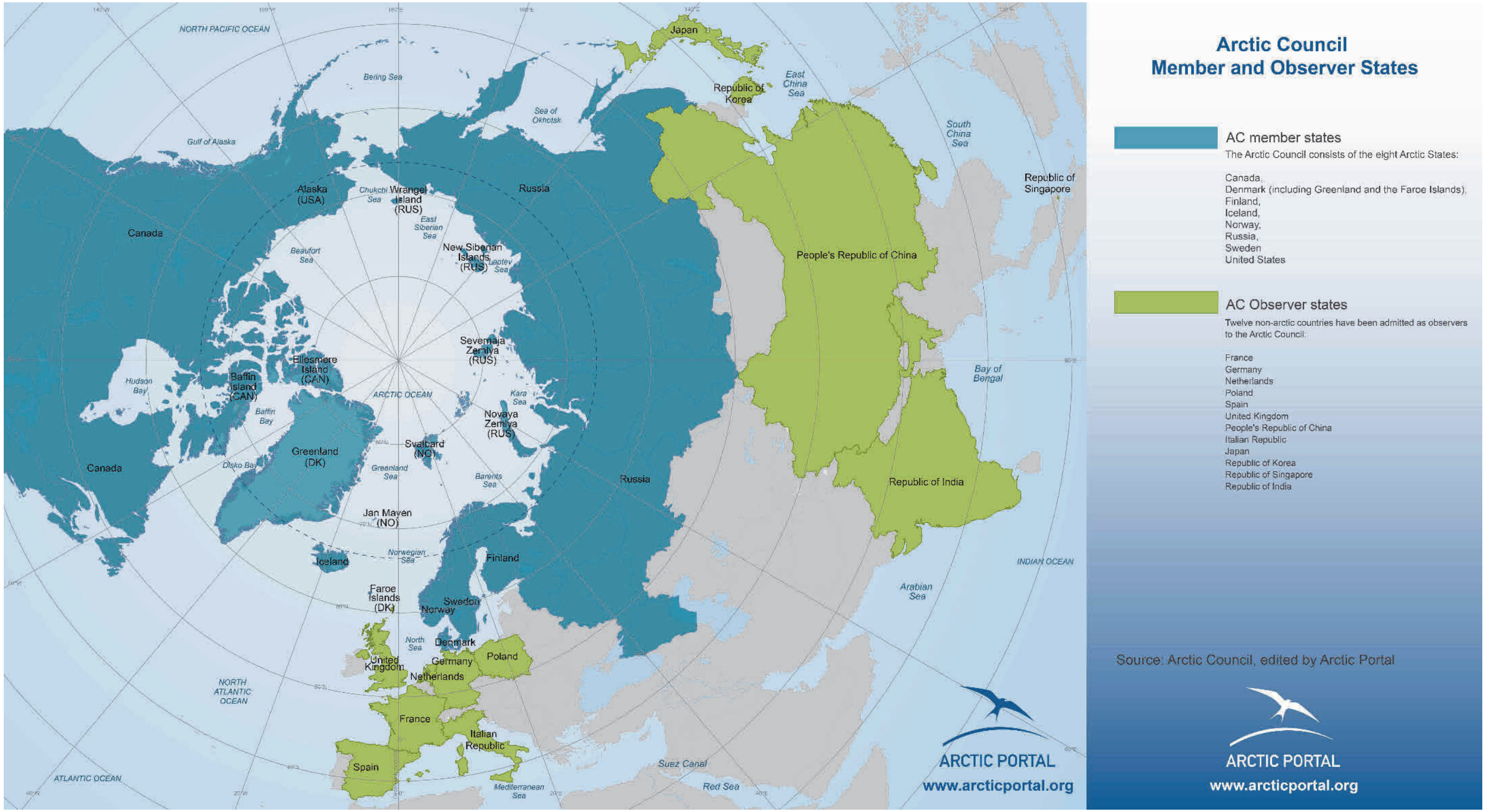

Figure 15 Arctic Council Member and Observer States (Arctic Portal 2016 reproduced with permission)

Over the past decade, the Arctic has attracted notable interest from non-Arctic coastal states located in Asia. Accordingly, in May 2013, five Asian countries, China, Japan, India, Singapore and South Korea, were granted permanent observer status on the Arctic Council (Figure 15).

The policies pursued by the Asian states tend to focus more on economic than security interests, some of which directly involve the NSR (Tonami 2014). For a country as dependent on shipping as China, the Arctic, and the NSR in particular, provide a strategic level economic opportunity in the long-term (Hong 2012; Solli et al. 2013). For example, the NSR could potentially diversify China's energy supply by reducing its dependency on routes along the Strait of Malacca (Zhang 2011). In contrast, Japan's interests are mostly concentrated on research (Tonami 2014). The strategy of South Korea is to keep up with other non-Arctic states, especially in shipping related aspects (Kim 2015). For example, South Korea has adopted an incentive policy to promote the use of the NSR in terms of port fee reductions (Kim 2015).

Given the strategic location of the NSR between East and West, political and national security issues are inherently present. Over a decade, the predominant stance of Russia has been to use nationalist-toned rhetoric and policies to enforce its sovereignty, which include an increased military presence in the Arctic region (Baev 2013; Flake 2013; Klimenko 2016; Martikainen et al. 2016). In its Arctic policy, Russia has identified the areas close to the NSR as both a strategic priority and as a resource base for the 21st century. This is due to Russia's economic dependency on the extraction of natural resources given its unilateral industry structure (Emmerson 2011).

It may be argued that the Arctic and the NSR are predominantly linked in Russian minds. Over the course of the past ten years, Russia has unequivocally displayed political ambition in promoting the use and development of the NSR to the global maritime community. For example, in 2011, Vladimir Putin declared Russia's goal to transform the NSR into a globally significant transport route (Putin 2011). At the same time, Russia has continued asserting exclusive national control over the NSR (Solski 2013). However, the Russian governance of the NSR has been disputed, namely by the USA (Lalonde and Lasserre 2013). This is largely due to the contrasting interpretations of the UNCLOS convention and especially the question of control over the straits along the NSR.

The changed geopolitical scene after 2014 has affected Russia's Arctic policy. The increased political turmoil and the joint Western sanctions imposed on Russia in the wake of the Ukrainian crisis have forced Russia to step eastwards towards China. Accordingly, a number of bilateral Sino-Russian agreements concerning the energy sector and the use of the NSR have been signed (Røseth 2014).

The past few years have underlined the leverage of political forces in terms of the Arctic's development. Despite Russia's considerable investment, progress has been sluggish. It has become evident that development is not only dependent on ownership of the region, but also on international cooperation in terms of market access and capital investment in combination with expertise and technology (Klimenko 2014). Similarly, Russian ambitions toward the NSR were subsequently adjusted as the Deputy Transport Minister Viktor Olersky stated in late 2013:

> *"It is 100 % sure that the NSR is no alternative to the Suez Canal"* (Pettersen 2013).

Overall, political factors have a substantial bearing on the NSR. However, the current increased geopolitical tensions may not exhaustively be viewed as unfavorable in terms of generating traffic. To some extent, an increase in maritime activity along the NSR has taken place that serves strategic needs. This approach applies especially in case of Russian domestic transports. In addition, an increasing partnership between Russia and China might result in increased maritime activity. As a sign of this, China has openly touted its ambitions to use the route on a more regular basis (Paris and Chiu 2015).

Last but not least, as global shipping is highly dynamic, the political sphere of influence extends well beyond the NSR involving alternative routes and modes of transportation. In this respect, the changes in the political situation of the neighboring countries of the Suez Canal and Russia's Trans-Siberian railroad policy may have implications for the NSR (e.g. Bendall 2010; Rodemann and Templar 2014).

3.2 Economic issues

Macroeconomic factors drive the demand for maritime transport services. Economic interests, especially the ones related to energy are closely linked to maritime activity in the Arctic and the NSR. Already the region produces about 25 per cent of the world's natural gas and 10 per cent of its oil, most of which comes from Russian areas (AMAP 2008). Future expectations are put on the untapped reserves, presumed to be high by any standards. The unilateral structure of the Russian economy makes it reliant on the export of natural resources. This exacerbates the importance of the Arctic as conventional sources are depleting and alternative sources are needed in order to maintain a level of production at a reasonable level (Emmerson 2011).

The exact magnitude of the Arctic natural resources is fairly uncertain (See e.g. Yenikeyeff and Krysiek 2007; Buixadé Farré et al. 2014). The published estimates should be considered with caution since they tend to be based on assumptions regarding geological conditions in the area, of which little is actually known (e.g.

Bishop et al. 2011). Probably the most renowned appraisal is the United States Geological Survey (USGS) which projected that the Arctic reserves would account for about 30 per cent and 13 per cent of the world's undiscovered gas and oil, respectively (Bird et al. 2008; Gautier et al. 2009). In volume terms, they would total approximately 90 billion barrels of oil (equivalent to 12.6 billion tonnes), 1,669 billion cubic feet of natural gas (equivalent to 47 billion cubic meters), and 44 billion barrels of natural gas liquids. Gas is mostly concentrated within Russian territories (52 per cent), whereas oil deposits are largely located in areas of the USA (Bird et al. 2008).

A separate and contrasting study on Russian offshore and deep-water potential suggests even higher figures reaching up to 52 billion tonnes of oil and 90 billion cubic meters of gas (Kontorovich et al. 2010). In addition, the Russian Arctic is expected to host vast reserves of minerals, such as nickel, diamonds and uranium (e.g. Safonov 2010; Dobretsov and Pokhilenko 2010). Nonetheless, whatever the specific numbers may be, it is clear that Russian reserves are more than sufficient to attract exploration and create demand for maritime transport services.

However, tapping the reserves for production is uncertain as it is subject to several external factors. A salient feature is the dependency on high prices for oil and gas with which to cover the higher production costs due to the greater operational and financial risks (Harsem et al. 2011). Oil production costs in the Arctic are estimated to vary between 40–100 USD per barrel (IEA 2008). The unfavorable cost and lead-time differentials relative to their southern counterparts are prominently expected to influence production levels. Already the dynamic changes in the global energy market have shifted the time horizon of the Arctic projects from the mid to the long-term and moved business plans from the category of far-fetched to indefinitely postponed (Baev 2013). In the short-term, Ermida (2014) expects the Arctic figures to grow only 6 per cent compared to the 60 per cent aggregated incremental production of Africa, Asia and North America.

By 2050, the Arctic's share of the global hydrocarbon production is expected to account for only 8–10 per cent (Lindholt and Glomsrød 2012). Furthermore, the same estimate predicts that the Arctic will lose its relative importance in the gas market, but sustain its position in the oil market. An industry trend that arguably influences maritime activity is gradually shifting production from conventional onshore locations to offshore (Peters et al. 2011).

Any natural resource production taking place in pristine and sub-zero conditions raises environmental concerns, especially in Western countries. Increasing awareness of climate change and the tightening of environmental regulations may reduce the demand for Arctic hydrocarbons, particularly in case of the introduction of low-cost renewable energy sources (Sander et al. 2014).

Finally, changes in the cost structure of alternative routes may drive shifts in demand. There are some indications that especially the Europe–Asia container trade is highly price elastic. For example, a 30 per cent increase in Trans-Siberian Railroad tariffs in 1.1.2006 caused a collapse of the trade flows (Hämäläinen 2007). This implies that the opportunity cost approach is effective for parallel routes.

3.3 Social issues

Strictly from the perspective of shipping, social aspects can be linked directly to the human-related issues in ships and ports, such as the wages of crews and associated personnel. If the scope is extended, it involves factors that indirectly influence shipping, such as the demographics that create the drivers for the demand for transport.

The Arctic is a vast but sparsely populated area. It covers around 8 per cent of the Earth's surface and has a population of around 4 million (Arctic Council 2009; AHDR 2015). The Russian Arctic has the highest population of all the Arctic countries, comprising around a half of the total. Unlike Alaska and Canada, the population of the Russian Arctic has seen a continuous decline due to the continued post-Soviet contraction in its economic activity (AHDR 2015).

Generally speaking, there exists a mutual dependency between NSR maritime activity and the population of the Russian Arctic. A maritime infrastructure requires a critical mass of labor to function, while the region needs economic activities to stimulate immigration. In this respect, activity related to the building and refurbishing of the infrastructure constitutes the most prominent areas of development.

Obviously, the low population, in relative terms, offers marginal demand for regional and international maritime activity along the NSR. A potential increase in activity may impact on the demand for auxiliary services, including ship bunkering and repairs. However, the overall impact on the permanent population is likely to be limited owing to the temporal and seasonal nature of the required labor (Sander et al. 2014). With those issues in mind, shipping along the NSR is not likely, in the short to mid-term, to be largely influenced by social aspects. In theory, if the decline in the population continues, it may influence wage levels as people have to be recruited with the promise of higher salaries. This, in turn, could result in increased operational costs, such as port fees.

3.4 Technological issues

Innovations in shipbuilding and ice navigation technology have traditionally facilitated the utilization of the NSR. In this regard, one of the milestones has been the introduction of nuclear power in the propulsion systems of ships. Since the late-1950s, this environmentally controversial technology has enabled the establishment of the NSR maritime system, the workhorses of which are the nuclear-powered fleet of world's most powerful icebreakers (e.g. Gritsenko and Kiiski 2016).

Technological development has the capacity to unlock a number of challenges related to shipping along the NSR. Traditionally, an icebreaker's maximum width has constituted a physical constraint on shipping or alternatively led to the suboptimal utilization of capacity in terms of the use multiple icebreakers at a time (e.g. Safronov 2011). This constitutes one of key issues in terms of improving the NSR's competitiveness against open-water routes. In other words, a safe passage for larger-sized vessels needs to be guaranteed without using a similar sized icebreaker. Recently, a novel solution has been introduced to tackle the icebreaker width issue. An oblique icebreaker concept enables an icebreaker to open a larger path than its own dimension of width would allow (e.g. McCulley 2013). In this regard, the azimuth thruster system has been a major innovation in improving the propulsion and maneuverability of a ship in ice (Appolonov et al. 2011). It is often incorporated with double acting ships (DAS), which are equipped with an open-water efficiency in the fore, while possessing an icebreaking performance in the aft (e.g. Niini et al. 2006). Innovations like these have not only improved safety but also operational capabilities.

By and large, solutions that could help to decrease the operational difference between open-water and icebreaking performance exist, but they come at a cost. Usually vessels equipped with DAS are smaller-sized and more expensive to build than their open-water counterparts. This, in turn, has narrowed their economies and deployment areas. Novel concepts for diminishing the gap would be pivotal.

When scanning the relevant technological innovations potentially influencing NSR activity in the future, one should not be confined to shipping-related technologies. Obviously, concepts like autonomous ships may be beneficial to some extent, but cannot be seen as a short-term option for the Arctic given the more challenging conditions and as yet unproven technology. Being a derivative of need to transport cargoes, Arctic shipping is influenced by breakthroughs in natural resource extraction techniques. Technological solutions enabling the safer and cheaper exploitation of Arctic natural resources will undoubtedly make them more appealing, and thus indirectly influence maritime activity.

3.5 Environmental issues

For over a decade climate change has created increasing interest in the Arctic. The dramatic transformation of the climate appears observable and progressing. Rapidly warming temperatures, with a pace well over global means, are being accompanied by a substantial loss of Arctic sea ice and snow cover (e.g. Cohen et al. 2014). The most substantial loss of ice has been during summer periods, while the decline in winter has been more moderate (Figure 16).

The average decrease in March has accounted for around 6 per cent, while the rate has doubled to 12 per cent in September (NSIDC 2016). The excessive warming is attributable to an effect known as Arctic amplification, which involves surface albedo changes in snow and ice (e.g. Serreze and Barry 2011).

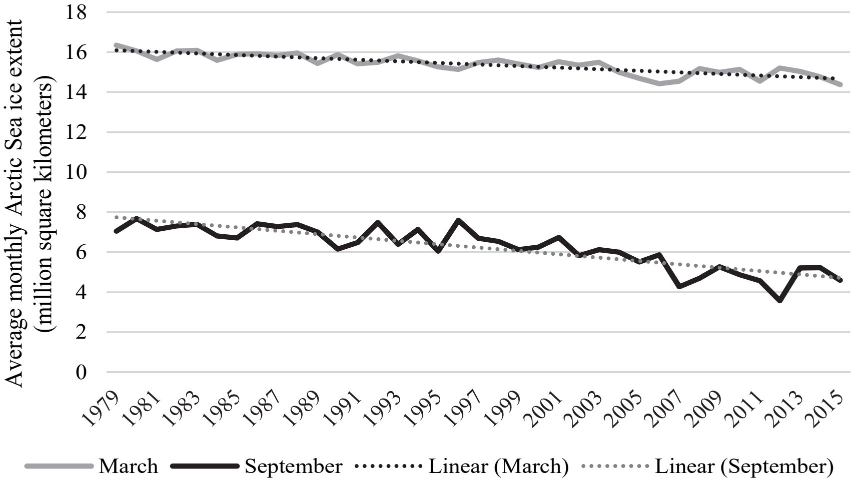

Figure 16 The average Arctic Sea ice extent in March and September 1979–2015 (NSIDC 2016)

Arctic Sea ice cover is not only rapidly losing extent but is also becoming younger and thinner (Rodrigues 2009; Maslanik et al. 2011; Stroeve et al. 2012), suggesting improved accessibility for ships along the NSR (Stephenson et al. 2011; 2013). From 1979 to 2005, the probability of an open-water vessel being able to transit along the NSR was around 40 per cent or less; in 2006–2015 the probability increased up to 61–71 per cent; and by 2040–2059 it is expected to increase up to 94–98 per cent (Smith and Stephenson 2013).

The speed of the thawing and the reduction in ice has been remarkably fast by all accounts (Figure 17). Khon et al. (2010) projected the NSR's navigational season to extend from three to six months by the end of the century. These figures appear almost already met. Lei et al. (2015) reported that the season has increased from 84 days in the 1980s to 114 in the first decade of 2000s and reached 146 days in 2012. The melt has also unveiled a new routing option for large-sized vessels. The High Latitude Route, which passes the New-Siberian Islands northwards, was open for record 42 days in 2012 (Lei et al. 2015).

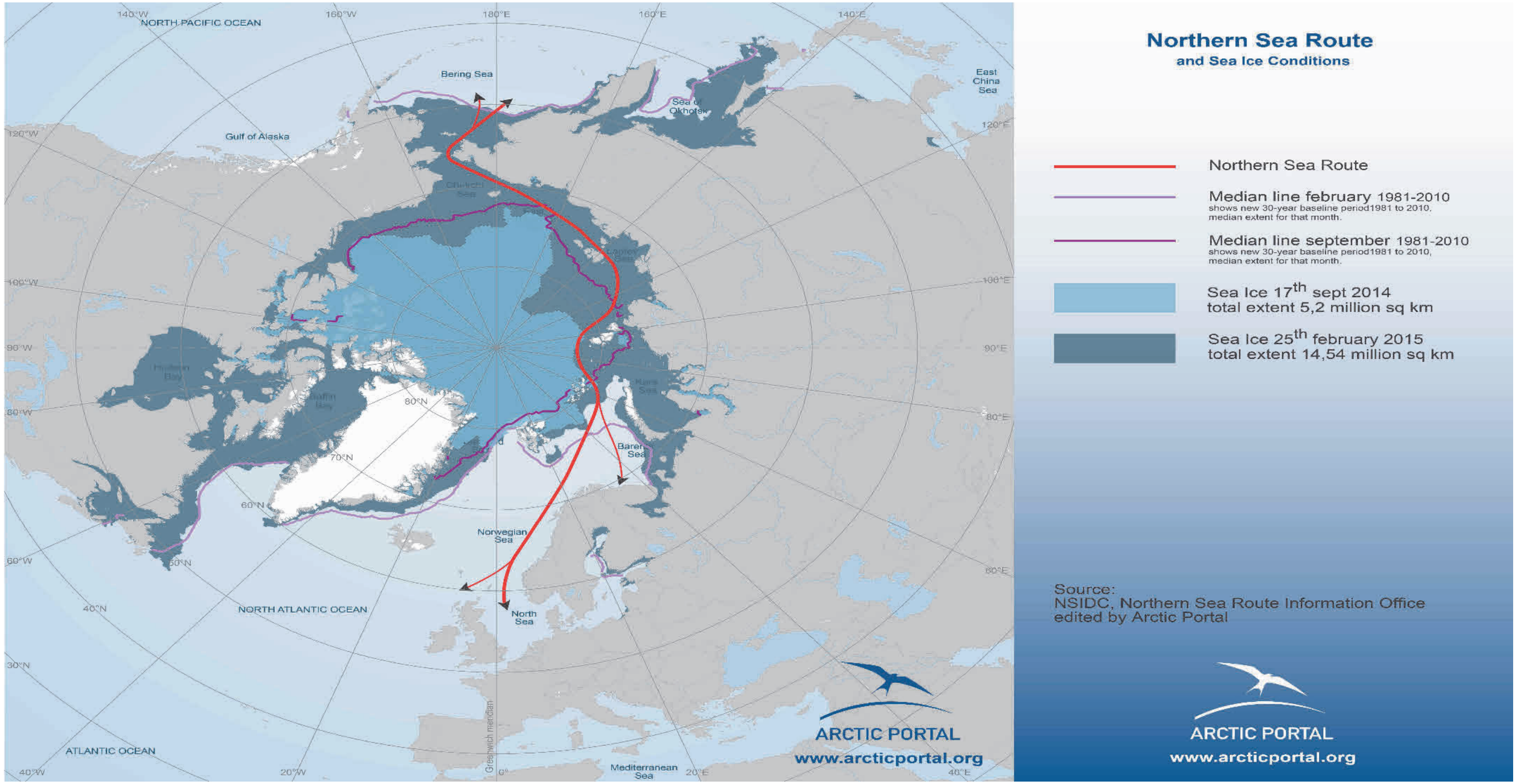

Figure 17 The development of ice-conditions along the Northern Sea Route (Arctic Portal 2016 reproduced with permission)

Despite the relatively well documented present changes, there is uncertainty over the future, because the course and speed of the climate change remains unclear. A prevalent approach, also postulated in this thesis, views that climate warming and ice reduction will continue in a unidirectional path in accordance with numerous climate models (e.g. ACIA 2004; IPCC 2007). The main cause of the phenomenon appears to be the accumulation of greenhouse gases of anthropogenic origin in the atmosphere. The course of change has been prominent to a degree that an almost ice-free Arctic Sea in summer is expected within this century (ACIA 2004; IPCC 2014).

An alternative hypothesis (Frolov et al. 2005, 2009) asserts that climate change and consequently the movement of the Arctic Sea ice cover will follow an oscillatory rather than unidirectional path. Accordingly, the warm period will end by 2015–2020 and then start to cool while the ice cover gradually increases up to the 2030s until another warming period begins and causes a subsequent decrease in ice cover up until the 2060s (Frolov et al. 2009). In addition, other factors may influence climate dynamics, such as the changing circulation patterns of the Gulf Stream (Rahmstorf et al. 2015) or increasing methane emissions from the thawing Arctic tundra (Parmentier et al. 2015).

On the operational level, the prevalent outlook implies that the preconditions for shipping are gradually improving, which will result an increase of Arctic maritime activity (e.g. Arctic Council 2009). This will mostly concern seasonal activity as the winter ice will remain, but will slowly be replaced by first-year ice, which is thinner and easier to penetrate than multi-year ice (Sander et al. 2014; Bourbonnais and Lasserre 2015). The occurrence of Arctic winter ice and drifting ice from glaciers in addition to icing from sea spray means that the vessels will need to be equipped for ice, even in the summer (Sander et al. 2014).

In addition, extreme weather events, such as storms, may become more frequent (Hakkinen et al. 2008; Kolstad and Bracegirdle 2008). For the NSR, studies suggest a spatial diversion in conditions. Stephenson et al. (2014) predict that within the period 2013–2027, navigation will be less reliable and more challenging in the Laptev, East-Siberian and eastern parts of the Kara Sea. Accordingly, icebreaker escorts will have to continue as a prominent part of the activity in the NSR (Stephenson et al. 2014).

Increasing maritime activity in the Arctic is likely to impact negatively on the environment. Several studies have quantified the future magnitude of ship-based emissions in the Arctic (Paxian et al. 2010; Peters et al. 2011). Lack and Corbett (2012) suggest that emissions of black carbon, a known amplifier of climate change (Sand et al. 2013), will increase owing to the suboptimal engine load profiles. Shipping also poses other types of hazards to the environment, including the spreading of invasive species from ship ballast water, discharges of oil, sewage, garbage, harmful cargoes, marine mammal strikes and noise disturbance (Brosnan et al. 2011).

There are some misconceptions about the effects of shipping in the Arctic. A commonly portrayed image is that shorter distances would be a more environmental friendly option in terms of reduced carbon dioxide (CO_2) emissions (e.g. Furuichi and Otsuka 2015). In principle, shorter distances may indeed lead, in relative terms, to reduced CO_2 emissions due to lower fuel consumption. However, this approach has two deficits as it ignores other emission particulars and their impact on a vulnerable area (e.g. Sander et al. 2014). In addition, Arctic conditions make the picture more complicated given the reduced energy efficiency of smaller-sized vessels with temporarily increased power requirements (Lindstad et al. 2016). In brief, there are implications that an increase Arctic shipping activity may lead to an amplification of the effects of climate change. For example, Lindstad et al. (2016) argue that there are no general climate benefits for utilizing the NSR, even with cleaner fuels, since the additional impact of emissions more than offsets the effect of shorter voyages.

3.6 Legal issues

The governance of Arctic shipping is fragmented. Vander Zwaag et al. (2008) correctly term it a complicated mosaic. It consists of several international and national legal regimes that set the standards. International regulation is organized through several United Nation bodies, such as the International Maritime Organization (IMO) and the International Labour Organization (ILO) as well as conventions like Safety of Life At Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), the United Nations Law of the Sea (UNCLOS 1982) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). In practice, the situation is, however, far more complex. For example, some of the conventions have not yet been adopted or their implementation is still pending. Additionally, in line with the global nature of shipping, the largest flag states and suppliers of mariners are not Arctic countries.

The legal framework regulating shipping along the NSR is largely based on the UNCLOS and the IMO doctrines, which have been adopted into the national legislation of the Russian Federation (Figure 18). Moreover, in some respects the regional entities, business and private law, industrial bodies and research endeavors contribute to the regulatory environment. The purpose of Figure 18 is neither to provide an exhaustive list nor reflect the hierarchy of the actors involved, but to show the complexity of the situation.

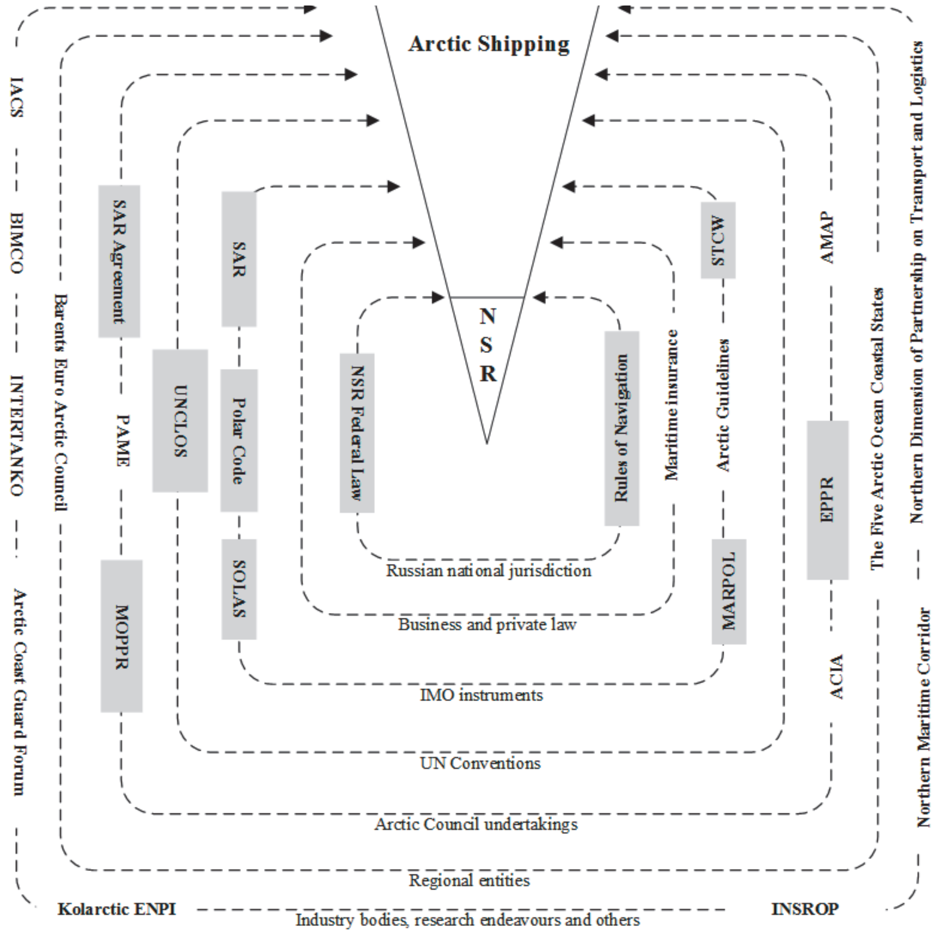

Figure 18 Exemplified regulatory environment of the Northern Sea Route (legally binding multilateral agreements highlighted in grey)

Russia aligns its governance over the NSR based on Article 234 of UNCLOS, which allows the coastal state a right to unilaterally adopt and enforce laws and environmental regulations in its Exclusive Economic Zone (EEZ) where ice coverage causes exceptional hazards to navigation, and where the environment is especially vulnerable (Ragner 2000b). This interpretation has allowed Russia to enact laws regarding icebreaking and its fees.

Some of the littoral states (e.g. Russia and Denmark) have made claims that UNCLOS Article 76 provides legal grounds for the expansion of their national territories in the Arctic Sea. Usually the EEZ extends up to 200 nautical miles (NM) from the baseline, but it may be extended up to 350 NM, provided that there is a natural prolongation of the land territory. However, Russia and other littoral states are already bound to organize and coordinate SAR activities in their respective area extending beyond the EEZ boundaries (NSRIO 2016b).

UNCLOS contains some contradictory elements, which have raised questions, namely from the USA over the legitimacy of Russia's NSR control. Article 37 "international straits" stipulates that the regime of transit passage applies only to straits which are used for international navigation (e.g. Molenaar 2014). In 2008, five Arctic Sea littoral states (Canada, Denmark, Norway, Russia, and the USA) released the Ilulissat Declaration that manifests their will to settle their overlapping area claims under the auspice of the UNCLOS.

The Arctic Council (AC) is an intergovernmental forum established by the circumpolar states in 1996 after the Ottawa Treaty. AC functions as a cooperative medium primarily addressing issues in relation to sustainable development and environmental protection in the Arctic. Its mandate excludes sovereignty and military related issues. AC is based on a soft law format, meaning that its decisions are usually non-legally-binding. There are two important exceptions to the general rule. In 2011, a legally-binding treaty on SAR preparedness was signed and was followed in 2013 by an agreement on cooperation on Marine Oil Pollution Preparedness and Response (MOPPR) (Solli et al. 2013; Molenaar 2014). These exceptions are expected to entail only a partial change in AC's policy. Kao et al. (2012) argue that the regime will not shift from soft to hard law, i.e. legally-binding conventions. Rottem (2015) supports the notion by asserting that AC's focus is to remain in decision-shaping and to facilitate communication rather than be a decision-making body.

So far the instruments of IMO dedicated to Arctic shipping have been inadequate as they have only consisted of recommendatory standards: the Arctic Shipping Guidelines and the Polar Shipping Guidelines, which are non-legally binding in nature (IMO 2002; 2010). In order to tackle this deficiency, IMO has been designing a mandatory International Code for Ships Operating in Polar Waters (the Polar Code), which is finally expected to enter into force on the first of January 2017 (IMO 2016). The Polar Code is built on the existing framework and encompasses a wide range of design, construction, equipment, and operational requirements for improving maritime safety. It contains mandatory measures covering the safety and the prevention of pollution while also providing recommendatory provisions. However, some important issues are not included, like the spillage of residual heavy fuel oil (HFO) and CO_2 emissions (Sakhuja 2014). There are contradictory expectations regarding the implications of the Polar Code with respect to the future use of the NSR. Lee and Kim (2015) note that some shipping companies expect it to promote shipping while others view it as setting the bar for the activity.

Unlike the most areas of shipping, the practice of marine insurance is not regulated by any international convention. Instead, it is laid down in law at a national level as a business and private matter. Other influential actors in shaping the regulatory environment of the NSR are industry bodies, such as the International Association of Classification Societies (IACS), and joint voluntary meetings of government officials, like the Arctic Coast Guard Forum. It was established on 30 October 2015 to develop a common situational awareness (Østhagen 2015). Regional entities, like the Barents Euro-Arctic Council, may also contribute (see e.g. BEATA 2013).

4 THE NORTHERN SEA ROUTE AS A SHIPPING ROUTE AND A MARITIME SYSTEM

4.1 Definition

Russian law defines the NSR as covering the water area adjacent to the Northern coast of Russia, comprising the internal waters, the territorial sea and the adjacent zone and the EEZ (Russian Federation 2012). In the East, the NSR extends to the line of maritime demarcation with the USA and the Cape Dezhnev parallel in the Bering Strait. In the West, it encompasses up to the meridian of Cape Zhelania to the Novaya Zemlya archipelago, where the eastern coastline of the Novaya Zemlya Archipelago and the western borders of the Matochkin Strait, the Kara Strait and the Yugorsky Strait constitute its boundaries (Figure 19).

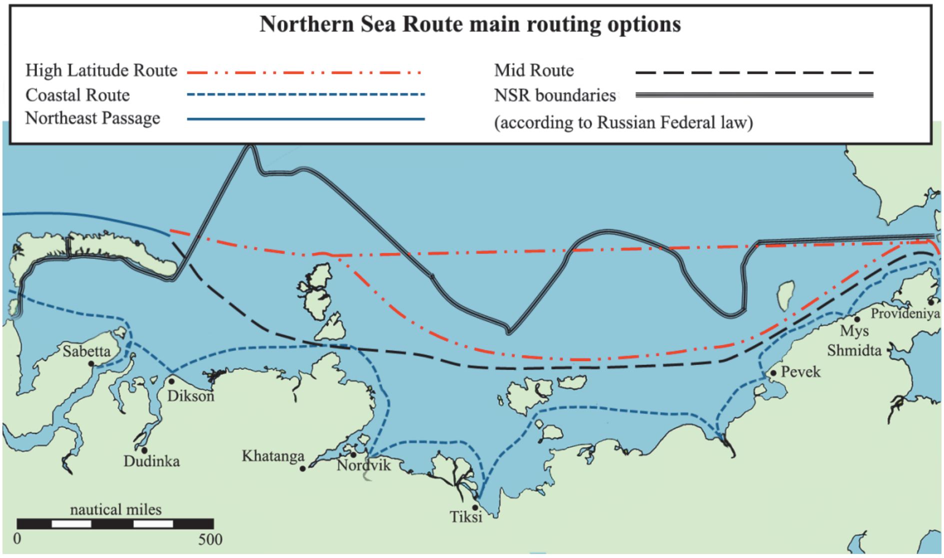

Figure 19 The boundaries and main routing options of the Northern Sea Route

Compared to other shipping routes, the NSR has a rather broad definition, which is attributed to the physical characteristics of the route. The NSR contains all possible routes through the numerous straits, passages, and island groups north of the Eurasian land mass and the four epicontinental seas: Kara, Laptev, East Siberian and Chuckhi Sea (Mulherin 1996). In total, there are three main route options within the NSR: 1) the Coastal Route; 2) the Mid Route; and 3) the High Latitude Route. The actual route choices are based on the vessel dimensions and prevailing ice conditions (Drent 1993). The factual distances of the routes range between 1,970 and 3,500 NM (Google Earth 2015).

4.2 Navigational conditions along the NSR

Bathymetry and ice are two features that largely characterize navigation along the NSR (Stephenson et al. 2014). The Russian Arctic continental shelf has a shallow bathymetry, imposing draft limitations on the ships sailing along the NSR (Figure 20). Similarly, almost all activity along the NSR is constrained by ice apart from brief ice-free periods in the autumn.

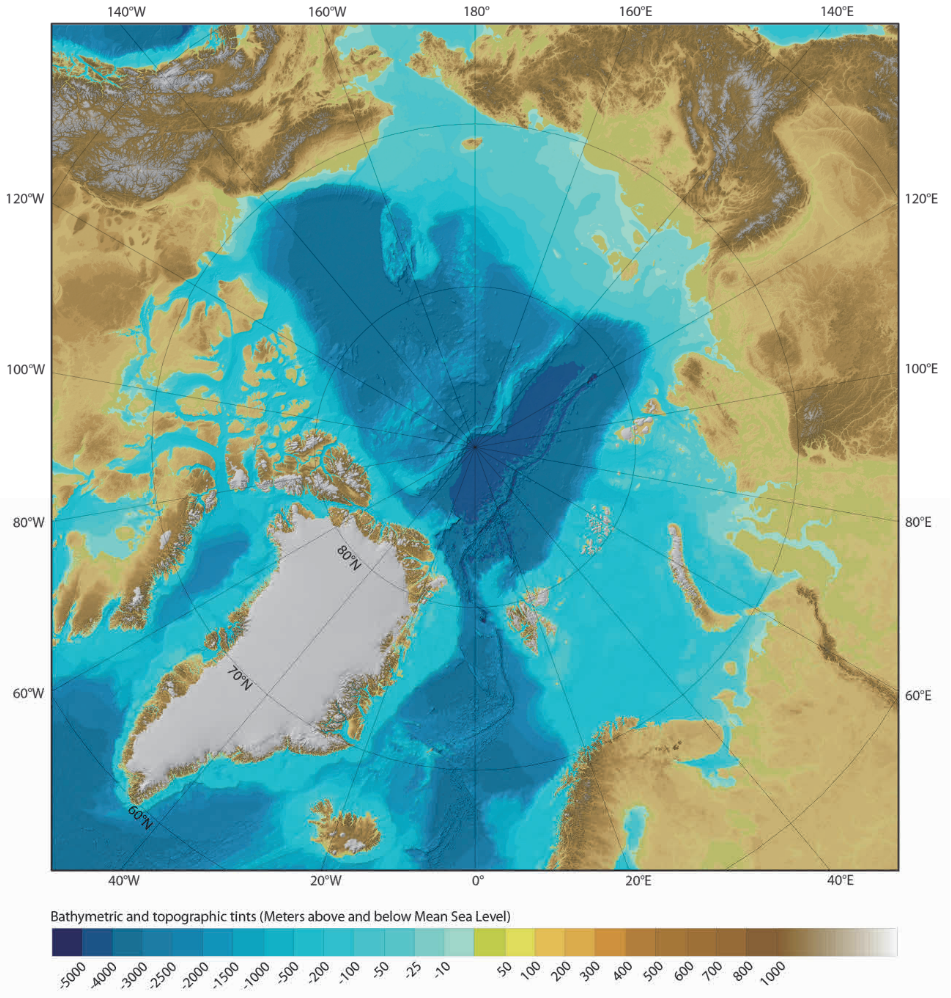

Figure 20 The Arctic Sea's bathymetry (Jakobssen et al. 2012 reproduced with permission)

The issue of shallowness is exacerbated along the Coastal Route and is significant between narrow points, where several straits have prohibitively shallow waters (Figure 21). In particular, the straits of Matochkin, Yugorsky, Dimitry Laptev and Sannikov have noticeably low water depths (Table 7).

A= Matochkin Strait	C= Yugorsky Strait	E= Vilkitsky Strait	G= Dmitry Laptev Strait
B= Kara Gate	D= Shokalsky Strait	F= Sannikov Strait	H= Long Strait

Figure 21 The key seas, capes, islands and straits along the NSR

Each of the three NSR routing options has individual features. The Coastal Route has the longest distances and shallowest waters, but on the other hand, ice conditions are usually the lightest. In contrast, the Mid Route has higher water depths but ice is more likely to be encountered. Recent thawing has opened also the High Latitude Route for short periods offering greater water depths and the shortest geographical distances.

Table 7 The physical characteristics of the straits along the Northern Sea Route (Mulherin 1996; New World Encyclopedia 2016)

Name of the Strait	Depth (m)	Length (NM)	Width (NM)
Matochkin (A)	12	55	1
Kara Gate (B)	21	18	14
Yugorsky (C)	12	21	6
Shokalsky (D)	37	80	10
Vilkitsky (E)	25	60	30
Sannikov (F)	13	120	16
Dmitry Laptev (G)	6.7	63	30
Long (H)	20	–	75
Bering	30–50	–	46

The route choice decision has implications for vessel design. Traditionally, if the itinerary included port calls, the maximum dimensions were 9 meters in draft and 30 meters in beam, restricting the vessel capacity to 20,000 DWT (Brubaker and Ragner 2010). By choosing a more northern route, the size can be increased up to 50,000 DWT, taking into account the 12.5 meter draft and 30 meter breadth restrictions (Ragner 2000b), which are equivalent to 4,500 TEU in containerships (Liu and Kronbak 2010). The former restriction refers to the depth of the straits and the latter to the maximum width of the Arktika-class nuclear icebreakers.

Nowadays all of the previous restrictions are being relaxed to some degree. One deeper port (Sabetta) is under construction, larger icebreakers (width 34 meters) are being built and thinning ice-cover has opened a deep-draft route. Such development has occasionally enabled Suezmax-sized tankers to sail along the NSR. For example, in 2011, *MT Vladimir Tikhonov* with 162,000 DWT transported 120,000 tonnes of gas condensate through the NSR (NSRIO 2016a). Although the vessel was not fully laden and was escorted by two icebreakers, it still opened a new era with regard to the vessel sizes.

The length of the annual navigational season follows the changes of ice-cover. Spatially heterogeneous conditions prevail along the NSR in terms of annual, seasonal and regional variation in the East-West and North-South axis (e.g. Stephenson et al. 2014). The most sheltered ice conditions typically prevail in the western parts of the NSR and near the continent. The ice encountered along the NSR is one-year old and has a maximum thickness up to 1.6 meters, which means that it melts every summer (NSRIO 2016e). The entire NSR can usually be free of ice between September and October. During that period, a vessel may be able to maintain a reasonable speed that is equivalent to open-water routes. With the help of icebreakers, the navigational season can be extended from late June to early December.

The present-day conditions along the NSR include numerous potentially hazardous weather and natural phenomena, like extreme temperatures, chilly winds, fog, poor visibility and darkness (Table 8). Some studies suggest (e.g. Bourbonnais and Lasserre 2015) that the melting ice may have adverse effects on maritime activity. Even though the navigability of the NSR would improve, substantial challenges remain including icing caused by sea spray and polar storms. Moreover, the melting ice and longer ice-free periods increase the risk of icebergs (e.g. Østreng et al. 2013).

Table 8 The typical meteorological conditions along the NSR (JHC 2012)

NSR water area	**Kara Sea**	**Laptev Sea**	**East Siberian Sea**
Winter season	October-May	October-June	October-May/June
Typical temperature (°C)	-26	-30	-21
Extreme temperature (°C)	-48	-50	-48
Ice thickness (m)	1.8-2.5	1.6-2.5	1.2-2
Summer season	June-September	July-September	Mid June-September
Typical temperature (°C)	7	8	15
Extreme temperature (°C)	20	26	30
Foggy days	100	75	80

The actual sailing speeds and implicit transit time largely depend on the ice and weather conditions but also on the availability of icebreaker assistance. Delays of several days, due to the need to wait for the organization of the escorts, have been reported (Lee and Kim 2015). This means that the shortest path will not always be the fastest.

4.3 Geographical distances using the Northern Sea Route

The main advantage of the NSR is linked to its shorter sailing distances between the Atlantic and Pacific Oceans compared to the principal canal routes. From the Northwest European ports to destinations located in the Northern Pacific, the distance advantage is up to 50 per cent shorter, but diminishes the further south the port is located. Equidistance signals the geographical location where the distance is similar for both SCR and NSR options. For example, the equidistance from Le Havre extends to Darwin Australia.

Although the NSR's shorter geographical distance enables, in principle, savings in the duration of the voyage, the effects of the actual conditions on sailing speeds should not be neglected. Table 9 illustrates the NSR's distance advantage both in absolute terms and in time by using a 12 knots average speed within the NSR area and 18 knots elsewhere.

Table 9 Savings (%) in sailing distance (on the left) and time (on the right) through the NSR compared to the Suez and Panama Canal routes (advantages over 20 % highlighted in orange) (Portworld Distance Calculator 2015) [5]

NSR distance advantage (%)	**Origin port**								**NSR time advantage (%)**	**Origin port**							
Destination port	Lissabon, PT	Le Havre, FR	Antwerp, BE	Hamburg, DE	Turku, FI	Gothenburg, SE	Narvik, NO	Murmansk, RU	**Destination port**	Lissabon, PT	Le Havre, FR	Antwerp, BE	Hamburg, DE	Turku, FI	Gothenburg, SE	Narvik, NO	Murmansk, RU
Nome, US	57	53	55	57	55	58	67	71	Nome, US	47	41	43	45	44	46	55	60
Dutch Harbor, US	52	45	47	50	48	51	60	65	Dutch Harbor, US	42	33	35	38	37	39	48	53
Tomakomai, JP	29	41	43	45	45	47	56	59	Tomakomai, JP	17	30	32	34	35	36	46	49
Yokohama, JP	23	36	38	40	40	42	52	57	Yokohama, JP	11	25	27	29	30	31	42	47
Busan, KR	17	31	33	35	36	37	48	53	Busan, KR	4	19	22	24	25	27	37	43
Shanghai, CN	9	24	26	29	30	31	42	48	Shanghai, CN		12	15	18	19	20	32	38
Vancouver, CA	7	21	24	28	27	29	39	46	Vancouver, CA		7	10	14	14	15	25	33
Kaohsiung, TW		16	18	21	23	24	36	42	Kaohsiung, TW		3	6	10	12	12	25	31
Hong Kong, HK		12	14	18	19	20	33	39	Hong Kong, HK			2	6	8	8	21	28
Manila, PH		8	11	14	16	17	30	36	Manila, PH				2	5	5	18	25
San Francisco, US		8	12	16	16	17	28	36	San Francisco, US				1	2	2	13	22
Darwin, AU		1	3	7	9	10	22	29	Darwin, AU							11	18
San Diego, US			2	6	7	8	19	28	San Diego, US							4	13
Ho Chi Minh City, VN				2	5	5	19	27	Ho Chi Minh City, VN							7	15
Singapore, SG							9	17	Singapore, SG								5
Jakarta, ID							8	16	Jakarta, ID								4
Fremantle, AU							6	15	Fremantle, AU								4
Yangoon, MMR								3	Yangoon, MMR								
Chennai, IN									Chennai, IN								

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[5] Calculated by using the NSR routing: Kara Gate-Vilkitsky Strait- North of the New-Siberian Islands- Long Strait (See Figure 21)

The effects of the NSR's slower speeds relative to the principal canal routes in terms of the distance advantage are notable. For example, from Ho Chi Minh City the distance advantage is valid up to Hamburg, Germany, while if time is considered the advantage extends only up to Narvik, Norway. The distance between these two points is around 1,000 NM.

4.4 Operational procedures

The administration of the NSR is organized in a way that the Northern Sea Route Administration (NSRA) is the government body responsible for the facilitation of safe shipping, including the issuance of navigational permits, provision of weather and navigational information, and the coordination of SAR activities (NSRA 2016). The Federal State Unitary Enterprise (FSUE) Atomflot provides icebreaker assistance and ice-pilots, if needed.

The organization of the two relevant NSR authorities belongs to different government agencies. Since 2008, the nuclear icebreaker fleet has been under the authority of the FSUE Atomflot, which is a subsidiary of the Russian State Atomic Energy Corporation, Rosatom, which is responsible for all nuclear related activities. Hence, it is de facto under the direct control of the president of the Russian Federation. In contrast, the NSRA is a federal institution under the Federal Agency of Sea and River Transport, which, in turn, reports to the Russian Ministry of Transport (NSRA 2016). The interplay between the various state bodies and their conflicting interests may cause challenges in terms of the NSR development (e.g. Moe 2014).

Navigational permits to use the NSR may be requested from the NSRA via email with an application form containing the relevant details of the voyage and ship (NSRA 2016). In order to be allowed to enter the NSR, the ships need to be compatible with certain technical requirements relating to, among other things, the ice-class. The predominant ice-classes of ships along the NSR in most cases fall into categories equivalent to Finnish-Swedish Ice-Class Rules (FSICR) IA and IAS (NSRIO 2016a; see also Chapter 4.6.4). If there are favorable ice conditions ships with lower ice-classes are allowed to enter the route (NSRIO 2016c).

If the application is accepted, the ship owner must contact FSUE Atomflot to organize icebreaker assistance and the settlement of the fees. This, a rather complicated procedure, has been deemed especially time-consuming (e.g. Moe 2014). Also the separate issue of ice-piloting must be resolved, which is mandatory when there is inadequate crew experience regarding ice navigation (NSRIO 2016c).

After agreeing the icebreaking formalities, the actual navigation along the NSR in most cases takes place in a way that ice-class ships sail in the wake of Russian icebreaker(s). The icebreaker led formation is known as an ice-convoy[6]. However, over the past few years, especially during the brief ice-free season, some ships have been allowed to sail independently provided that favorable conditions prevail.

4.5 Maritime activity

This sub-chapter elaborates on the current diversified shipping activities taking place along the NSR. In the first part, the types of traffic and demand drivers behind them are identified, while the second part elaborates on the actual cargo volumes.

4.5.1 Traffic types and their drivers

All maritime activity within the boundaries of the NSR may be segregated into three separate traffic types depending on the nature and direction of the activity. The intertype segmentation of the traffic is essential because the changing environment influences the segments differently (Guy and Lasserre 2016). More importantly, the demand drivers, i.e. the factors determining the need for each activity, are different (Sander et al. 2014). Following the Arctic shipping activity typology of Sander et al. (2014), the three traffic types in the NSR context are:

- Transit
- Destinational
- Internal.

4.5.1.1 Transit traffic through the NSR

The strict Western definition of transit traffic refers to navigation that passes through the NSR's entire length without port calls, using it as a transport corridor between the Pacific and Atlantic Oceans (e.g. Arctic Council 2009). However, there are discrepancies over the meaning of transit traffic (e.g. Gritsenko and Kiiski 2016). Typically, in Russia, all activity that traverses the route, regardless of any port calls made within the NSR area, is predominantly denoted as transit. Especially in the mass media, the interchangeable meanings often tend to cause misperceptions over the actual nature of NSR shipping activity.

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[6] For more information about convoy practices see e.g. Goerlandt et al. (2016)

In this thesis, unless otherwise stated, transit refers to the Western terminology. The primary driver for transit traffic operating in open-market conditions is its relative cost competitiveness against conventional routes (e.g. Sander et al. 2014). For shortcuts like the NSR, the attractiveness of the route increases if fuel prices are high (e.g. Liu and Kronbak 2010).

4.5.1.2 Destinational traffic in the NSR

Destinational traffic involves all types of movement to and from the NSR, including fishing, tourism, scientific expeditions and resource extraction related activity. In this respect, the transport of oil and gas constitute the principal commodities (e.g. Buixadé Farré et al. 2014), of which the demand is dependent on several factors (Wijnolst and Wergeland 2009; Lacoste and Comtois 2012):

- The size of the resource base
- Total resource demand
- Distribution of demand
- Developments in the producing and exporting areas
- Distance implications of the trade patterns
- Development of commodity markets, especially the prices of hydrocarbons.

4.5.1.3 NSR internal traffic

Internal traffic refers to activity taking place within the borders of the NSR. The activity is usually associated with the supply of settlements and industrial sites. It is driven by the socio-economic development of the region (Guy and Lasserre 2016). This market does not follow open market mechanisms as it is mostly politically and pragmatically guided with regard to demographic features of the area (Brooks and Frost 2012; Pelletier and Guy 2015).

4.5.2 Traffic volumes

The NSR has a long history as a former Soviet and now Russian domestic waterway. After the collapse of the Soviet Union volumes plummeted, but have been recovering for almost a decade (Figure 22).

Destinational and internal traffic have contributed to the bulk of the volume, while transit has produced only two brief periods of activity: the first in the 1990s and the second during the past decade. In this regard, there are contradictory references in the literature over the first international NSR transit. Some studies suggest that a Finnish tanker *MT Uikku* in 1997 was the first Western merchant ship to sail through the NSR after the collapse of the Soviet Union (e.g. Brubaker and Ragner 2010). However, other studies, such as Drent (1993) and Gritsenko and Kiiski (2016), argue that the first vessel was a French polar supply vessel *MS L'Astrolabe* in 1991. The differing opinions may be a result of the scientific nature of *MS L'Astrolabe*'s voyage which had only a negligible commercial purpose.

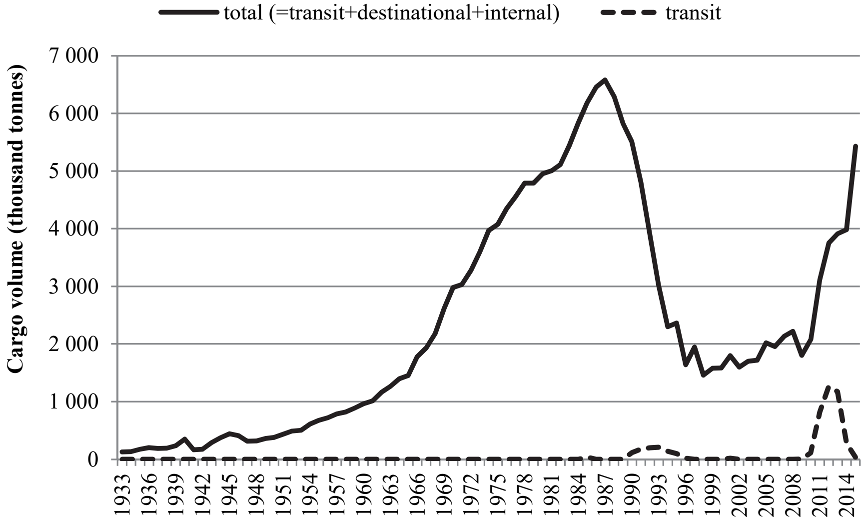


Figure 22 The Northern Sea Route cargo volumes 1933–2015 (NSRIO 2016a)

Maritime activity 2007–2015 along the NSR, which official Russian statistics denote as transits, is presented in Table 10. From 2007 to 2013, transit volumes in the NSR experienced, in relative terms, a brief period of nascent continuous growth. Most of the activity by ship type concentrated on the general cargo, bulker and tanker categories, while only a few LNG-carriers and no containerships (FCC) using the NSR. In 2014, increased geopolitical tensions together with plummeting oil prices ended this trend and, after years of continuous growth, the number of transit voyages decreased from 71 in 2013 to 31 in 2014 and only 18 in 2015 (NSRIO 2016a).

Table 10 The division of the NSR's transit traffic volumes 2007–2015 according to ship and traffic types (NSRIO 2016a)

Year	Total ****)	International *)	Traffic type		Ship type						
			Transit	Dest. **)	General cargo	Tanker	Bulker	LNG	FCC	Cruise	Other
2015	18	8	18	–	4	2	–	–	–	1	11
2014	31	7	31	22 ***)	15	27	1	–	–	3	7
2013	71	29	41	30	18	37	5	2	–	1	8
2012	46	28	38	8	–	25	10	2	–	–	9
2011	41	20	38	3	4	17	4	–	–	1	15
2010	13	6	10	3	3	2	1	–	–	1	6
2009	5	3	3	2	–	3	–	–	–	–	2
2008	3	3	2	1	2	–	–	–	–	–	1
2007	2	2	1	1	1	–	–	–	–	–	1

*) includes vessels with non-Russian flag and/or involved in international trade (i.e. the origin or destination outside Russia)

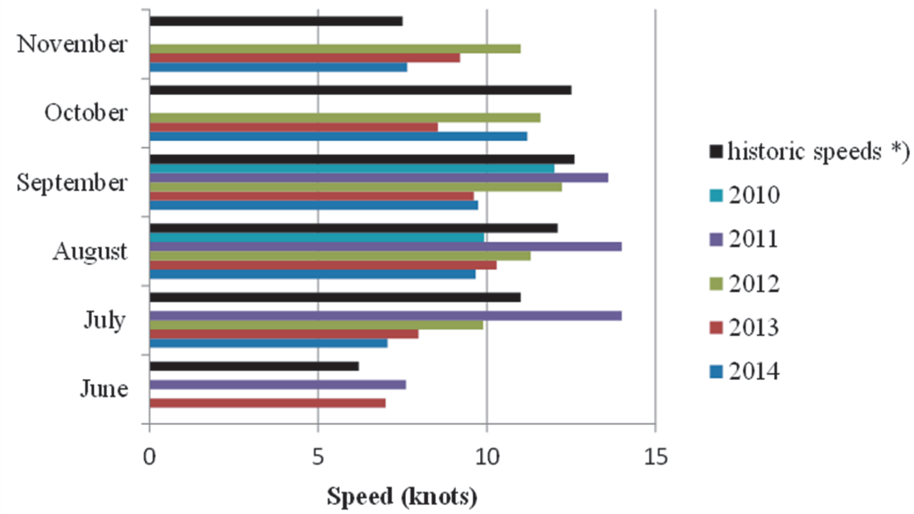
**) Compiled by the author based on NSRIO (2016a) data

***) For the first time official statistics separated destinational traffic from transit volumes

****) Russian official transit statistics according to NSRIO (2016a)

The in-depth analysis reveals that a substantial proportion of the recorded transits were connected to Russia, including domestic trade or Russian-flagged vessels. In addition, 30 destinational voyages were recorded as transits in 2013.

Given the extraordinary operating environment of the NSR, vessel speeds provide a valuable indicator of the nature of the activity. Figure 23 contains the compiled average speeds per month of the transits 2010–2014. A distinctive feature of the speeds is the substantial monthly variation. It seems that the highest average speeds (around 12 knots) are achieved during the August to October period. This stems from the annual cycle of ice formation along the NSR because the ice-free period usually occurs within this period.



*) Based on Norilsk SA-15 type vessel activity in late 1980s
(Wergeland 1992 after Liu and Kronbak 2010)

Figure 23 The average speeds of transit voyages per month 2010–2014 (NSRIO 2016a) and average speeds from the 1980s

The average sailing speeds of the Norilsk SA-15 cargo ships along the NSR in the late 1980s, offer a point of reference to evaluate the development of transit speeds. It appears that the despite recent climate changes the speeds have not changed much. In fact, they appear to have remained similar to those of two decades ago. However, this finding has to be considered with a few limitations in mind. First, the historic speeds consist of activity most likely taking place in the western part of the NSR where conditions usually tend to be easier. Second, the design speeds of SA-15 are not comparable with the ones of containerships, which could use speeds well above 20 knots.

Regardless of the statistical discrepancies, between 2011 and 2013 there indeed was a brief glimpse of international interest as the number of purely international voyages reached over 20 for three consecutive years. The detailed descriptions of the cargoes transported within this period are shown in Figure 24.

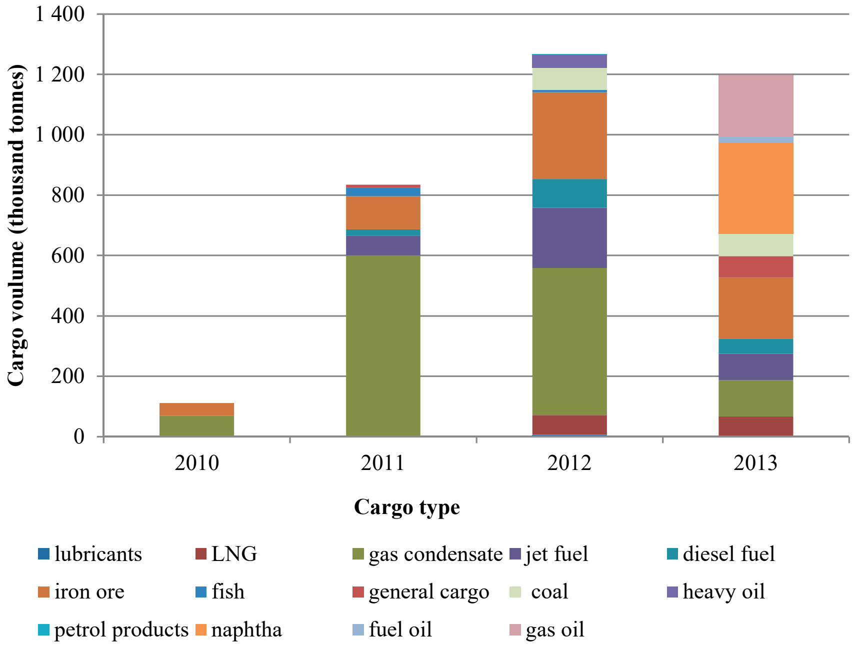


Figure 24 The contents of transit cargo along the NSR 2010–2013 (NSRIO 2016a)

The majority of the transported cargo falls into the wet and dry bulk categories. During this four-year period, the share of gas condensate has been substantial (especially in 2011–2012) but subsequently shows a decreasing trend. Containers are a key cargo type in global shipping but are yet to be seen in large numbers along the NSR. The share of ballasting ships is at least one third of all voyages. According to Moe (2014) this indicates that trade is heavily unbalanced due to a shortage of suitable return cargoes.

To sum up, despite the recent media perception of increasing international interest in NSR transits, it appears that most of the media publicity was a result of differences in statistics practices. Furthermore, there are no signs that shipping along the NSR would be increasing rapidly, instead a fleeting glimpse of international interest due to high oil prices and an enthusiasm for testing the potential of the route was seen. Most of the voyages were not regular but of an experimental nature and were largely sponsored by the governments of Russia and the Northeast Asian states and they did not express any long-term commitment (e.g. Moe 2014). In fact, purely Russian origin and destined voyages comprised the majority (see e.g. Humpert 2015).

With these observations in mind, it is worth analyzing how the situation has developed during the past few years in terms of traffic and cargo types along the NSR (Table 11).

Table 11 The division of activity along the NSR 2013–2015 according to cargo and traffic type (thousand tonnes) (NSRIO 2016a)

Year	Transit	Internal and destinational					
		Oil & oil products	Gas condensate	Coal	Ore concentrate	Other dry cargo	Total volume
2013	1 176	606	126	419	34	1 673	2 858
	41 %	21 %	4 %	15 %	1 %	59 %	
2014	274	757	125	230	81	2 510	3 703
	7 %	20 %	3 %	6 %	2 %	68 %	
2015	40	860	114	356	80	3 983	5 432
	1 %	16 %	2 %	7 %	1 %	73 %	

Over the past three years, it appears that transit traffic has lost its momentum while the roles of destinational and internal traffic have increased. The share of transit traffic has dropped from 41 per cent to 1 per cent in just three years. In contrast, the share of internal and destinational traffic has increased. According to cargo types, the share of "other dry cargo" had increased up to 73 per cent by 2015. This cargo type is mostly associated with the supply of Russian domestic projects for the building of Arctic settlements and industrial sites.

4.6 Maritime infrastructure

The functionality of the NSR relies on extensive maritime infrastructure comprising port facilities, navigational aids as well as the fleet of icebreakers and ice-classed ships, including their experienced crews (Bukharin 2006).

4.6.1 Ports

Overall, there are very few ports within the basin of the Arctic Sea. The most important ones in volume-terms are Churchill in Canada, Prudhoe Bay in the USA and Murmansk in Russia. With regard to the NSR, Murmansk constitutes the first major port after exiting the route from the West. In total, there are less than a dozen ports along the NSR and they are often small-sized, poorly equipped and in poor condition as they date from the Soviet era (Table 12).

Table 12 Russia's major Arctic ports (NSRIO 2016d; OAO Novatek 2014)

Port	Main cargo types	Depth (m)	Berth length (m)	Operational period	Facilities
Murmansk	GC, B & C	15	265	Year-round (ice-free)	Ship repair, warehousing, cranes, railway ramps etc.
Sabetta **)	LNG	13	n/a	Year-round *)	n/a
Dudinka	GC & C	12	260	Year-round *)	Cranes, forklift, railway ramps
Dikson	GC & B	14	100	Year-round *)	Ship repair, mooring berth, storages
Khatanga	GC & B	4.6	350	June-September	Cranes, forklifts
Tiksi	GC, B & C	5.6	158	July-October	Cranes, forklifts, storages
Pevek	GC & B	9.0	186	July-October	Cranes, forklifts, storages
Provideniya	GC, B & C	10.2	147	May-December	Ship repair, cranes, forklifts, storages
*) = icebreaker assisted passage, **) due to open in 2017					
B = bulk, GC = general cargo, C = containers, LNG = Liquefied Natural Gas					

Most of the ports are open seasonally with the exceptions of Murmansk, Sabetta, Dudinka and Dikson. These ports largely handle general and bulk cargoes. The port of Sabetta, due to open in 2017, will specialize in LNG-cargoes. Limited ship repair facilities pose challenges as Dikson is the only port along the NSR to provide such services. Furthermore, the water depths in the port quays are considerable hindrances as Murmansk is practically the only one with the capacity to accommodate large-sized vessels.

4.6.2 Navigational aids

Regardless of the movements of the ice, harsh weather will remain an obstacle to navigation along the NSR (Hill et al. 2015). Increasing maritime activity also increase the risk of accidents; some narrow escapes along the NSR have already taken place. In September 2013, tanker *MT Nordvik* was struck by an ice floe while sailing in the Matisen Strait resulting in a ruptured ballast tank (NSRIO 2013). Eventually, after repairs and off-loading the cargo, the vessel was able to exit the NSR area without any damage to the environment.

In order to mitigate the risks involved, technical solutions are needed to address the possible risks of collisions, groundings, on-board fires, machinery breakdowns and medical emergencies. The navigational aids for dealing with the aforementioned issues, include reliable nautical charts, onboard navigation systems, satellite communication and fast SAR services (Hill et al. 2015). Most of the existing technology is designed for conventional maritime conditions but neglects the challenges posed by the Arctic. This is especially relevant in terms of escape, evacuation and rescue equipment (Gunnarson 2015).

Accurate ice and weather information are essential prerequisites for sustaining safe shipping through the treacherous Arctic waters. The hydrographic data of the NSR has a varying level of quality. In most cases it is inadequate as a detailed topography is available for about 90 per cent of the Arctic routes (Arctic Council 2009).

Modern navigation relies on marine communication systems, which are dependent upon satellite coverage. In high latitudes, where the NSR is located, connections provided by satellites that use the traditional geostationary orbits are limited, resulting in gaps in coverage. The connections start to deteriorate when passing 72° North latitude and after 75° North latitude they become unreliable (Gunnarson 2015). In this regard, one solution would be to use satellites with highly elliptical orbits, which have a better coverage in high altitude regions (WMO 2013).

The scarcity of places of refuge due to the shallow ports along the NSR emphasizes the need for alternative solutions. In this respect, land-based support infrastructure, i.e. SAR facilities are essential. The NSR comprises one SAR region, which is controlled by the Maritime Rescue Coordination Center located in Dikson and two Maritime Rescue sub-centers in Pevek and Tiksi (NSRIO 2016b). Only Dikson operates year-round whereas Tiksi and Pevek are open from July to October (Gunnarson 2015).

Since the demise of the Soviet Union the SAR capacity of the NSR has been in decline. Recently, Russia has published ambitious plans to develop the shore-based infrastructure by investing around 30 million USD in order to establish 10 SAR centers in the ports of Murmansk, Arkhangelsk, Naryan-Mar, Vorkuta, Nadym, Tiksi, Pevek, Provideniya, and Anadyr (Pettersen 2011). However, only three of the planned rescue stations were operational in 2015 (NSRIO 2016b).

This means that substantial parts of the NSR lie outside SAR coverage. On top of that, the capacity of the rescue equipment, consisting of vessels, aircrafts and helicopters, is impaired by the limited coverage of the fueling depots and airfields as well as the restricted icebreaking capacity of the rescue vessels (Gunnarson 2015).

In practice, Russian icebreakers are the only potential respondents in cases of emergency. In addition, dealing with oil spills is extremely challenging in Arctic waters due to limited support for clean-up activities and the extreme climate conditions. The mechanical oil spill recovery rate in ice is estimated to account for only around 1–5 per cent (Knol and Arbo 2014).

4.6.3 Icebreakers

Although relatively few in number, icebreakers are essential in places where the sea freezes every winter, let alone in the Arctic. Russia has traditionally been committed to using icebreakers. It has the highest number of active and newbuilding orders of icebreakers in the world (Table 13).

Table 13 The world and Russian active icebreaker fleet including newbuilding orders as of January 2015 (CRSL 2015)

	Total World fleet	Russian flagged		
		Total	Nuclear-powered	Diesel-powered
Icebreakers *)	86	36	6	30
	100 %	42 %	7 %	35 %
Newbuildings	14	13	3	10
	16 %	93 %	21 %	71 %
*) number includes also offshore supply vessels				

The icebreakers constitute a key facilitator for safe passage along the NSR due to the ice-infected waters, long distances, remoteness and rudimental port network. According to Russian law, only Russian icebreakers are allowed to provide services along the NSR (NSRIO 2016c). Contemporary seasonal shipping requires icebreakers and especially so at the beginning and at the end of the navigational season. On the other hand, during the ice-free season a back-up emergency response capacity is needed. The need for icebreakers is expected to increase if there is a further decline of ice and an increase in traffic volumes (e.g. Stephenson et al. 2014; Klimenko 2014).

Russia has a fleet of the world’s most powerful nuclear-powered icebreakers, which were largely built during the Soviet era. After the demise of the Soviet Union, there was a period of icebreaking overcapacity because of the modest activity along the route (Ragner 2000b). However, during the last decade the situation started to change. Uncertainties over the financing the expensive newbuilding projects caused Russian newbuilding activity to be suspended for over a decade. An ageing fleet, with no renewals since 2007, and gradually recovering activity along the NSR provided the basis for claims that demand for icebreaking would soon surpass the available capacity (e.g. Ragner 2000a; Moe 2014).

While settling the funding issues of the renewal of the icebreaker fleet, Russia has adopted a policy of refurbishing their ageing nuclear icebreakers by conducting reactor service life extensions (Bukharin 2006). Without these procedures, most of the icebreakers would have already reached the end of their service life (Figure 25). Finally, during the past few years, Russia has been able to commence several newbuilding projects in order to replace the fleet with new generation nuclear icebreakers.

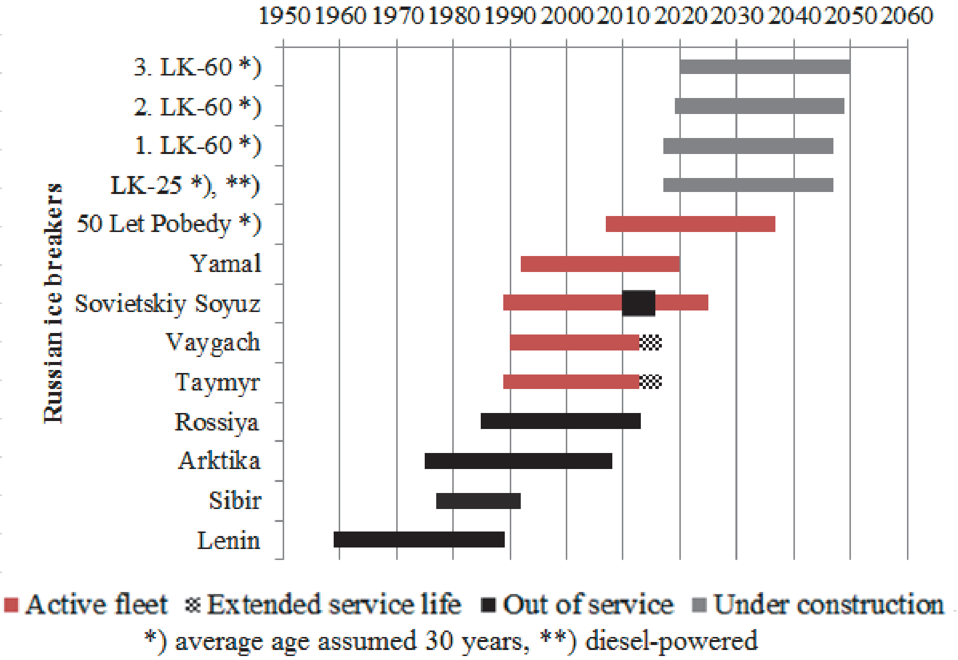


Figure 25 The projected service life of Russia's active and retired nuclear icebreaker fleet including newbuildings (Moe 2014; Korolkov 2014)

A lack of icebreaker capacity is likely to be noticeable in the form of delays, particularly if NSR traffic increases (Marken et al. 2015). While the media and Russian government officials have already promoted the ostensibly fast transit times of the NSR, the actual times that ships need to wait before being allowed to enter the route are not disclosed. There are no official statistics on the topic; however, some indications exist. For example, Lee and Kim (2015) cited that five days of delay occurred during the trial voyage of the Korean shipping company, Hyundai Glovis.

Assessing the future icebreaking capacity has proven challenging as it depends on several factors. Despite the upcoming fleet renewals, the capacity may not be able to sustain growth at the level intended (Moe 2014). In particular, there is an uncertainty over the actual icebreaking capacity needs of the Yamal-LNG project. In principle, the Arctic LNG carriers would be capable of independent operations year-round (OAO Novatek 2014). However, the economics of such operations may be questionable (e.g. Guy and Lasserre 2016), on the other hand, if icebreakers are needed, a capacity deficit may arise.

4.6.4 Ice-classed fleet

Ice-class vessels constitute one of the key elements of the Arctic maritime system and their demand is projected to follow the level of shipping activity (Sakhuja 2014; Stephenson et al. 2014). Ice-class is a concept that refers to the technical standards of vessels operating in waters affected by ice, ensuring an adequate level of safety and operational performance. The implementation of ice-class rules is unharmonized as each classification society and maritime authority has created their own regimes. However, some equivalency exists between them.

Figure 26 presents a rough equivalency between various ice-class schemes in terms of a ship's structural strength. Requirements pertaining to the strengthening of a ship's hull are commonplace, but the Finnish-Swedish Ice-Class Rules (FSICR) lay down standards for minimum engine power as well. In first-year ice-conditions, which resemble those along the NSR (NSRIO 2016e), the FSICR is often considered an industry standard (e.g. Riska 2010).

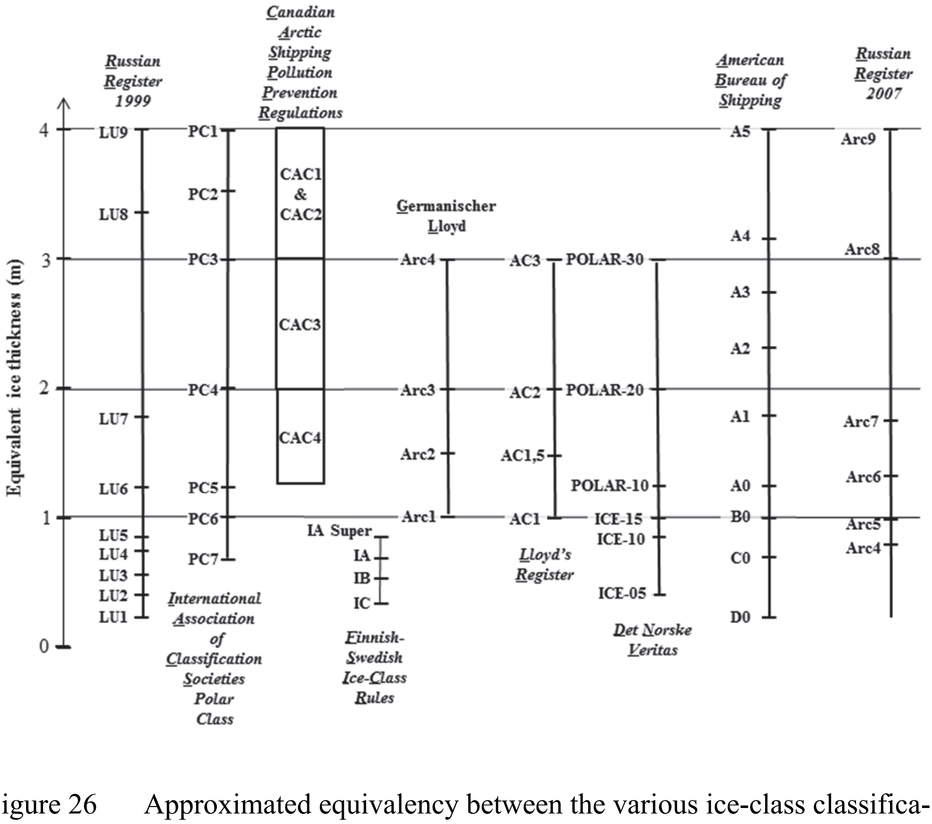


Figure 26 Approximated equivalency between the various ice-class classification regimes based on ice thickness (m) (Appolonov et al. 2007 after Riska 2009; IMO 2014)

Another important safety aspect is winterization, which aims to mitigate the risks of cold and harsh conditions on vessels. Winterization procedures include deicing, heat tracing, mitigation of ice effects, protection of operating conditions, piping arrangements and prevention of ice accretion (Yang et al. 2013).

In this thesis, ships of various ice-classes have been divided into two groups: escorted vessels and ice-going vessels depending on their ice performance (e.g. Riska 2010) and their consequent requirements for icebreaker assistance along the NSR.

4.6.4.1 Escorted vessels

This category of ships includes vessels that typically require icebreaker assistance during the NSR navigational season. By and large, this refers to ice-classes conforming to the equivalency of the IA Super and IA notations of the FSICR. Also, ice-class IB may be applicable, to some extent, given the recent relaxation of the NSR admission criteria. Table 14 shows the composition of the global fleet by ship type, including the ice-classed fleet as of January 2015 based on Clarksons World Fleet Register data (CRSL 2015).

Table 14 The world fleet composition of open-water and ice-classed vessels by ship type as of January 2015 (CRSL 2015)

ship type	total fleet	open-water	ice-classed	IAS	IA	IB	IC	ID
tanker	13 413	11 535	1 878	37	614	266	397	564
bulker	11 251	10 310	941	8	35	55	281	562
container	5 096	3 458	1 638	13	333	17	83	1 192
car carrier	767	672	95	0	19	0	60	16
roll on - roll off	1 242	960	282	51	106	26	49	50
gas carriers	1 683	1 447	236	0	25	53	94	64
other	55 015	50 489	4 526	90	1 207	548	1 209	1 457
total	88 467	78 871	9 596	199	2 339	965	2 173	3 905
share	100 %	89 %	11 %	0 %	3 %	1 %	2 %	4 %

In total the ice-classed fleet consists of 11 per cent of the world's total fleet. However, in the highest ice-class types (IAS and IA) that are capable of seasonal Arctic navigation, the number is less than 5 per cent. In a ship type comparison, if the category "other" is excluded, the tanker fleet has the highest numbers (over 600 vessels with an IA ice-class), which are largely remnants from the Baltic oil trade boom a decade ago (See e.g. Koskinen and Hilmola 2005).

4.6.4.2 Ice-going vessels

Ice-going capability refers to purpose-built merchant vessel designs with a high ice-class notation (usually above IAS), enabling independent operation in Arctic waters. The autonomous icebreaking requirement influences a ship's hull's strength and bow shape as the conventional bulbous bow is replaced by spoon or landing craft bows (von Bock und Polach et al. 2014). The number of the ice-going ships may increase coupled with the development in technology, but that is not expected to preclude the need for icebreakers (e.g. Arctic Council 2009).

Table 15 shows the composition of the world's ice-going fleet as of January 2015 by ship type based on data from Clarksons World Fleet Register (CRSL 2015).

Table 15 The active fleet and newbuilding orders for ice-going vessels as of January 2015 (Amended from CRSL 2015)

ship type	number of vessels	average DWT	beam (m)	LOA (m)	draft (m)	Status
bulker	2	28 495	27	189	11	Active fleet
multipurpose	5	18 400	23	169	10	
supply	1	1 930	19	82	9	
tanker	1	18 902	26	169	10	
heavy lift	2	24 500	43	194	8	In order
gas carriers	15	85 000	50	299	12	
tanker	6	42 000	34	249	10	
total	32					

In early 2015, there were less than a dozen ships equipped with the capacity to operate independently. However, the number of newbuilding orders signals that the fleet size is going to more than double within the next few years. The active fleet consists of nine multipurpose, tanker, supply and bulker ships. The majority belongs to the Russian metallurgy company, Norilsk Nickel, which currently operates five multipurpose ships and one tanker with an ice-class of Arc7. These vessels are engaged in year-round destinational shipping operations in the western parts of the NSR, transporting nickel concentrate from Dudinka to Murmansk. The amount of newbuilding orders is considerably higher relative to the active fleet, totaling 23. Most of them (15 gas carriers) are being built for the Yamal-LNG project (e.g. OAO Novatek 2014).

4.6.5 Crews

A specialized fleet is nothing without competent personnel at the helm of the ships. Obviously, if the number of ships is to increase so will the demand for crews. Operating in Arctic waters requires specialized skillsets and expertise especially in terms of ice navigation and operating machinery in sub-zero conditions (e.g. Tikka et al. 2008). In addition, familiarity with ice and snow conditions as well as understanding satellite-based surface data is needed. Crews should also be able to withstand physical and psychological challenges relating to fatigue, darkness and remoteness, which often lead to human errors owing to impairments in preparedness, decision-making and cognition (Sakhuja 2013, 2014).

In the main, the NSR does not postulate specific crew requirements as such, other than those already included in the relevant international conventions, namely the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). However, if a ship has an inexperienced Master or Captain, the usage of ice-pilots is compulsory (NSRIO 2016c). The upcoming Polar Code of the IMO determines the qualifications for crews operating in polar waters in accordance with the provisions of the STCW Convention and Code (IMO 2010b; IMO 2016).

The contemporary global market for seafarers is largely populated by Asian-based crew members, who are not inherently familiar with operating in icy waters. This will create a demand for additional training, which may also influence wage levels of the qualified crews. Availability of ice navigation training is, however, limited. Only countries with ice-bound coasts, such as Russia and Finland, provide such training in their standard curricula.

5 SHIPPING ECONOMICS IN THE NORTHERN SEA ROUTE

This Chapter analyses the profitability of a ship owner operating in the NSR in comparison to the Suez Canal. This is studied through operational cashflow stemming from estimated but yet realistic revenues and costs. Many of the studies analyzing the micro-level profitability of the NSR tend to be rather one-sided and focused on cost, while assuming that shorter distances leads to corresponding savings. Cost comparison approach is reasonable if the revenues are considered equal (e.g. Erikstad and Ehlers 2012) but may not result in an optimal outcome in terms of maximizing the profits of the ship owner, which ultimately determines the ship owner's routing choices (Evans and Marlow 1990). In this regard, Stopford's (2009) shipping cashflow model is used as the frame of reference (Figure 27).

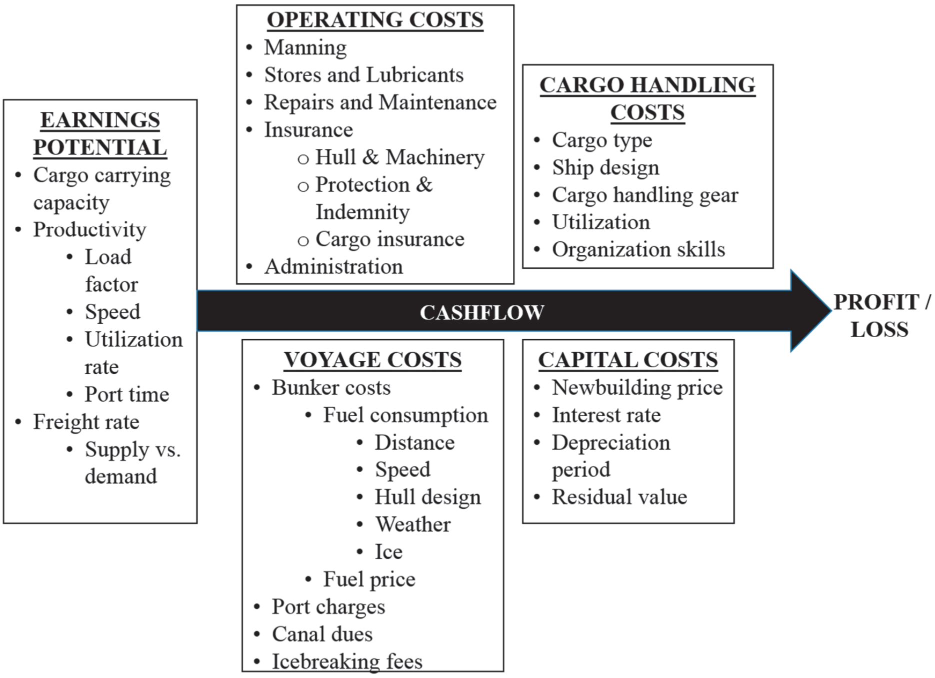


Figure 27 Shipping cashflow model (modified from Stopford 2009)

The model contains elements that scrutinize the revenues of a ship, while also including the expenditure accrued while operating, maintaining and financing the ship. Wijnolst and Wergeland (2009, 336) have defined cashflow as depicting the cycle of cash starting from inflows in the form of freight revenues over the lifetime of the ship minus the outflows to cover the direct costs. One of the essentials behind the ship owner's decision to operate a ship on a certain route is its earnings potential (Veenstra and Ludema 2006). In other words, how much money one can accumulate by trading in a particular area.

In terms of shipping costs, there is no unified typology on categorization (e.g. Evans and Marlow 1990). A common classification used to categorize shipping costs follows the logic of Jansson and Shneerson (1987) and Stopford (2009) in which the costs are categorized as capital, operating, voyage and cargo handling costs. The same typology is, in many respects, followed in this thesis, while also containing some modifications. The voyage costs usually comprise the variable costs incurred during the commercial employment of the ship, including bunker costs, icebreaking fees, canal tolls and port dues.

In this thesis, the focus on voyage costs is primarily on icebreaking fees and bunker costs with a special emphasis on fuel economy. These items constitute the most relevant ones in the case of the NSR, and are thus discussed separately. Cargo handling costs and port dues are assumed to be similar irrespective of the route used and thus they are excluded from the analysis.

5.1 The generic earnings potential profile of a NSR ship

The earnings potential usually comprises three basic elements: freight rates, cargo carrying capacity and productivity (Veenstra and Ludema 2006; Stopford 2009). Out of these, the freight rate is determined by the market and is therefore out of the individual ship owner's influence. The vessel's cargo carrying capacity is determined in the design phase in accordance with its intended purpose and trading area. Unlike the two previous, productivity is largely dependent on the ship owner's operational decisions and is acknowledged to be a key determinant in retaining a competitive edge (e.g. Hughes 1996). In the main, the basic vessel productivity dichotomy distinguishes between time at sea and time in port (e.g. Laine and Vepsäläinen 1994). More specifically, Wijnolst and Wergeland (2009) list six influencing factors: speed, port times, load factor, off hire, ballast factor and average length of haul.

The aforementioned factors are largely dedicated to open-water conditions and thus do not exhaustively address the issues needed to assess the vessel's earnings potential in the NSR context. In this regard, the ice-class of the vessel is the decisive nominator, which is used as a determinant when establishing the generic profile of a NSR ship's earnings potential relative to the SCR ship. Together with the productivity and cargo carrying capacity, two separate and NSR specific issues are incorporated into the equation: 1) the operational risks involved; and 2) the distance savings potential. Figure 28 shows the generic earnings potential profile of a NSR ship based on its ice-class relative to a SCR counterpart.

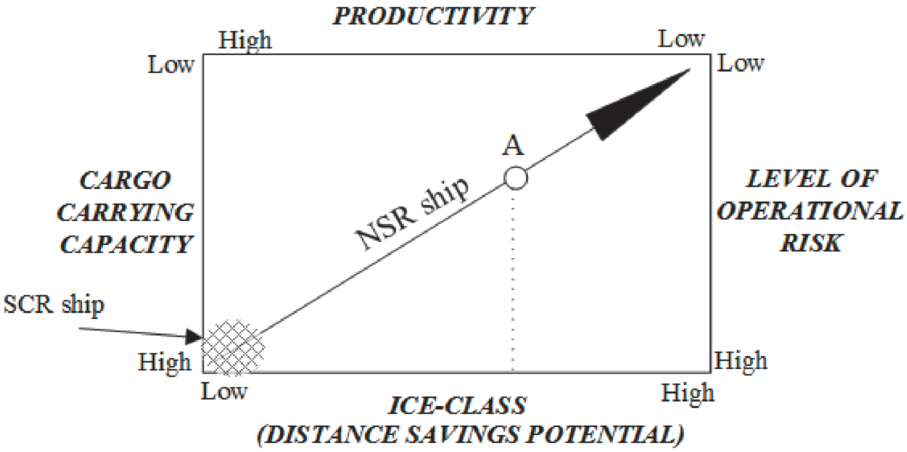


Figure 28 The generic earnings potential profile of a NSR ship based on ice-class

The arrow illustrates a NSR ship with various ice-classes scaled from low to high. At point A, the vessel has an above average ice-class, which entails a longer operational season along the NSR, and it thus has the ability to exploit the distance advantage for a longer period. The level of operational risk for the ship, in relative terms, is lower than medium, entailed by the higher ice-class. Respectively, the vessel has a lower cargo carrying capacity, which is attributable to the extra weight of ice strengthening. Finally, the productivity of the vessel is on the lower side of the scale due to sailing speeds and load factors that are dependent on climate conditions. The rasterized sector describes the respective earnings potential of an open-water ship operating in the NSR.

The following sub-chapters elaborate on the content of the above generic earnings profile in more detail. Although being a generic profile, the special prerequisites in terms of each method of operation: liner, industrial and tramp (Lawrence 1972) must be taken into consideration. In many respects, the three methods have different connotations with regard to their earnings potential.

The service pattern of tramp ships resembles taxis given that their movement is subject to the availability of cargoes, which is usually associated with bulk shipping. Liners may be associated with a bus-like service owing to their dependency on published itineraries and schedules, which most often involves containerships and car carriers (e.g. Fayle 2013). Industrial shipping is usually described as the cargo owner also having ownership of the ship (e.g. Christiansen et al. 2013), while not being exclusively limited to any specific mode of shipping.

5.1.1 Freight rate

In terms of NSR usage, high freight rates are argued to constitute one of the key motivators (Cariou and Faury 2015). In principle, shortcuts, like the NSR, enable ship owners to increase fleet performance, which is especially relevant in times of high freight rates. Similarly, the NSR has been found to be especially favorable for specialized ship types, like LNG-carriers, which usually tend to enjoy higher time charter rates (e.g. Raza and Schøyen 2014). Overall, the significance of freight rate may point towards bulk rather than container shipping given the more suitable operational method. Bulk shipping has more allowance in terms of seizing short-term market opportunities in the form of freight rates.

5.1.2 Cargo carrying capacity

By definition, the term cargo carrying capacity may have at least two meanings in terms of the NSR, all of which indicate reduced capacity for NSR vessels relative to the SCR. On similar sized vessels, ice-class vessels tend to have a lower cargo carrying capacity relative to open-water ships (e.g. Laulajainen 2009). A vessel's ice-strengthening burdens its effective capacity, at least for the highest ice-class categories, as more steel is added on to the hull of the vessel. Accordingly, Erikstad and Ehlers (2012) denote it as the "lost opportunity cost" and argue that it is of relatively less importance for liners than for bulk vessels.

By itself, the ice-class inflicted loss of capacity may not be significant. However, when that is combined with conditions-related restrictions, i.e. the physical constraints of the NSR in the form of icebreaker width and shallow waters, there is a substantial loss of potential. The capacity norm for NSR vessels is roughly equivalent to Panamax-sizes (50,000–75,000 DWT), although occasionally larger-sized vessels have been able to use the route. To put this into perspective, the sizes of the vessels using the Suez Canal may be even four times greater. In container shipping, where economies of scale prevail, this constitutes a substantial constraint (e.g. Carmel 2013). On the other hand, limited water depths may not be as problematic for ship types with shallow drafts, like PCCs.

5.1.3 Productivity

The productivity of a NSR vessel is comprised of several elements, most of which are subject to conditions. The load factor describes how much of a ship's cargo carrying capacity is being used on laden voyages. Together with the off-hire the load factor can be considered an indicator of the demand for transport services at a particular time. The unpredictability, seasonality and cargo-matching issues involved in the present-day NSR influence in terms of lower load factors, namely in liner trade (Lasserre 2014; Lee and Kim 2015). On top of that, the ability of shipping companies to position their seasonal container shipping service offering has been questioned (e.g. Lasserre and Pelletier 2011).

Similarly, the challenging sailing conditions in terms of safety reasons may be attributable to lower load factors, in particular for containerships, where cargo is loaded on deck. In addition, the shortage of intermediate ports along the NSR will most likely be shown in lower load factors (e.g. Notteboom 2012; Carmel 2013). In contrast, the productivity loss in bulk shipping is not as substantial. This is because trading takes place on an actual demand basis neither relying on networks nor being sensitive to variations in a schedule (Guy and Lasserre 2016).

Speed has a dual effect on earnings and costs. On one hand, faster speeds enable more efficient trading in terms of more annual voyages, but, on the other hand, it means increasing fuel consumption. The average speeds along the NSR are in optimal conditions are usually between 12–14 knots. As a rule, the longer the ship trades along the NSR annually, the lower the speeds are. This applies to both ends of the sailing season when ice is encountered. In terms of vessel design speeds, the usual NSR speeds are more suited to bulk ships rather than liners, which, on average, tend to have higher speeds. The optimum speed for a bulker is determined by the freight rate relative to bunker price while in container shipping the goal is more on maintaining the schedule (Wijnolst and Wergeland 2009; Lasserre 2014).

The port time of the vessel has obvious effects on vessel productivity, but cannot be considered a significant differential between the NSR and the SCR. Hypothetically speaking, frozen containers above the deck due to the NSR's low temperatures could result in longer port call times due to defreezing procedures.

5.1.4 Operational risk level

Given the extraordinary conditions along the NSR, the higher ice-class entails more operational safety and reduces the risks posed by the conditions. From the business point of view, uncertainty and realized risks are traditionally the causes of lost productivity. In principle, the current NSR rules of navigation allow ship owners, to some extent, to bear additional risk in terms of using lower ice-classed or even open-water vessels along the NSR. Taking such risks may reward short-term profit seekers for seizing available opportunities. On the other hand, realized risks, like accidents, may have unexpected and far-reaching consequences extending well beyond bad publicity.

5.1.5 Distance savings potential

The main advantage of the NSR relates to shorter sailing distances between particular areas. Depending on the ice-class of the ships, the annual navigational season for escorted vessels extends to almost half-year at best, whereas for ice-going ships it may be longer. For vessels, with a low ice-class, the season along the NSR lasts only a few months at best. The productivity advantage of heavily ice-classed ships, also known as the ice-going ships, relies on autonomy, increased accessibility and longer operational periods in order to enjoy the benefits of the shorter sailing distances of the NSR. It is postulated that the higher the ice-class the longer a ship can operate along the NSR in a year.

5.2 The generic shipping cost profile of a NSR ship

The ice-class of a vessel, operating along the NSR, has implications for shipping costs. Figure 29 shows the generic cost profile of a NSR ship, comprising four cost dimensions: operating, fuel economy, icebreaking and capital costs.

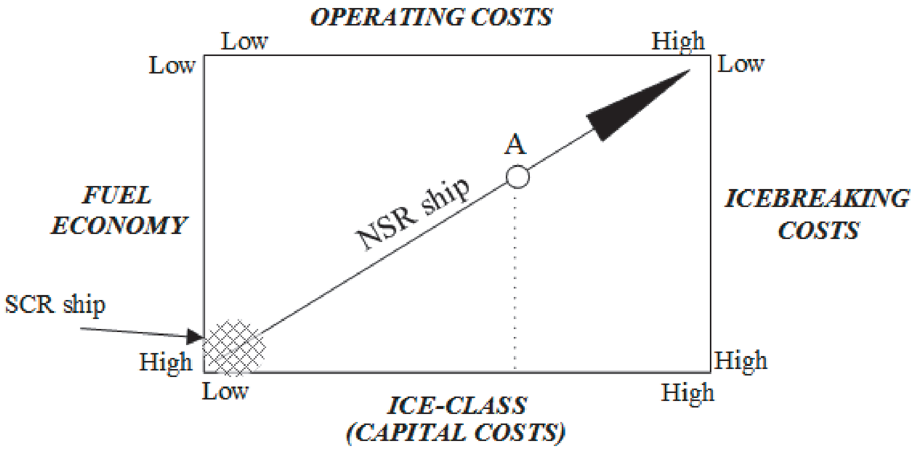


Figure 29 The generic shipping cost profile of a NSR ship based on ice-class

The arrow illustrates a NSR ship with various ice-classes (scaled from low to high). At point A, the vessel has an above average ice-class, which results in higher capital costs. Respectively, the vessel has lower icebreaking fees. On the other hand, a longer navigational period in more challenging conditions will result in the vessel being burdened by higher operational costs in terms of additional insurance and maintenance costs. Finally, the fuel economy of the vessel will be on the lower side of the scale due to the impaired fuel economy caused by operational conditions, more powerful engines and a suboptimal hull shape. The rasterized sector describes the respective cost profile of an open-water ship operating in the NSR.

In the following part of the Chapter, the components of the generic cost profile are discussed in more detail.

5.2.1 Operating costs

Operating costs are accrued in order to maintain the vessel's trading capability, comprising insurance, crew and maintenance costs.

5.2.1.1 Insurance costs

Shipping in the Arctic is characterized by the high level of risk involved. Loughnane et al. (1995) reported a 19 times higher severe incident rate in the Arctic compared to open-water. Based on accidents occurred during the severe Baltic Sea winters, Tikka et al. (2008) identified the lack of crew experience as the primary cause of accidents. From 2004 – 2014, the number of incidents in Arctic waters increased from 3 to 55. Of these, engine breakdown with a share of 36 per cent, was the most common incident type (Dobie et al. 2015).

According to the NSR's accident data from the late 1980s, around 10 per cent of the damage occurred while operating independently; 60 per cent during the icebreaker escorts; and the remaining 30 per cent was caused during towing, grounding and other miscellaneous operation in ice-infected waters (Eger and Mejlænder-Larsen 2013). In this regard, the eastern parts of the NSR were especially treacherous as most of the damage occurred in the East-Siberian and Chukchi Seas.

Maritime insurance is a vehicle for mitigating the associated risks and consists of three separate components: Protection and Indemnity (P&I), Hull and Machinery (H&M) and cargo insurance. P&I covers third-party liabilities encountered during the commercial operation of a vessel. H&M provides protection against damage done to the ship or its equipment. Cargo insurance covers damage to the cargo itself.

Traditionally, the importance of establishing a sound Arctic maritime insurance policy has been underlined, while at the same time pointing out uncertainty regarding practices and rate levels (e.g. Verny and Grigentin 2009; Arctic Council 2009). One of the main challenges has been a lack of the comprehensive statistics needed by insurance companies in order to evaluate the risks involved (e.g. Gold 1999). If such details were not available, a common practice has been to provide insurance on a case-by-case basis, which, in turn, entailed increased margins to compensate for the higher uncertainty involved. Particular concerns were wreck removal, pollution salvage and towage, including cargo and crew claims (Eger and Mejlænder-Larsen 2013).

Accordingly, determining the actual price of insurance has been a controversial issue in existing literature. Table 16 shows a compilation of additional Arctic premiums varying between 0–200 per cent (Arpiainen 1994; Laulajainen 2009). A study by Erikstad and Ehlers (2012) argued that the NSR now has comparable insurance levels relative to the Suez Canal due to the fact that most damages are left below the deductible limit and thus not claimed. Moreover, increasing piracy along the SCR is suggested as offsetting the differential (e.g. Raza and Schøyen 2014).

Table 16 Extant literature estimates on Arctic shipping insurance premiums and other relevant insurance cost items in USD per day, gross tonne (GT), gross register tonne (GRT), TEU, voyage or roundtrip.

Author	P&I	H&M	Cargo	SCR piracy add.
Laulajainen 2009	equal to Suez			
Falck 2012	equal to Suez			
Erikstad & Ehlers 2012	equal to Suez			
Arpiainen 1994	no	170–200 %	100–200 %	
Wergeland 2013	no	200 %		no piracy add
Raza and Schøyen 2014	no	281,250 USD/roundtrip		158,204 USD/roundtrip
Liu & Kronbak 2010	25 %	100 %		
Sarrabezoles et al. 2014	0–50 %	0–50 %	0–50 %	
Srinath 2010	43 %	100 %		
Somanathan et al. 2007; 2009	50 %	50 %		
Lasserre 2014	50 %			
Pruyn 2016	100 %	30 %		USD 18/GT
Schøyen & Bråthen 2011	125,000 USD/voyage			
Niini et al. 2006	800 USD/d			
Verny & Grigentin 2009	1,177 USD/d	1,167 USD/d	1,000 USD/d	
Kamesaki et al. 1999, Furuichi & Otsuka 2013; 2014; 2015	8 USD/GRT	2 USD/GRT		40 USD/TEU

During recent years, knowledge about insurance practices and prices together with accident statistics has been accumulating. Faury (2015) reported that insurance companies have recently changed their risk evaluation practices more collaborative by working together with ship owners that possess experience of Arctic navigation. A study by Sarrabezoles et al. (2014) revealed that actual insurance fees might not be as high as anticipated by the previous literature. However, they concluded that the indirect requirements in terms of the vessel ice-class needed to obtain insurance remains a significant financial burden.

Maritime insurance coverage is currently essential in the NSR and not only for risk mitigation purposes. One of the admittance criteria for entering the NSR is proof of P&I insurance (NSRA 2016). On the other hand, several procedures are needed in order to maintain insurance coverage along the NSR. For example, cargo owners have to be notified in order to avoid any possible claims of deviation from the contracted route if the cargo is lost, damaged or delayed (UK P&I Club 2014).

5.2.1.2 Crew costs

Crew costs are dependent on a number of factors, like the type of vessel and level of automation (Wijnolst and Wergeland 2009). The size of the crew and their professional qualifications are determined by international conventions. In this respect, the Arctic waters pose a unique context. Operating in a more challenging environment sets additional requirements for the crew on-board. Human resource attributes such as ice navigation experience and the endurance to cope with burdensome conditions are needed for the crews in the Arctic.

Many studies recognize these issues and suggest they will increase crew costs, while others implicitly exclude them (Lasserre 2014). In this respect, two distinct approaches may be identified as causing the increased crew costs: higher wage levels (Liu and Kronbak 2010) or increased crew size (Somanathan et al 2007, 2009). However, only a few studies explicitly provide estimates on the magnitude of the cost increase (Table 17).

Table 17 Estimates of the Arctic crew cost increment relative to open-water routes

Author	Crew cost additional (%)
Lasserre 2014	10
Liu and Kronbak 2010	10
Somanathan et al. 2007; 2009	11–14

Overall, the impact of the crew cost increment in the NSR context can be considered negligible, which is consistent with the body of the literature (e.g. Erikstad and Ehlers 2012).

5.2.1.3 Maintenance cost

In order to proactively prevent the occurrence of breakdowns and to follow their scheduled maintenance program, ships need to undergo regular maintenance and dry docking procedures. The more challenging operational conditions in the Arctic inevitably put additional strain on equipment and ship. Table 18 shows the compiled estimates of the extra maintenance costs for Arctic ships.

Table 18 Estimates of the extra maintenance costs for ships operating in the Arctic, according to extant literature

Author	premium (%)
Kamesaki et al. 1999	none
Schøyen and Bråthen 2011	20
Lasserre 2014	20
Wergeland 2013	23
Verny and Grigentin 2009	100
Liu and Kronbak 2010	100
Somanathan et al. 2007, 2009	150

It appears that Arctic conditions do indeed increase ship maintenance costs. The differential usually accounts for between 20–150 per cent extra on top of the usual maintenance costs.

5.2.2 Fuel economy

The expenditure, accrued by the fuel burned by the ship's main and auxiliary engines at given fuel prices constitutes the bunker costs. This cost component is of great importance in shipping in general (e.g. Chen et al. 2014), and especially in terms of the NSR's perceived advantage in delivering bunker cost savings. The level of the fluctuating bunker price at a given time ultimately determines the magnitude of these costs (see Figure 1). Some studies suggest that the fuel price for NSR vessels is higher than regular HFO as specific fuel for low temperatures has to be used (Lasserre 2014; Beveridge et al. 2016). The focus of the discussion in this sub-chapter is on fuel economy and more specifically on the fuel consumption of a NSR vessel in various conditions.

In open-water conditions the fuel consumption of a vessel is dependent on variables such as the size of the ship, hull design, speed, weather and engine profile (Wijnolst and Wergeland 2009). In addition, issues like antifouling paints, propeller type and engine retuning are to be considered (MAN 2011).

A vessel's speed is usually optimized at the design phase in a way that the cost savings and alternative revenues lost with speed reductions are balanced (Evans and Marlow 1990; Wijnolst and Wergeland 2009). There are some exceptions to the general rule given that liners may prefer to use speeds that are not optimal but necessary to maintain a given schedule (Evans and Marlow 1990). Furthermore, the optimum speed is variable owing to the influence of the external factors, namely the price of fuel, freight rates and voyage distance (Evans and Marlow

1990). Table 19 shows a compilation of the speeds used in existing literature ranging from 0–26 knots.

Table 19 The speeds along the NSR and SCR used in extant literature

Author	NSR	SCR
	knots	
Verny and Grigentin 2009	17	24
Somanathan et al. 2007	11	20
Lasserre 2014	14	20
Furuichi and Otsuka 2013; 2014	12.8–14.1	20
Liu and Kronbak 2010	10	18
Hua and Dong 2014	2.4–4.87	20
Eide et al. 2010	0–19	19
	0–24	24
Xu et al. 2011	25.8	
Wergeland 2013	13	23
	12	14
Cho 2012	16	
	26	
von Bock und Polach et al. 2014		15.94
	12.58	
	12.09	
Raza and Schøyen 2014	12	19.5
Schøyen and Bråthen 2011	8.3–8.7	14.4
Pruyn 2016	9–11	14.3

Most authors distinguish the speeds between the NSR and the SCR, while others boldly suggest fixed speeds, regardless of the operational constraints. For example, Cho (2012) and Xu et al. (2011) use speeds of over 25 knots in the NSR. In current Arctic conditions this seems unlikely in terms of the safety and fleet capability.

The basic principles of fuel consumption estimations rely on determining the total resistance (divided into three main groups: frictional, residual and air resistance) that the ship needs to overcome at given speeds (e.g. MAN 2011). In this respect, the required engine power together with the applied speeds are often used as the parameters to estimate the fuel consumption of the vessels (Hughes 1996). Although auxiliary engines also contribute to a ship’s total fuel consumption, given their overall significance the discussion henceforth will refer only to a ship’s main engines.

Many studies use the so-called Propeller Law[7] as a basis for calculating fuel consumption, which if not properly used may lead to inaccurate estimates primarily for three reasons:

1. First, the Propeller Law is often adjusted with a certain multipliers to account for the ambient conditions, but the application and values of the multipliers are not harmonized. The concept of Sea Margin[8] is often used to account for the impact of rough weather. Similarly, an operational margin for the engine is sometimes reserved (MAN 2011, 29). It is also suggested that, within the normal speed range of specific ship types, the power used in the formula could be higher than three (MAN 2011, 21)

2. Propeller Law is often used to provide aggregate-level fuel consumption on daily basis, which does not account for the impact of changing conditions.

3. The operating method (ice-going, escorted or open-water) determines whether use of the Propeller Law is applicable. Ice-going capability means that ships navigate independently through the ice, while escorted ships sail in the wake of an icebreaker. Thus the more ice that is present and/or the lower speeds are, then the less reliable the Propeller Law derived fuel consumption curve becomes.

In absence of access to exact empirical data on ambient sailing parameters, the Propeller Law is used in this thesis to provide the minimum level of fuel consumption, while also recognizing its obvious deficits. Figure 30 shows the fuel consumption curves of two Panamax IA ice-class and open-water bulkers (75,000 DWT) at various speeds which have been derived by using the Propeller Law. The impact of the more powerful engines installed on an IA ice-class ship compared to open-water ship (15,000 kWh vs. 11,000 kWh) is notable as the curves are divergent especially at higher speeds. The parameters behind the curves can be found in Appendix 2.

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[7] The Propeller Law refers to the approximation that the fuel consumption of a vessel is proportional to the third power of the speed (Hughes 1996, 198). In some cases it is referred as a cube law.

[8] The Sea Margin relates to an allowance used to adjust the engine power requirements in terms of the ambient sailing conditions (Hughes 1996, 200). Often used Sea Margin is 15 per cent, while for large containerships 20–30 per cent margin may be valid (MAN 2011, 28).

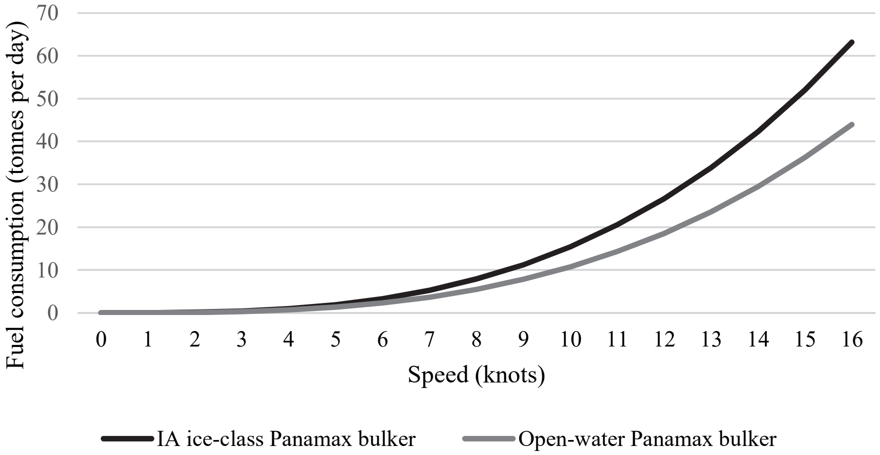

Figure 30 Illustration of estimated fuel consumption relative to speed of Panamax (75,000 DWT) IA ice-class and open-water vessels derived by using the Propeller Law

When preparing more detailed fuel consumption analyses for ice-infested waters specific ice parameters are used to calculate the resistance in accordance with a vessel's operational capability for either ice-going or escorted navigation. The ability to break ice requires engines that are more powerful and a special hull design compared to ships sailing in open waters. It may force ships to slow down, or even to reverse in order to ram through pressure ridges or thick ice formations (Bourbonnais and Lasserre 2015). There are a number of ways to estimate ice resistance, usually by separating it into different components (Cho and Lee 2015). For example, during icebreaker escorts, brash ice resistance causes additional friction (Riska 2010). Some studies have calculated it by using a specific formula (e.g. Omre 2012). All of these practices and conditions have a negative impact on a vessel's fuel economy. Even in open-water conditions, an ice-classed vessel will suffer impaired fuel economy corresponding to its ice-class (e.g. Erikstad and Ehlers 2012).

Despite the doubts of Lack and Corbett (2012) over the reliability of the fuel consumption calculations in the Arctic due to variable engine loads and conditions, it seems that the subject is relatively well-documented in the literature. The increased fuel consumption of ice-classed vessels operating in ice-infested waters has been recognized in several accounts. Ragner (2000a) considers the consumption to be extremely variable but a rule of thumb provides figures two to three times higher. That is in line with the estimate of Bourbonnais and Lasserre (2015) of at least one-and-a-half to two times extra. A different approach to the same subject considers consumption through extra engine loads. According to Niini et al.

(2006) the engine loads while icebreaker escorts account for 70 per cent compared to 100 per cent when ships break ice. Similarly, Somanathan (2007) estimated the power requirement to double when operating in ice.

A number of studies have identified the impaired fuel economy of ice-classed vessels in open-water conditions. Erikstad and Ehlers (2012) argue that the higher open-water consumption is a result of the extra weight, bow shape and hull appendages, which cause increased frictional resistance due to the potential draft increase. Their estimate was that the increment on fuel consumption ranged between 5 per cent and 15 per cent depending on the ice-class for a vessel sailing at about 21 knots. Lasserre (2014) used the 8 per cent fixed increase, while Pruyn (2016) used a 5 per cent increase. Dvorak (2009) had the lowest estimate by arguing that the ice-class will only result in a 0.3 per cent increase in fuel consumption due to the increased amount of steel. Furuichi and Otsuka (2013, 2014, 2015) used a fixed 10 per cent extra in vessel’s specific fuel oil consumption (SFOC).

5.2.3 Icebreaking fees

Icebreaking and ice-piloting are two services that are often needed when operating along the NSR. The Russian icebreaking service provider, Atomflot, is the main authority responsible for collecting the fees for these services. These traditionally mandatory-like fees are levied based on the effective tariff, which was revised in 2014. More specifically, the Russian Federation Law on Natural Monopolies stipulates that the fees are based upon the amount of service rendered, which is determined by the size and ice-class of the vessel as well as the distance of pilotage and the navigational season (NSRIO 2016c). Accordingly, higher ice-classed vessels are rewarded with lower icebreaking fees.

In comparison to the open-water routes, icebreaking fees constitute an additional cost component. Since the opening of the NSR to international traffic in 1991, icebreaking fees have remained high and are thus considered one of the major obstacles to the NSR’s attractiveness (Arctic Council 2009). The reasoning behind the high tariffs is that they are used to provide funding so that the nuclear icebreaker fleet can operate on tariff-based income. In practice, however, this is as yet unrealized and the icebreaker fleet requires government subsidies (Moe 2014).

Russia’s icebreaking tariff policy has been complicated for ship owners due to changes in tariffs, ambiguous application approaches, a lack of precedent and poor transparency (Arctic Council 2009). The icebreaking tariffs and their application schemes have evolved in tandem with the fluctuations in cargo volumes (Gritsenko and Kiiski 2016).

In many respects, the contemporary icebreaking tariff scheme, published in 2014, has made the fees more competitive compared to the previous versions, while still containing some peculiarities. First, the tariff indicates the maximum level of the fees, allowing Atomflot to adopt lower fees. This flexible pricing policy, similar to the Suez Canal, should improve the NSR's position in a market setting where discounted fees may attract more traffic (Moe 2014). However, in practice, such an authority discretion dependent policy is argued to be time-consuming and consequently increases uncertainty and discrimination (Moe 2014; Lee and Kim 2015).

Second, the actual status of the icebreaking fees – mandatory or not – has traditionally raised discussion. Before the legislation revision in 2012, the fees were indeed stated by law as mandatory. There was one implicit exception to the general rule. According to Solski (2013) the fees were not stipulated if the ships were capable of independent navigation, like the fleet of the Russian metallurgy company Norilsk Nickel. Since the adoption of the new rules in 2012, the situation has become clearer in this respect as icebreaking assistance is no longer mandatory. The adopted rule is now that the ships will pay for the services rendered. However, what is still not clear is the definition of the services rendered, especially the question of who covers the costs accrued for the icebreaker back-up preparedness, which is pivotal for ensuring safe shipping (e.g. Niini et al. 2006; Moe 2014).

From the ship owners' perspective, such an ambiguous and non-transparent pricing policy may create negative perceptions regarding administrative arbitrariness, which will not encourage a decision-making process favoring use of the NSR. De facto, most Western ships are likely to use the icebreaker escorts in the foreseeable future in order to adhere to insurance requirements (e.g. Sarrabezoles et al. 2014).

5.2.4 Capital costs

Capital costs are related to the newbuilding or purchasing price and the way the ship has been financed regarding loans and capital depreciation (Wijnolst and Wergeland 2009). De facto operation in the NSR usually requires that a ship is ice-classed, which incurs extra building costs due to the additional strengthening of the hull and the requirement for more powerful engines. In the literature the magnitude of these costs varies considerably based on the design, ice-class and trading area of the vessel (e.g. Erikstad and Ehlers 2012). By and large, vessels with a high ice-class (above IAS), i.e. ice-going ships, have considerably higher newbuilding prices relative to the lower ice-classed (escorted) ships (Table 20).

Table 20 A compilation of the estimates of the additional capital costs of ice-classed vessels according to extant literature (Finnish-Swedish Ice Class Rules equivalent ice-classes highlighted in grey)

Author	ice-class	premium (%)
Somanathan et al. 2007; 2009	CAC3	30
Srinath 2010	CAC3	40
Chernova and Volkov 2010	high + DAS	30 – 40
Eide et al. 2010	DAS	120
	PC4 + bulbous bow	30
Iceland Ministry of Foreign Affairs 2005	DAS	25
PWC 2009	DAS	134 – 167
Laulajainen 2009	Arctic	70 – 100
	Baltic	15 – 20
SOF 2001	IAS	36
Lasserre 2014	IAS	20
Pruyn 2016	IAS – IA	5–7
Erikstad and Ehlers 2012	IC – IAS	6.5 – 12
Verny and Grigentin 2009	n/a	200 *)
Furuichi and Otsuka 2013; 2015	IA	10
Dvorak 2009	IA	1
Liu and Kronbak 2010	IB	20 – 30
Østreng 2013	n/a	30
Xu et al. 2011	no	0
*) based on 60 Million USD price of Panamax containership in 2008 (CRSL 2015)		

Most of the estimates are based on heuristic industry estimates without mentioning any specific source, which severely complicates the assessment of their validity. Moreover, some authors have adopted a rather poetic approach in terms of describing the basis of their estimates:

> *"This extra cost will be inversely proportional to the level of global warming and therefore to the reduction in the area of pack ice in the Arctic Ocean."* (Verny and Grigentin 2009, 114).

A recent survey by Beveridge et al. (2016) revealed that in current conditions ship owners find it difficult to recoup the additional capital costs of ice-class ships.

5.3 Sensitivity analysis

The sensitivity analysis in this sub-chapter tests how changes in different shipping cost parameters affect the required distance advantage of the NSR in terms of its economic competitiveness relative to the SCR. The analysis involves containerships and dry bulkers of various sizes.

Here, distance advantage means the relative difference in cost competitiveness between alternative routes from a ship owners' point-of-view. Distance advantage is a relative compound measure that takes into account the distance of sailing and the corresponding operating cost of the ship, which for example are a function of the speed maintained by the vessel and its daily running and capital costs. Expressed in percentages, the value "11 per cent" means that the NSR would need to be 11 per cent shorter in order to break-even with the SCR for a given vessel type.

5.3.1 Basic assumptions

A containership with a cargo carrying capacity of 4,000 TEU is used along the NSR, while sizes in the SCR involve vessels of both 4,000 TEU and 18,000 TEU. The former size is currently the maximum size for ships when accounting for the physical constraints of the NSR while the latter currently constitutes the upper limit of vessels along the SCR. Furthermore, as container shipping operates under liner shipping principles, the period of analysis is set to a calendar year. This means that NSR ships are deployed in combined seasonal NSR and SCR operation. See Appendix 1 for the specific containership details and basic assumptions behind the analysis.

Dry bulkers operate under tramp shipping principles which are illustrated in the analysis by fixing two time-chartered (T/C) dry bulk carriers on a roundtrip basis either by using the NSR or the SCR. The roundtrip includes one leg in ballast and the other leg in laden conditions. The sizes of the applied vessels are: Panamax (75,000 DWT) is used in both routes, while Capesize (150,000 DWT) is used only along the SCR. See Appendix 2 for the specific dry bulker details and basic assumptions behind the analysis.

The analysis includes two market scenarios that contain opposite market conditions denoted henceforth as: 1) Low and 2) High. The Low scenario illustrates the prevailing market conditions as of September 2016 by using T/C freight rate at 5,000 USD per day for Panamax dry bulkers (See Appendix 3) and fuel prices USD 250 per tonne[9]. The High scenario is based on T/C rates at USD 25,000 per day for Panamax dry bulkers and HFO fuel prices (USD 600 per tonne) that largely reflect market conditions in mid-2008 when the global economy was booming.

The results of the sensitivity analysis needs to be considered with the limitations in mind. The NSR calculations are built on an illustrative model of reality. They assume constant sailing conditions and fixed speeds throughout the navigational

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[9] This study assumes that all fuel used in the sensitivity analysis is Heavy Fuel Oil (HFO). Price of HFO in September 2016 was around USD 250 per tonne (Bunkerworld 2016).

season, which do not necessarily reflect the actual ambient conditions. In reality, the navigational conditions along the NSR vary during the season, especially at the beginning and the end of the season, entailing slower speeds and higher fuel consumption than on the average conditions. These limitations may cause biased results, such as favoring containerships, which have a longer operational period. Therefore, the results must be regarded as best-case scenarios in terms of the sailing conditions.

5.3.2 General findings

In short, the market conditions have a diverse impact to the competitive position of the NSR in various vessel categories. The difference between Low and High scenarios using proxy values shown in Appendix 1 and Appendix 2 indicate that the required distance advantage of the NSR appears more important for dry bulkers than for containerships.

This is supported by the finding that for similar-sized 75,000 DWT dry bulkers, the distance advantage is 31 per cent in the Low scenario, and 20 per cent in the High scenario, respectively. In other words, the distance advantage difference between Low and High scenarios is 11 percentage points. The respective distance advantage for different-sized dry bulkers (75,000 and 150,000 DWT, respectively) in the Low scenario is 67 per cent and 29 per cent in the High scenario, i.e. a 38 percentage point differential.

For similar-sized containerships, the difference between Low and High scenarios is 12 percentage points (4,000 TEU ships; Low scenario = from 33 per cent; High scenario = 21 per cent). For different-sized containerships (4,000 vs. 18,000 TEU) the differential is 19 percentage points (from 224 per cent in the Low to 205 per cent in the High scenario).

These figures provide the starting point for the in-depth analysis regarding how sensitive to parameter value changes is the competitive position of the NSR relative to the SCR. Table 21 and Table 22 show the compiled results of the sensitivity analysis, which are discussed in more detail in the following parts of the Chapter.

Table 21 Sensitivity analysis of cost components for liner and tramp shipping operated vessels (container and dry bulk ship) along the NSR compared to SCR (measured in required distance advantage of NSR in % to be more economical compared to distances along SCR) by using values resembling the market conditions as of September 2016 (Low scenario; implying a low T/C level and low fuel price)

Sensitivity parameters and units		Container ship (TEU) in combined seasonal NSR and SCR shipping on annual basis		Dry bulk ship (DWT) in a roundtrip voyage (including laden and ballast leg)	
		NSR & SCR 4 000	NSR = 4 000; SCR = 18 000	NSR & SCR 75 000	NSR = 75 000; SCR = 150 000
		Values indicate the required distance advantage of NSR in % to be more economical compared to distance along Suez Canal			
Fuel (HFO) price (USD/tonne)	100	43 %	▨	36 %	80 % *)
	500	23 %	▨	28 %	58 % *)
	1 000	15 %	▨	26 %	52 % *)
	1 500	12 %	▨	26 %	50 % *)
NSR sailing speeds (kn)	1	▨	▨	▨	▨
	5	▨	▨	48 %	93 % *)
	10	36 %	▨	30 %	65 % *)
	15	31 %	▨	35 %	72 % *)
NSR season length (days)	60	70 %	▨	Not applicable for a single time-chartered roundtrip	
	90	50 %	▨		
	120	39 %	▨		
	180	29 %	▨		
Ice-class additional building cost (%)	0	15 %	▨		
	25	33 %	▨		
	50	49 %	▨		
	75	65 %	▨		
Load factor (%)	20	▨	▨	▨	▨
	40	▨	▨	▨	▨
	60	44 %	▨	71 %	▨
	80	11 %	▨	41 %	80 % *)
Icebreaking fees (%) difference to current level	-50	19 %	▨	11 %	35 % *)
	-25	25 %	▨	20 %	50 % *)
	0	33 %	▨	31 %	67 % *)
	25	41 %	▨	43 %	85 % *)
Suez Canal tolls (%) difference to current level	-50	50 %	▨	49 %	89 % *)
	-25	41 %	▨	40 %	77 % *)
	0	33 %	▨	31 %	67 % *)
	25	26 %	▨	23 %	57 % *)
Time charter rate level for Panamax (USD/day*)	5 000	Not applicable for liner shipping (ship is assumed to be owned by ship operator)		31 %	67 % *)
	7 500			28 %	79 % *)
	10 000			25 %	90 % *)
	15 000			22 %	▨

NSR distance advantage required for economic viability of the NSR

0–20 %, e.g. Hamburg – Hong Kong (~ 20 %)	41–60 %, e.g. Narvik – Yokohama (~ 50 %)
21–40 %, e.g. Hamburg – Yokohama (~ 40 %)	61–100 %, e.g. Port Sabetta – Yokohama (~ 65 %)

▨ Not realistic; NSR would have to be over 100% shorter than SCR

*) Time charter rate for Capesize (i.e. Suez route) is fixed at USD 7,500/ day

Table 22 Sensitivity analysis of cost components for liner and tramp shipping operated vessels (container and dry bulk ship) along the NSR compared to SCR (measured in required distance advantage of NSR in % to be more economical compared to distances along SCR) by using market values resembling the market conditions in mid-2008 (High scenario; implying a high T/C level and high fuel price)

Sensitivity parameters and units		Container ship (TEU) in combined seasonal NSR and SCR shipping on annual basis		Dry bulk ship (DWT) in a roundtrip voyage (including laden and ballast leg)	
		NSR & SCR 4 000	NSR = 4 000; SCR = 18 000	NSR & SCR 75 000	NSR = 75 000; SCR = 150 000
		Values indicate the required distance advantage of NSR in % to be more economical compared to distance along Suez Canal			
Fuel (HFO) price (USD/tonne)	100	43 %		18 %	22 % *)
	500	23 %		20 %	28 % *)
	1 000	15 %		21 %	32 % *)
	1 500	12 %		22 %	35 % *)
NSR sailing speeds (kn)	1				
	5	89 %		38 %	51 % *)
	10	22 %		20 %	29 % *)
	15	23 %		22 %	31 % *)
NSR season length (days)	60	46 %		Not applicable for a single time-chartered roundtrip	
	90	32 %			
	120	25 %			
	180	19 %			
Ice-class additional building cost (%)	0	10 %			
	25	21 %			
	50	32 %			
	75	43 %			
Load factor (%)	20				
	40	88 %		90 %	
	60	29 %		49 %	61 % *)
	80	3 %		28 %	37 % *)
Icebreaking fees (%) difference to current level	-50	13 %		15 %	22 % *)
	-25	17 %		18 %	26 % *)
	0	21 %		20 %	29 % *)
	25	26 %		23 %	33 % *)
Suez Canal tolls (%) difference to current level	-50	31 %		25 %	33 % *)
	-25	26 %		22 %	31 % *)
	0	21 %		20 %	29 % *)
	25	17 %		18 %	27 % *)
Time charter rate level for Panamax (USD/day*)	10 000	Not applicable for liner shipping (ship is assumed to be owned by ship operator)		25 %	9 % *)
	25 000			20 %	29 % *)
	50 000			17 %	60 % *)
	100 000			15 %	

NSR distance advantage required for economic viability of the NSR	
0–20 %, e.g. Hamburg – Hong Kong (~ 20 %)	41–60 %, e.g. Narvik – Yokohama (~ 50 %)
21–40 %, e.g. Hamburg – Yokohama (~ 40 %)	61–100 %, e.g. Port Sabetta – Yokohama (~ 65 %)
Not realistic; NSR would have to be over 100% shorter than SCR	
*) Time charter rate for Capesize (i.e. Suez route) is fixed at USD 50,000/ day	

5.3.3 The impact of fuel price

It appears that with equal vessel sizes in container shipping (4,000 TEU) the relative advantage of the NSR increases the higher the fuel price becomes. In this setting and with (very) high fuel prices (price of HFO at least 1,000 USD per tonne), the Europe-Asia container trade between Hamburg–Hong Kong along the NSR seems competitive. In contrast, when an 18,000 TEU vessel is deployed in the SCR and a 4,000 TEU vessel in the NSR, there is no similar effect. In fact, the potential for the NSR is not realistic as the results indicate that the NSR would have to be over 100 per cent shorter than the SCR. This is arguably because of the massive scale advantage of the Suez (over four times higher capacity) that masks the effects of fuel price.

In dry bulk shipping, the relative advantage of the NSR behaves differently depending the market conditions. In the Low scenario, it follows a pattern similar to containerships, where competitiveness increases the higher the fuel price becomes. In the High scenario, however, the competitiveness of the NSR deteriorates due to higher fuel price. This somewhat surprising result is largely due to the higher fuel consumption of ice-classed NSR vessel relative to open-water vessel as determined by their engine power (15,000 kWh vs. 11,000 kWh), respectively. Moreover, the type of tramp operation applied in this calculation (including high T/C rates) may amplify the impact as it involves a single roundtrip comprising one leg in ballast and the other leg in a laden condition.

Overall, bulk shipping's competitiveness along the NSR seems to be especially sensitive to market fluctuations. The current market setting (Low scenario) does not encourage the use of the NSR on Europe – Asia transports, at least if Capesize is involved. The required distance advantage range is 50–80 per cent, which narrows the potential to shipments where the origin is inside the Arctic Circle and destination in ports of Northeast Asia. For equal-sized vessels, the Low scenario is not as dismissive given that the required distance advantage covers roughly the Hamburg-Yokohama voyage.

In contrast, with similar-sized vessels in the High scenario, the NSR seems to have a reasonable potential as the range of distance advantage needed is between 18–22 per cent, which roughly covers areas between Hamburg and Hong Kong. Similarly, where double-sized vessel (Capesize) is utilized on the SCR, the required distance range is between 22–35 per cent. This encompasses areas between Hamburg and Yokohama. See Appendix 4, Appendix 5,

Appendix 6 and Appendix 7, which contain the cost graphs created to analyze fuel price sensitivity in the Low scenario, while Appendix 30, Appendix 31, Appendix 32 and Appendix 33 contain the respective graphs in the High scenario.

5.3.4 The impact of NSR sailing speeds

The speed of ships using the NSR is largely subject to the ambient conditions rather than being an intentional decision of the ship owners. Apart from the unrealistic one knot speed intentionally used as an ultra-low reference speed in the calculations, it seems that other speed categories do influence the relative competitiveness of the NSR. In most cases increasing the speeds to 10 knots improves the NSR's competitive position relative to the SCR, while a further increase to 15 knots decreases it. The only exception to the rule is the similar-sized containership in the Low scenario where speeds higher than 10 knots increase the relative advantage of the NSR.

It seems that the highest potential for the NSR (measured as the required NSR distance advantage) is in similar-sized dry bulkers (20–22 per cent in the High scenario and 30–35 per cent in the Low scenario). In contrast, there is very little potential for NSR containership with a size of 4,000 TEU compared to 18,000 TEU in the SCR. Similar-sized containerships (4,000 TEU) appear to have reasonable potential in both scenarios, provided that speeds are at least 10 knots (22–23 per cent in the High scenario and 31–36 per cent in the Low scenario).

In general, speeds appears to be a more influential factor for dry bulkers than containerships. This may be attributable to the differing operating method in the model (i.e. annual sailings for containerships vs. one roundtrip for dry bulkers). In addition, market conditions seem to underline the effect of speeds on the impact of bunker cost. This is especially relevant in dry bulkers when Panamax used in the NSR and Capesize in the SCR. Here, the required NSR distance advantage in the Low scenario would account for 65–93 per cent compared to 29–51 percent in the High scenario. The former interval refers to distances via the NSR e.g. from Sabetta in western Russian Arctic to Yokohama, while the latter interval extends distances from Yokohama to Hamburg. Appendix 8, Appendix 9, Appendix 10 and Appendix 11 contain the detailed graphs with regard to the NSR sailing speed sensitivity in the Low scenario, while Appendix 34, Appendix 35, Appendix 36 and Appendix 37 show the respective graphs in the High scenario.

These observations suggest that the potential of the NSR is subject to conditions in terms of maintaining reasonable sailing speeds (at least 10 knots). This questions the potential, at least for the time being, of extending the navigational season of the NSR with more powerful icebreakers into year-round operations.

5.3.5 The impact of NSR navigational season length

Another characteristic component of the NSR sailing conditions is the length of its annual navigational season. The sensitivity of this item was tested only with containerships given its annual time perspective containing seasonal operations along the NSR. Perhaps unsurprisingly, with similar-sized vessels (4,000 TEU) the NSR's relative advantage compared to the SCR increases the longer the route is open. If the route is open half a year, the NSR would be competitive for distances that are between Hamburg and Yokohama / Hong Kong depending on the scenario. For different containership sizes (4,000 TEU in the NSR and 18,000 TEU in the SCR), the NSR is not a realistic option given that the distance advantage would have to be over 100 per cent shorter than the SCR.

When taking into account the limitations of the model used in the sensitivity analysis, it seems that the current potential may not be sufficient for containerships to use the NSR on a regular-basis. See Appendix 12 and Appendix 13 for the detailed graphs of the analysis for the Low scenario and respectively Appendix 38 and

Appendix 39 for the High scenario.

5.3.6 The impact of additional building cost of ice-classed vessels

The sensitivity of the cost differential between building an open-water and an ice-classed ship in terms of NSR usage is evaluated in this section. The analysis concerns only containerships given that dry bulkers are expected to be time-chartered and thus building costs are irrelevant.

By rule, the higher the cost differential, the less competitive the NSR becomes. It seems that if there was no construction cost differential, a similar-sized containership using the NSR would require a distance advantage of only 10 per cent in the High scenario and respectively 15 per cent in the Low scenario. If the cost differential was 75 per cent, the NSR competitive advantage in either scenario would only be valid for distances between e.g. Narvik and Yokohama. In practice, such a high construction cost differential would refer to building a higher ice-classed vessel with a higher capacity for independent operations. In contrast, for different-sized containerships operating along the NSR and the SCR, there is no realistic potential to be gained by using the NSR. The required distance advantage would have to be at least 100 per cent.

These findings emphasize the notion that fleet type choices need to be aligned with the intended purpose and trading area. See Appendix 14 and Appendix 15 for the detailed cost graphs of the analysis for the Low scenario and respectively Appendix 40 and

Appendix 41 for the High scenario.

5.3.7 The impact of NSR load factors

The results of the analysis regarding the NSR load factor sensitivity indicate that the higher the load factors are, the more competitive the NSR becomes. The highest potential is for similar-sized containerships, which, depending on the scenario and assuming an average load factor of 80 per cent, need only 3 or 11 per cent distance advantage for the NSR to retain its relative advantage. Even a 100 per cent load factor is not sufficient to provide a realistic potential for 4,000 TEU ships along the NSR relative to 18,000 TEU ships used in the SCR.

With similar-sized dry bulkers, an increasing load factor improves the NSR's competitive advantage substantially as the required distance advantage decreases in the Low scenario from 71 per cent to 41 per cent. This is equates approximately to a distances between Narvik and Yokohama. The effect is not as substantial when accounting for the use of Capesize in the SCR. There is a more dramatic decrease in the High scenario, where the required distances drop from 90 per cent to 28 per cent, when load factor increases from 40 per cent to 80 per cent.

Overall, it seems that load factor has more influence on the potential of containerships compared to dry bulkers. This finding is arguably attributable to the load factor proxy 65 per cent load for containerships using the SCR, which is substantially lower than the 90 per cent load factor proxy for dry bulkers. In practice, such high load factors (if TEU weighing at 14 tonnes) may not even be realistic owing to the ship’s carrying capacity limitations, for example, due to stability issues.

Finally, one could also question the validity of load factor as a parameter, given that they indicate realized potential. For the NSR, this is highly speculative as the volume of cargo demand is largely unknown. See Appendix 16, Appendix 17, Appendix 18 and Appendix 19 for the detailed graphs of the analysis for the Low scenario and respectively Appendix 42, Appendix 43, Appendix 44 and Appendix 45 for the High scenario.

5.3.8 The impact of icebreaking fees

The results of the sensitivity analysis show that the lower the icebreaking fees the more competitive the NSR becomes. Furthermore, the results also underline how market conditions influence the relevance of the icebreaking fees. These, in turn, affect the cost differentials of the NSR relative to the SCR.

It appears that, when High scenario is concerned, changes in icebreaking fees seem to be rather insignificant in terms of NSR’s relative advantage. Changes in fees between -25 and +50 per cent would only result NSR distance advantage to change from 13 to 26 per cent in containerships. Respectively, fee changes will result a change of 15 to 23 per cent in similar-sized dry bulkers and 22 to 33 per cent when Capesize bulkers are deployed in the SCR. Overall, the potential can be considered substantial.

In contrast, in the Low scenario icebreaking fees have more leverage on competitive position of the NSR. Similar changes in icebreaking fees (between -25 and +50 per cent) will increase the required NSR's distance advantage from 19 to 41 per cent in containerships; from 11 to 43 per cent in similar-sized dry bulkers; and 35 to 85 per cent when Capesize bulkers are being deployed in the SCR. The initial discounted fee levels obtained from the Atomflot in 2013 used as the proxy value may explain this finding. In addition, the combination of high fuel prices and freight rates may mask the importance of icebreaking fees.

Overall, it seems that substantial icebreaking fees discounts improve the competitive position of the NSR. Substantial changes in fees – especially discounts – may initiate responses from the competitive routes, i.e. in Suez Canal tolls, which complicates the analysis. See Appendix 20, Appendix 21, Appendix 22 and Appendix 23 for the detailed diagrams of the analysis for the Low scenario and respectively Appendix 46, Appendix 47, Appendix 48 and Appendix 49 for the High scenario.

5.3.9 The impact of Suez Canal tolls

Changes in Suez Canal toll have an impact on NSR's relative advantage. A Suez toll increase improves the competitiveness of the NSR relative to SCR, while decrease in tolls reduces it. In general, the impact of Suez Canal tolls on NSR's competitive positions bear similar characteristics than icebreaking fees.

The market scenarios (Low vs. High) amplify the effect of Suez Canal toll changes in a different manner. In the High scenario, the required NSR distance advantage in all vessel size variants is levelled at between 17 per cent and 33 per cent, which signals rather substantial potential as such for the NSR. The case is different in the Low scenario, where especially after toll discounts, the required NSR distance advantage in all vessel size variants ranges between 40 per cent and 89 per cent. This equals to distances between Narvik and Yokohama or between ports that are located even further north. See Appendix 24, Appendix 25, Appendix 26 and Appendix 27 for the detailed diagrams of the analysis for the Low scenario and respectively Appendix 50, Appendix 51, Appendix 52 and Appendix 53 for the High scenario.

5.3.10 The impact of time-charter rates for dry bulkers

Analysis on the sensitivity of time-charter rates concerns only dry bulkers. Containerships are excluded as they are assumed to be owned by the shipping operator. It is assumed that the T/C rates of Capesize vessels are fixed at USD 7,500 per day in the Low scenario and respectively USD 50,000 per day in the High scenario, while the Panamax rate is variable. According to BIMCO (2016) T/C rates for both Panamax and Capesize were in September 2016 in a low level at around 7,500 USD per day for the former and at 5,000 USD for the latter (See Appendix 3).

It appears that increasing T/C rates in both scenarios improves the relative advantage of the NSR in similar-sized dry bulker category. On a very high level at USD 100,000 per day in the High scenario, the required distance advantage is only 15 per cent, which equals the distances between Hamburg and Hong Kong. Similarly, in the Low scenario, T/C rate at USD 15,000 per day requires only 22 per cent distance advantage.

The picture is totally different when Capesize vessels are included. In this case, NSR's relative advantage is dependent on the difference between Capesize and Panamax T/C rates. This means that the differential reaches its highest point in the High scenario when Panamax T/C rates are at USD 10,000 per day and respectively in the Low scenario when T/C rates are at USD 5,000 per day. Overall there is very little potential for the NSR when Capesize vessels are used in the SCR, except when a combination of high fuel prices and very low T/C rates prevail. For Panamax-sized vessels the NSR could be a viable option, in particular for distances within the Hamburg–Yokohama range. See Appendix 28 and Appendix 29 for the detailed diagrams of the analysis for the Low scenario and respectively Appendix 54 and Appendix 55 for the High scenario.

5.4 Preconditions for profitable shipping along the NSR

In this Chapter, the aim was to analyse the profitability of a ship owner operating along the NSR compared to the SCR. In extant literature, a common approach to assessing ship-wise profitability along the NSR usually focuses on cost comparisons relative to the Suez Canal. As noted by Carmel (2013), an implicit assumption that is often drawn in this respect is that shorter distances correlate to similar savings in time and costs. To some extent, this may be valid in ideal cases, but more often than not, the situation is far more complex.

A sensitivity analysis confirmed that all the parameters contribute to determining the NSR’s competitive position relative to the SCR. Especially influential were climate (speed and season length) and market conditions (charter rates and fuel price) based variables that determine the environment in which the ship owner has to work and make decisions. Three of the four components (speed, season length and fuel price) are directly connected to bunker costs either by determining their level or the potential savings in them. The fourth component (charter rates) concerns only bulk shipping in this analysis, the level of which is mostly beyond the ship owner's control.

The issue of vessel size restrictions of the NSR pose a seemingly obvious disadvantage to its competitiveness. The analysis showed that where similar-sized vessels are concerned the potential seems reasonable relative to the SCR for both containerships and dry bulkers. However, this finding should be considered with caution since the somewhat simplified sailing conditions used in the analysis may favor containerships. Moreover, one could also question the relevance of a containership with a capacity of 4,000 TEU used in the Suez Canal. Deployment of larger vessels in the SCR proved not entirely dismissive for the potential of the NSR. Apart from containerships, dry bulkers appeared to have some potential, but this is subject to market conditions.

The large number of variables complicates the analysis and may lead to suboptimal conclusions in terms of retaining the ship-wise profitability. Therefore, the focus should be shifted from a single cost component to a level. This is where the separate cost components are bundled into a logical entity, which is easily understandable for ship owners. In this respect, considerations should address subjects like the type of equipment used, as retaining ship-wise profitability depends very much on the fleet choices.

The sensitivity analysis confirmed that the building cost differential of the ice-class vessel relative to the open-water vessel has a substantial impact on the competitive position of the NSR. Yet capital costs and their difference are only one of the many factors affecting shipping economics along the NSR.

A higher ice-class influences a vessel's earnings potential by narrowing its deployment areas but at the same time enables a longer operating season along the shorter routes through ice-infested waters. The higher the ice-class, the more optimized the vessels are for ice navigation, while in open-water conditions they tend to suffer adverse fuel economy due to their more specialized design. Occasionally, the adoption of slow steaming may compensate for that, if ice-free conditions prevail.

At least for the time being, the higher ice-classed ships are smaller-sized on average compared to their open-water counterparts, thus suffering the effects of negative economies of scale. On top of that, their cargo carrying capacity is further impaired by the ice-strengthening. The effects of the ice-class are diverse in terms of costs, on one hand, a higher ice-class entails lower icebreaking fees but, on the other hand, higher operating costs are the result of a more demanding and riskier operating environment. Furthermore, specialized ships are more expensive to build thus incurring higher building costs.

Hence, the prevailing conditions and intended purpose are decisive factors in determining optimal ship design in terms of reaching profitability (e.g. von Bock und Polach et al. 2014). Currently, the navigational season is mostly restricted to the summer-autumn period, albeit the winter navigation could be technically viable but is not an economically rational decision. Ice conditions during winter are still considered too challenging, even for the ice-going ships to operate in a predictable manner and maintain a reasonable speed (Bourbonnais and Lasserre 2015).

There are several studies supporting the argument that the ship-wise profitability of operating along the NSR is dependent on the chosen ship's ice-class and its suitability for the prevailing climate conditions. The highest ice-class is by no means the optimum as the costs of the highest ice-class vessels exceed the benefits at some point. Omre (2012) argued that in easy ice conditions all ice-classes along the NSR would be more profitable than an open-water ship along the SCR. In this respect, IC class was found optimal, while IB was preferred in more challenging conditions. Erikstad and Ehlers (2012) argue that IA will be the most prominent ice-class for the future Arctic liner transit shipping. Sørstrand (2012) had similar findings as he found that IA needs around 60 operating days along the NSR provided that there is enough ice along the route and fuel prices are at a relatively high level.

A study by von Bock und Polach et al. (2014) concluded that, owing to ambient conditions, the ice-class would not increase profitability because an open-water ship along the SCR was superior relative to an NSR ship. In an ice-class comparison, a ship equipped with a higher ice-class (Arc5) was found more profitable than the respective one with a lower class (Arc4). Similarly, Esa (2015) concluded that during severe NSR winter conditions the economy of an open-water ship along the SCR was superior, whereas in milder conditions the NSR ship equipped with DAS was superior.

To sum up, attaining ship-wise profitability by using the NSR is a trade-off between i) the margin of the greater costs; ii) revenues gained from increased performance at a given time; iii) compared to the differentials of the alternative routes (e.g. Cariou and Faury 2015). Macroeconomic dynamics influence ship owner's earnings potential and costs, but the ship-wise profitability along the NSR is largely dependent on climate conditions and how well the equipment is suited to the intended purpose at a given time.

6 PESTEL COMPARISON OF THE ARCTIC SEA ROUTES

The Arctic Sea is a semi-enclosed Ocean, which includes three main maritime corridors: the Northwest Passage, the Transpolar Passage and the Northern Sea Route (Figure 5). This Chapter uses the structure of the PESTEL framework to analyse the differences between the Arctic Sea routes in terms of the risks involved to shipping up to 2030.

6.1 Political risks

The location of the NSR, largely in Russian territorial waters, makes it politically challenging due to the present geopolitical tensions caused by the Ukrainian crisis. The economic sanctions placed on Russia have resulted considerable hindrances to international cooperation (e.g. Klimenko 2014).

Respectively, the NWP is largely located in Canadian territorial waters, which seemingly constitutes no prominent political disputes. However, there are some yet unreconciled issues regarding the control of the NWP (e.g Molenaar 2014). In short, the USA does not recognize the sovereignty of Canada over the NWP due to its differing approach on the UNCLOS convention (e.g. Moe and Jensen 2010). This means that the USA considers the NWP an international waterway whereas Canada considers it an archipelago within its domestic waters. The differences may escalate if the exploitation of natural resources is initiated in the vicinity of the route.

The remote geographical location of the TPP has kept it away from the sphere of interest of any political actors. However, the political significance may increase, if claims made by Russia or other Arctic states over the extension of their EEZs are accepted by the United Nations tribunal.

6.2 Economic risks

Shipping and natural resource related issues are the primary economic incentives behind the interest in the Arctic Sea routes. From the shipping point of view, all of them (the NSR, the NWP and the TPP) provide shorter distances between the Atlantic and the Pacific Oceans. In the literature, the NSR is usually compared to the

SCR (e.g. Liu and Kronbak 2010), while the NWP has been similarly analysed vis-á-vis the PCR (e.g. Somanathan et al. 2007). If the current level of maritime activity is used as an indicator, the NSR has, in relative terms, the highest potential (Table 23). However, on a global scale the potential is miniscule.

Table 23 The transit traffic volumes of the Suez and Panama Canals, the Malacca Strait and the Arctic Sea routes by vessel number 2009–2015 (compiled by the author from various sources: Østreng et al. 2013; Headland 2015; SCA 2016; PCA 2016; MDPM 2016; Guy and Lasserre 2016; NSRIO 2016)

Route	2009	2010	2011	2012	2013	2014	2015
Northern Sea Route	5	13	41	46	71	31	18
Northwest Passage	17	19	18	30	22	17	15
Transpolar Passage	All time total: 66 partial transits out of which 7 made full transit						
Panama Canal	14 342	14 230	14 684	14 544	13 660	13 481	13 874
Suez Canal	17 504	18 050	17 664	16 665	16 744	17 544	17 483
Malacca Strait	71 359	74 133	73 528	75 477	77 973	79 344	80 959

The interest in the NWP first materialized in 1969 when icebreaking tanker *SS Manhattan* sailed through the route on its trial voyage from Prudhoe Bay, Alaska to the Atlantic Ocean (Emmerson 2011). Thus far, the activity has mostly been linked to services for remote communities and mining projects (Sander et al. 2014). Pharand (2007) identified 69 transits of foreign vessels through the NWP between 1903 and 2005.

Over the past few years, a new feature has been the introduction of larger-sized merchant vessels. In the summer 2012, the cruise ship *MS The World* sailed through the NWP with 508 passengers, and in August 2013 it was followed by Panamax-sized (75,000 DWT) dry bulk carrier, *MV Nordic Orion*, on its voyage from Vancouver, Canada to Pori, Finland (Lasserre 2014). In 2015, two Finnish icebreakers, *MSV Fennica* and *MSV Nordica*, traversed through the route in their voyage from Alaska to Europe (Headland 2015). In autumn 2016, around 1,600 passengers and crew members were on board *MV Crystal Serenity*, when it navigated through the NWP on its voyage from Alaska to New York accompanied by British polar research vessel *RRS Ernest Shackleton* (Business Wire 2016).

In extant literature, there are only a few studies that evaluate the market potential of the NWP. This may be attributed to weak interest and its limited potential. The Arctic Council (2009) considered its traffic potential to be limited and not viable for transits. A study by Fan et al. (2012) projected that the NWP could ideally take 0.37 MTEU away from the PCR. The drivers for demand appear to be similar to those of the NSR and NWP. Pizzolato et al. (2014) could not find a strong correlation between maritime activity in the Canadian Arctic and the decline of sea ice. This implies that the drivers of ship owners' decision-making regarding the NWP are similar to those influencing the NSR, where a complex mix of factors influences maritime activity.

Shipping along the TPP has hitherto consisted of scientific expeditions. So far, no merchant ship has sailed across the route. However, the total number of partial voyages is not trivial. A total of 77 voyages have reached the geographic North Pole, most voyages were accompanied by Russian nuclear-powered icebreakers, but also to a lesser degree, the diesel-powered icebreakers of various nations (Østreng et al. 2013). Of these voyages, only seven traversed through the Arctic Sea and qualified as a full TPP voyage (Østreng et al. 2013).

In the long-term, substantial infrastructural constraints appears to be limiting maritime activity along the Arctic Sea routes. The most critical issue is the lack of ports. Only the NSR has a string of ports but the maritime infrastructure is rudimentary, including the permanent provision of icebreakers. In this respect, Russia has actively developed its icebreaking tariff system in recent years, which has led to a more transparent pricing system.

In comparison, the contemporary icebreaking services of the NWP are limited, but de facto free of charge given that the Canadian government has covered the costs so far (Parsons et al. 2011). Lu et al. (2014) analysed the influence of the proposed NWP toll fee relative to the PCR and concluded that the advantage depends on the level of the fees. The NWP remains competitive if the fee proxy is 40 per cent lower than the PCR. Also ships with a capacity greater than 9,000 TEU were found to adversely affect the NWP's relative advantage. As for the TPP, neither infrastructure nor icebreaking services exist.

If other potential incentives to use the Arctic Sea routes are considered, i.e. the Arctic's natural resource potential, the overall picture looks diverse. The USGS estimated that the most substantial oil deposits are located in Alaska, while most of the gas is in the Russian Arctic (Bird et al. 2008; Gautier et al. 2009). This obviously provides a natural cargo base for shipping activity. However, the exact magnitude of shipping volumes cannot be directly drawn from extraction activity. According to Têtu et al. (2015) only three of the ten mines located in the Canadian Arctic use maritime logistics in their supply chains.

The resource potential of the TPP is more uncertain. Together with unsettled ownership issues, this does not provide a basis for large-scale activity along the TPP. In addition, there are substantial differences between the attitudes of the involved countries towards environmental issues e.g. in terms of natural resource exploitation. Environmental standards at a given point of time define the global balance between exploitation and environmental protection (Emmerson 2011) and these tend to be more important in Western countries than in Russia.

6.3 Social risks

In terms of social issues, there are no obvious differences between the Arctic Sea routes. The highest concentration of population is in the vicinity of the NSR, while the NWP has fewer people and the TPP is practically unpopulated. Therefore, it may be argued that, in relative terms, none of the routes constitute a demographically large enough mass to provide reasons for large-scale shipping other than transits and natural resource exploitation. The social risks can therefore be considered insignificant from the shipping perspective.

6.4 Technological risks

If a narrow scope is used to analyze the technological risks associated with Arctic Sea routes, the first thing to consider are the navigation requirements, which correlate with sailing conditions. For example, a high-level of autonomy is required for ships if they are to be capable of operating in isolation along the NWP and the TPP, owing to the non-existent navigational infrastructure and the severe ice-conditions. In practice, such requirements mean an icebreaking capability comparable to that of an icebreaker, something which is practically non-existent in both regions. Similarly, other technical navigational aids are needed.

When the scope is extended, a discussion on the technologies that influence the demand for sea transports is in order. The development of mining and other mineral extraction techniques are examples of such factors (Haley et al. 2011). In addition, the expansion of the Panama Canal, which finally opened on June 26 in 2016, is something that will alter the dynamics of global shipping patterns (e.g. Liu et al. 2016; Rodrigue and Ashar 2016) and could potentially reduce the demand for alternative routes, especially for the NWP.

There are also other technological solutions, like 3D printing, which have the future potential to diversify global trade flows (e.g. DHL 2016). However, the scant amount of scientific research into emerging technologies makes it challenging to predict their impact on shipping. Overall, the NSR can be considered to have the lowest risk from a shipping point-of-view with regard to technological issues compared to other Arctic Sea routes.

6.5 Environmental risks

From a geographical standpoint the three Arctic Sea routes are far from being alike. The NSR and NWP are coastal routes whereas the TPP is a mid-ocean route. The TPP offers the shortest link across the Arctic Sea (Humpert and Raspotnik 2012).

Shallow bathymetry in both the NSR and the NWP are constraining factors whereas that constraint is relaxed in the TPP. The Bering Strait has shallow water depths but only the usage of the largest oil tankers is restricted (Humpert and Raspotnik 2012).

The geographical features of the NWP are more complex than the NSR. While the NSR follows the course of the Russian Arctic coast passing relatively few straits and islands, the NWP comprises of a number of islands and straits along the Canadian Arctic coast, and thus it can be considered as an archipelago. Along the NWP, there are seven different routes of which six run through the southern part of the archipelago (Pharand 2007). In contrast, there are only three main routing options in the NSR.

The present and predicted climate conditions show variations between the Arctic Sea routes. Severe ice-conditions still persist especially in the TPP and NWP. For example, the 2011–2015 mean thicknesses of multi-year ice along the NWP ranged between 2 and 3 meters (Haas and Howell 2015). Accordingly, ice-conditions are likely to remain challenging and maritime activity will remain seasonal (Stephenson et al. 2013; Bourbonnais and Lasserre 2015). By the end of century, the navigational season of the NSR is expected to extend from three months to six months and from two to four months for the NWP (Khon et al. 2010). The predicted sequence of opening of the waterways is as follows: 1) the NSR; 2) the TPP; and 3) the NWP (Stephenson et al. 2011).

6.6 Legal risks

Arctic governance is largely based upon the national jurisdiction of the Arctic states, while also honoring bilateral, regional, and international treaties. The dominance of the Arctic Sea routes depends on the interpretation of the UNCLOS convention. Canada's control over the NWP and Russia's over the NSR has been disputed by the USA. Unlike the NSR, the NWP is not defined in Canadian law, entailing a rather broad definition of its boundaries (Molenaar 2014). Controversies have particularly concerned the allowance of Article 234 in terms of the unilateral governance of shipping (Solski 2013). There is no clear evidence of the stance of non-littoral states regarding their interpretation of the article. Molenaar (2014) argues that some countries like China, Japan, Norway, South-Korea and a few EU member states may share the perspective of the USA.

Despite the controversies, territorial claims are not likely to influence the development of shipping along the Arctic Sea routes. In 2008, the five littoral Arctic Ocean nations confirmed their commitment to UNCLOS by signing the Ilulissat Declaration. According to Moe (2012) there are still a few outstanding jurisdictional bilateral disputes: the maritime boundary between Russia and the USA in the Bering Sea; Beaufort Sea between Canada and the USA; Lincoln Sea between Canada and Denmark (Greenland); Hans Island between Canada and Denmark (Greenland).

The TPP is located in Arctic Ocean High Seas outside the national jurisdiction of the Arctic Sea littoral states. Hence it involves only a few legal uncertainties and controversies (VanderZwaag et al. 2008). It is governed by UNCLOS Article 87 asserting that waters beyond EEZ limits are part of the High Seas, providing freedom of navigation. Moe and Jensen (2010) suggested that ship owners may be willing to test the possibilities of the TPP in order to avoid the problems stemming from national jurisdiction.

The forthcoming IMO's Polar Code will constitute the main instrument for Arctic maritime safety as soon as it is ratified (see IMO 2016).

6.7 Summary of the risks and insights

This sub-chapter concludes the comparison of the Arctic Sea routes. Table 24 shows the compiled results categorized in accordance with the PESTEL framework in terms of the risk levels with regard to shipping along the Arctic Sea routes up to 2030.

Table 24 PESTEL categorization of risk levels (Low, Medium and High) with regard to shipping along the Arctic Sea routes in the present-day (X) and up to 2030 (Y)

Arctic Sea Route	Northern Sea Route			Northwest Passage			Transpolar Passage		
Level of risk	L	M	H	L	M	H	L	M	H
Political		Y	X	Y	X		X	Y	
Economic			XY		X	Y	X	Y	
Social	X	Y		XY			XY		
Technological		XY			Y	X		Y	X
Environmental		XY			Y	X		Y	X
Legal	Y	X		Y	X		X	Y	
L= Low, M = Medium, H = High, X = Present, Y= by 2030									

Present-day maritime activity along the NSR also entails High political risks due to the geopolitical turmoil between Russia and Western countries. By 2030, these tensions are expected to be alleviated but are expected to remain on the Medium level. In contrast, the NWP is currently involved with Medium level political risks owing to disputes between Canada and the USA. By 2030, these controversies will be resolved and the political risks will be reduced to Low. The TPP now has a Low political relevance owing to its remote location and limited accessibility. However, the receding ice may introduce a rise in new political tensions given its unsettled governance issues, thus causing Medium level political risks by 2030.

In terms of economic uncertainties, the NSR has High risks largely due to the vast, but expensive-to-extract natural resources and is thus subject to commodity market fluctuations. A similar market dependency is also valid for shipping prospects, which are dependent on, among other things, the price of oil. This situation is not likely to change by 2030.

In relative terms, the NWP holds the same economic risks as the NSR but owing to the Canadian Arctic's so far less materialized natural resource potential and relative lack of shipping activity, the market risks could be considered at a Medium level. In the mid-term, the situation remains highly speculative, but if new natural resource discoveries are made that lead into a large-scale extraction projects facilitated by maritime transports, the market risk increases to High.

Currently, the primary economic incentives of the TPP are associated with only testing the prospects for shipping, thus the economic risks can be considered Low. By 2030, if maritime activity along the TPP intensifies the risks also increase to Medium.

Social risks cannot be considered as the primary category involved in Arctic shipping. Currently, the NSR may be viewed as containing Low level risk owing to the decrease in demographics in the Russian Arctic, resulting in reduced demand for maritime transport. A potential implication may also arise from the limited provision of ice navigation capable crews, which, in turn, may increase crew costs. By 2030, the risk level may increase to Medium provided conditions improve for shipping and human activity intensifies along the Russian Arctic.

As for the NWP and TPP, the present social risk levels are Low due to limited human involvement and remoteness. In the mid-term, the risk levels are likely to remain the same as at present.

Technological risks in the NSR could currently be considered to be on a Medium level. By 2030, solutions in navigation domain may lower the risk levels but potential shifts in seaborne trade patterns due to technological breakthroughs will maintain the level at its current Medium level. As for the NWP and TPP their more challenging climate conditions and the expanding capacity of conventional routes, i.e. Panama Canal, set the bar higher for technological issues, which raises the present risk level to High, whereas by 2030 they are likely to have lowered the risk to Medium, provided that conditions continue to improve.

The current conditions along the NSR are undoubtedly challenging but are showing some indications of becoming less challenging. This equals to a Medium level environmental risk. By 2030, most of the climate models predict easier conditions, including lengthening ice-free periods. However, the risk level is likely to remain Medium given the high level of uncertainty over climate development. In addition, some dangerous phenomena, like storms are expected to become more frequent. The NWP and the TPP currently have High risk levels, owing to poor accessibility and the hostile conditions there. Their situations may lower to Medium risk by 2030, but that is contingent upon more favorable climate conditions. All of these climate predictions have a high level of uncertainty, thus all predictions can be considered rough estimates at best.

Currently, the legal risks involved with the NSR and the NWP can be considered to be on the Medium level. This is largely due to disputes regarding their governance and the impact of the upcoming Polar Code. By 2030, their risk levels may be reduced to Low provided that the aforementioned uncertainties are resolved. As for the TPP the risk factor currently constitutes a Low level uncertainty, which owes much to the minuscule interest shown towards the route and its governance. By 2030, the situation may have altered if the route becomes more accessible but that will entail new disputes over its control. The corresponding risk level will then be Medium.

In conclusion, the NSR has the highest market and political risks, while issues relating to technological, environmental and legal risks are, in relative terms, higher along the NWP and the TPP. Social risks appear rather insignificant by all accounts. This implies that the preconditions for shipping are most favorable along the NSR, the potential of which may be amplified or downsized by the macroeconomic factors regarding political and market conditions.

7 SUMMARY OF THE RESULTS

This Chapter summarizes the results of the appended articles and the concluding summary by synthesizing them based on the sub-research questions (RQ1–RQ3). Finally, the main research question (MRQ) is answered.

7.1 Economic viability

RQ1: *How does the cost of shipping along the NSR relate to the shipping markets?*

Articles I and III address this question by employing comparative cost calculation analysis in container shipping that incorporates different time periods of analysis, operational conditions and methods. Special focus is placed on vessel speeds, identified by the Arctic Council (2009) as pivotal for economic viability, which both articles address from different perspectives.

Article I employs a NSR scenario that consists of a single voyage in open-water conditions with a port-to-port routing setup where shipping costs are compared to those of the SCR. The scope is extended to account for the inventory costs accrued by shippers based on the voyage duration. Article III, in turn, hypothesizes a multiport network, where seasonal navigation along the NSR encounters gradually more difficult ice-conditions, while sailing the rest of the year along the SCR. This setting is a more realistic depiction of the proposed organisation of contemporary container shipping activity along the NSR.

The results of Article I challenge the arguments of Laulajainen (2009) and Lee and Kim (2015) by concluding that the benefits of the NSR are unbiased for both shippers and ship owners. Shorter and faster sailing times allow reduced logistics costs for shippers and reduced shipping costs for ship owners. Conflicting opinions may arise from the use of the differing charter types used in bulk and container shipping. Furthermore, the results of Articles I and III emphasize the overall impact of bunker costs and icebreaking fees on the economic viability of the NSR consistent with the findings of Liu and Kronbak (2010). Similarly, Articles I and III emphasize the effect of open-water and ice-conditions on fuel economy which support the remarks made by Lasserre (2014). Accordingly, the results of Article III do not support Furuichi and Otsuka (2015) who argue that the longer navigational season of the NSR leads directly to higher economic gains.

The concluding summary adds a new angle to this discussion by underpinning the impact of ship design on retaining the ship-wise profitability while operating along the NSR. It suggests, consistent with Erikstad and Ehlers (2012), that the optimum ice-class of a ship is dependent on the conditions.

Both Articles I and III show that the daily shipping costs in the NSR are higher than along the SCR during present day conditions, while at the same time underlining the potential of the NSR's shorter distances to mitigate the unfavorable cost differentials.

The concluding summary provides more insights on the cost differentials of the NSR, while also scrutinizing the distances needed for the NSR to retain its competitive position in container shipping and bulk shipping with varying vessel sizes. The sensitivity analysis found that where similar-sized vessels are concerned on average one-third shorter distances are needed in order for the NSR retain its relative advantage over the SCR. By contrast, if larger-sized vessels are used in the SCR, there was no potential for the NSR in container shipping, and only modest potential in dry bulk shipping, provided that favorable market conditions prevail. The findings about the poor potential for container shipping largely supports Carmel (2013). The dry bulk shipping's dependency on market conditions is in line with Cariou and Faury (2015).

7.2 Maritime infrastructure and related services

RQ2: *What are the main infrastructure constraints and the theoretical throughput capacity of the NSR?*

Articles II, IV, V and the concluding summary address the question in a complementary manner.

Article II investigates the development and composition of the ice-class fleet, which is one of the critical components of the NSR maritime system. The results of Article II reveal that despite the prevailed enthusiasm in the media, there are very few indications of a change in the composition of the ice-class fleet in recent years. The absence of large-sized containerships is an especially notable indicator of poor infrastructure capacity and weak industry interest, which is consistent with the findings of Lasserre and Pelletier (2011) and Beveridge et al. (2016). Moreover, some Arctic specific implications in terms of LNG carrier newbuildings were detected that support the notion of the potential for Russian destinational traffic, sharing the opinions proposed by Buixadé Farré et al. (2014).

Article IV investigates the supply of icebreakers, which constitute another critical maritime system component. The results are in line with the findings of Ragner (2000a; 2000b) and Moe (2014) who concluded that the decreasing icebreaker fleet, due to aging and sluggish renewals, poses concerns about the functionality of the NSR, particularly regarding a potential increase in traffic. Article IV's results also provide a quantifiable estimate of the NSR's contemporary throughput capacity, indicating that there is overcapacity in icebreaking. However, the capacity was found to account for less than one thousand annual voyages, which may be considered a significant barrier. The results were consistent with Ragner (2000b) but as such did not support Moe's (2014) estimate of a briefly occurring icebreaking pause.

Article V used the findings of Article IV and created a system dynamic simulation for a 50 -year development outlook for both an ice-class fleet and icebreakers. Several climate and cargo growth scenarios were employed to analyse the dynamics of the supply capacity in various conditions. The results indicated that icebreaking constitutes the most critical factor for growth in most cases and that the long-lead times of icebreaker deliveries may potentially cause interruptions to the NSR's functionality, as Moe (2014) also noted. It was also demonstrated that the NSR needs a critical mass of cargo of more than 30 MT in order to sustain functionality, which corresponds with the findings of the Arctic Marine Shipping Assessment (Arctic Council 2009). The result implies that substantial political leadership and sponsorship, namely from Russia, is needed in order to establish a sustainable and functional maritime system. This finding corroborates Lammers' (2010) conclusions.

The concluding summary contains an extensive literature review and provides similar remarks on ice-class fleet and icebreakers as in Articles II, IV and V. This part also investigated the supply of ports, navigational aids and qualified crews along the NSR. The results raised significant concerns over the level of NSR infrastructure in terms of the scant number of ports that are equipped with adequate water depths, inadequate provision of navigational aids (in particular SAR), and limited number of ice-navigation experienced crews. All of these findings are consistent with the Arctic Council (2009) and several other studies such as Granberg (1998) and Ho (2010).

7.3 Market potential

RQ3: *What is the potential demand for shipping along the NSR?*

Articles IV and V address this question by focusing on the supply and demand issues. In addition, the concluding summary provided an extensive literature review regarding the cargo potential of the NSR. In this respect, Article IV and the concluding summary identified the magnitude of the potential cargoes to be transported along the NSR. The results indicate, relative to the Suez Canal, a modest potential provided that climate conditions improve for shipping. In the current conditions, only a very limited potential was found. Most of the transit potential concentrated on container shipping, while the most prominent cargo base concerned bulk shipping of oil and gas. This type of activity fulfils the criteria of destinational shipping. These findings match those of Tavasszy et al. (2011) and Arctic Council (2009) but do not generally support the most optimistic estimates of Laulajainen (2009) and Bekkers et al. (2015).

Article V used a 50-year simulation to analyse the supply capacity of the NSR maritime system in various climate and cargo growth scenarios. The result showed that on average approximately one third of the potential cargo volume was lost due to inherent supply capacity constraints. From the ship owner’s perspective, this suggests that such uncertainty does not encourage the NSR to be consistently selected as a preferred route. By and large, the results support the findings of Article IV since they emphasize only a modest market potential, which is due to the limited infrastructural capacity. This finding is consistent with the results of Lasserre and Pelletier (2011) and Beveridge et al. (2016) who concluded small market potential.

Overall, the potential of the NSR is associated with a high degree of uncertainty given that it is subject to a number of external factors affecting its operational environment. This complex set of factors was analyzed using the PESTEL framework in the concluding summary.

Political issues were especially relevant given the current geopolitical turmoil, the effects of which also resonate in the Arctic. Economic aspects primarily involved matters that create demand for maritime transports. In this respect, natural resource potential was considered to be significant by any standard. However, the resources are expensive to extract and are thus dependent on commodity market conditions. Social considerations were found to be rather negligible. Technological development has the potential to improve competitive position of the NSR in the future in terms of improving safety and reducing the cost of transport. Although substantial uncertainties exist in terms of gradually progressing climate change, which pace and impacts are still largely unknown, environmental aspects were considered as the main catalyst to harness the NSR’s potential. The legal framework governing Arctic shipping is not yet fully harmonized. However, it possess the capacity to regulate shipping and facilitate the sustainable exploitation of the region.

Finally, the concluding summary provides a comparison of the Arctic Sea routes by applying the PESTEL framework in terms of the risks to shipping along the routes up to 2030. The NSR stands out as having the most favorable preconditions for shipping, while also being burdened by the highest market and political risks of the available Arctic Sea routes.

7.4 Feasibility of commercial cargo shipping along the Northern Sea Route

MRQ: *Could commercial cargo shipping become feasible along the NSR?*

Determining the feasibility of commercial cargo shipping along the NSR is a complex and time-dependent process because it is subject to several internal and external dynamic factors. Figure 31 shows the main factors affecting the decision-making of a ship owner's when choosing between the NSR and the SCR.

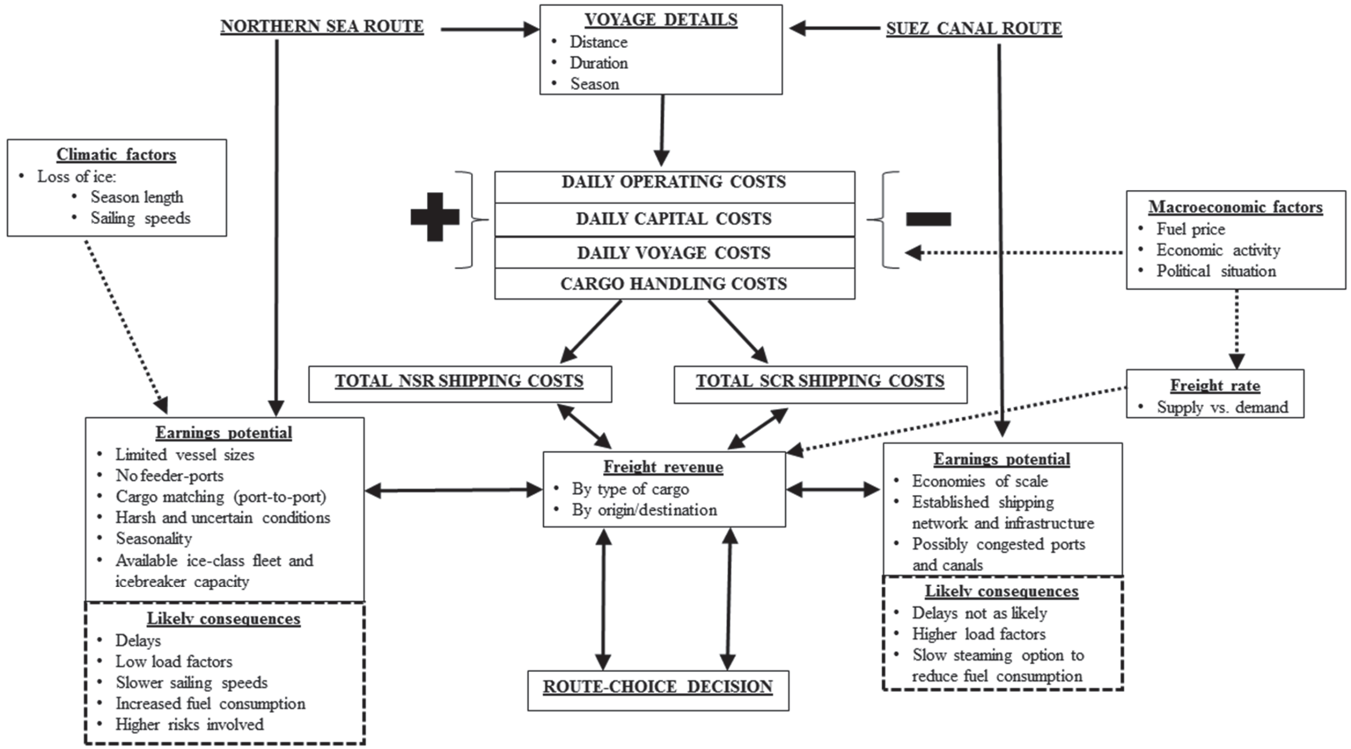

Figure 31 The main factors affecting the decision-making process of a ship owner when choosing between the Suez Canal Route and the Northern Sea Route

The economic viability of the NSR is dependent on balancing between the gains of seasonal distance advantage vis-á-vis the higher daily costs of shipping. In this respect, the optimum period prevails during ice-free conditions which, in turn, entail a favorable fuel economy. Ship-wise profitability can be improved by choosing the optimum ship design in terms of ice-class.

Given the contemporary impaired shipping economics of the NSR relative to open-water routes, commercial cargo shipping tends to be more dependent on market mechanisms and macroeconomic boosts than regular activity taking place elsewhere. In this respect, the most influential factors are high freight rates and prices for oil and gas, while not forgetting the leverage of political factors. Without the involvement of external incentives, maritime activity along the NSR is likely to remain marginal and focused on Russian needs.

The infrastructure capacity of the NSR in terms of supply of icebreakers, ice-classed fleet, seaports, navigational aids and crews appears inadequate and poses serious doubts over its capability to sustain growth in cargo volume. Substantial investments are needed that would require a major involvement from the Russian side. Investment in a specialized ice-going fleet could relieve, to some extent, the capacity constraints. At the same time, this would tie ship owners to specific routes that are predominantly burdened by a scarcity of cargoes.

In itself the market potential of the NSR for global shipping is limited, which is further constrained by contemporary climate conditions. Currently, this potential is overshadowed by macroeconomic factors, which may be subject to change. In the short-term, most of the activity is likely to be linked with natural resource extraction projects mainly in Russia or in its EEZ and domestic traffic sponsored by the Russian government.

Commercial cargo shipping along the NSR will arguably remain a niche market for ship owners, requiring special attention given its unique characteristics. The NSR as well as other Arctic Sea routes could help the management of existing ice-class fleets by extending their normal navigation season and by improving the mobility of the fleet and the utilization of its capacity.

Table 25 shows the relevance of the NSR as a shipping route by mode and traffic type. The scale of the cargo potential is measured in cargo volume in three indicative categories: Limited (0 – 4.99 MT); Moderate (5 – 20 MT); and Substantial (+ 20 MT).

In total, destinational traffic has greater potential for development than transit. In particular, container shipping is heavily disadvantaged by the climate conditions, which result in Limited potential at present, and that Limited potential is not expected to change by 2030. This is largely due to the narrow revenue potential, as the nature of the industry is built on regular itineraries and schedules. If climate conditions for shipping improve, the potential could be shifted to Moderate by 2050.

Pure Car Carrier (PCC) shipping will have similar constraints to present day conditions as container trade. However, given that the port-to-port shipping method used by PCCs is more suited to the NSR, the potential may increase to Moderate by 2030 and go even higher by 2050, provided that conditions improve.

Dry bulkers and Tankers have a Moderate level potential at the moment, which is not expected to change by 2030. This results from the prevailing conditions and the existing cargo base in terms of the Arctic's natural resources. In this regard, commodity market conditions will largely dictate the level of activity. The current potential mainly lies in seizing short-term opportunities, but potentially may increase to Substantial by 2050, contingent on the further decline of ice cover and high prices for commodities.

Table 25 The relevance of the NSR as a shipping route measured in cargo potential, by mode and traffic type from present day till year 2050

Mode of shipping	Present			By 2030			By 2050		
	L	M	S	L	M	S	L	M	S
Container	*			*				*	
Pure Car Carrier	*				*				*
Dry bulker		*				*			*
Tanker		*				*			*
LNG		*				*			*
L = Limited (0 – 4.99 MT), M = Moderate (5 – 20 MT), S = Substantial (+ 20 MT)									
Transit traffic categories highlighted in white; destinational traffic in grey									

Similarly, LNG shipping has Moderate potential in present-day conditions. The LNG industry and overall trade is dependent on the scarce supply of existing production facilities. Establishing new capacity is both an expensive and a lengthy process. After the Yamal LNG plant becomes operational[10], the LNG shipping will arguably contribute a major part of volumes along the NSR. That said, the potential is likely to remain on a Moderate level up to 2030 and subsequently increase to Substantial by 2050 if new capacity is constructed.

The conclusion of the thesis is that commercial cargo shipping along the NSR in the short-term can be feasible under the right circumstances, relating to particular shipping sectors in favorable market and climate conditions. Especially destinational traffic to and from ports along the Russian Arctic, which is most often

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[10] According to Russian sources, this is expected to happen already by year 2017 (e.g. OAO Novatek 2014), which could be regarded as a very optimistic estimate.

associated with bulk shipping may prove economically viable. However, the size of the market potential is limited. From a ship owner's decision-making point-of-view the contemporary shipping economies in bulk shipping favor seizing market opportunities to use the NSR without making a long-term commitment. On the other hand, more prominent involvement in shipping along the NSR would also require a number of fleet design considerations.

In the long-term, the development of the NSR involves a high degree of uncertainty as its feasibility depends on a number of external factors relating mainly to climate, political and market issues.

8 THE CONTRIBUTION OF THE THESIS

The contribution of the individual Articles I through V have been summarized in Table 6, and their results have also been explained in Chapter 7. In addition, the thesis also contributes to managerial, theoretical and policy-making fields. These are elaborated further in the following discussion.

8.1 Critical discussion

The results of the thesis showed that feasibility of commercial cargo shipping along the NSR is possible under right circumstances. Such occurrences relate to certain types of shipping, namely to destinational traffic, which is equipped with a suitable fleet type in terms of the ambient climate and market conditions. On a global level the potential for the NSR is so far restricted because of the scant maritime infrastructure, shortage of suitable cargoes and uncertainties related to the development of climate and market conditions as well as political atmosphere.

By and large, the main findings of this thesis are in line with the two previous international assessments addressing Arctic Shipping and the NSR in particular: the Arctic Marine Shipping Assessment conducted for the Arctic Council (2009) and the Strategic Assessment of the Development of the Arctic conducted for the European Union (Sander et al. 2014). The results of this thesis confirms some of the findings made in the previous literature, for example the cost analysis in bulk shipping made by Cariou and Faury (2015) and container shipping by Lasserre (2014). The results contain also some new avenues, which have not been quantified in the existing literature. In particular, the assessments of the contemporary throughput capacity and long-term supply capacity of the NSR provide new knowledge in the field of maritime economics.

This thesis contains some caveats that should be considered while assessing the validity, reliability and generalizability of the results. The positioning and subsequent research approach of the thesis from a philosophy of science perspective are briefly elaborated on here. The subject of the thesis is a real world phenomenon, thus the relevant parameters are pragmatic, and derived from an actual shipping context. The rationale behind the chosen research methodology has been supported by using well-established methods in the field of maritime economics and system dynamics, following the logic of Marlow and Evans (1990), Stopford (2009) and

Sterman (2000). The validity and reliability of the results should be considered if they are able to illustrate the phenomenon in question. In this case, the findings stem from the existing literature and able to represent the contemporary activity along the NSR.

Most of the data has been obtained from the well-established maritime databases such as Drewry Shipping Consultants and Clarkson Research Services Limited. Some paucity in the underlying data was detected, which involved e.g. missing or inaccurate ice-class data for some ships. Considerable efforts were made to identity such omissions, and subsequently such errors were corrected manually. Overall, validity of this data can still be considered good. In addition, some heuristic generalizations were made based on the experiences of practitioners. In order to further improve the validity of the findings sensitivity analyses have been conducted in order to account for the impact of various parameter values.

Estimating the fuel consumption of a vessel at a given moment is a complex issue, and is especially relevant when analyzing the economic potential of the NSR. The estimates provided by the conventional open-water designed methods are not fully able to capture the factual situation in Arctic shipping. In this thesis, the Propeller Law was employed to provide an estimate the fuel consumption both along the NSR and the SCR. Fuel consumption especially at low speeds, which is a characteristic for navigation along the NSR, turned out to be problematic. Due to this deficit in the formula, the absence of actual data on ice parameters, and the aggregated-level data used, the results indicate only a minimum level of fuel consumption along the NSR and SCR.

The adopted methodologies behind the fuel consumption estimations could have been more comprehensive in terms of calculating the specific resistances in open-water and ice-infected waters, respectively. In an ideal world and with perfect knowledge, the data would have comprised specific details on the ambient conditions at any given time, including data on e.g. ice, wind, temperature, current and wave conditions. Despite these limitations, the fuel consumption figures can be considered sufficient to provide valid input for the analysis of the feasibility of commercial cargo shipping along the NSR.

In retrospect, some of the appended Articles could have been formulated differently. For example, the assumption of the ice-free conditions in Article I is rather simplistic when considering the current conditions along the NSR. On the other hand, this assumption provides a best-case scenario that could reflect the situation in the future. In addition, Article III provides a reality check for Article I in terms of as it adds the impact of ice into the analysis. Eventually, these two viewpoints provide a rather comprehensive cost analysis for shipping along the NSR.

8.2 Managerial contribution

In the managerial field, this thesis contributes by providing normative tools, i.e. calculation and simulation models, for ship owners wishing to assess the feasibility of commercial cargo shipping along the NSR in a holistic manner. In addition, the thesis delivers comprehensive insights into the market potential and risks attached to the route. These contributions may be beneficial for ship owners while making decisions on whether or not to trade along the NSR. In this respect, the generic profiles of a NSR ship based on ice-class may provide guidelines for a ship owner's fleet investment decisions.

One of the main contributions of this thesis is its pragmatic input to the general discussion on Arctic shipping, some of which tends to be based on unrealistic perceptions and misconceptions. In this respect, the call for an unbiased and comprehensive review of the development of commercial shipping in the Arctic in general and along the NSR in particular, is imperative, and valuable not only for business people but also for a wider audience.

8.3 Theoretical contribution

This thesis contributes on a theoretical level given that shipping economics theory that considers Arctic shipping is relatively limited. This thesis applies and refines the basic theories of maritime economics in a novel context. It also provides a typology for cost categorization of Arctic shipping, models of the Arctic shipping market and related cashflow from ship owners' perspective. More importantly, the thesis provides new insights on the generic profiles of NSR ships and presents a process chart of ship owner's route-choice decisions.

The observations in this thesis towards the uncritical use of the so-called Propeller Law in the context of Arctic shipping fuel consumption estimations could be seen to hold some merit in the field of theory improvement. The discussion provides input to account some of the deficiencies associated with the Propeller Law formula. Within the maritime economics context this could ultimately lead to a more reliable future cost analysis in shipping in ice-infested waters in general, and shipping in the Arctic in particular.

8.4 Policy-making contribution

The results of this thesis provide a substantial contribution to the on-going Arctic policy-making discussion in terms of adopting national strategies. The Arctic region has recently gained increasing global attention of geopolitical importance. At the moment, the ownership of Arctic resources and the regulatory framework concerning Arctic shipping are being developed.

Finland, for example, participates in this process through its membership of the Arctic Council and by implementing Finland's Strategy for the Arctic Region 2013 (Finland's Prime Minister's Office 2013). Finland's role in the Arctic Council will be emphasized since it will chair the Council from the start of 2017.

In its strategy, Finland has stated that it aims to develop transport infrastructure in accordance with Arctic development. In this regard, one proposal suggests that the future Europe–Asia cargo volumes transported along the NSR could use the port of Kirkenes and continue by rail through Finland to continental Europe (Staalesen 2016). If realized, such a plan would require investments in the tune of several billion USD, by constructing a railway connection from Northern Finland to the Arctic Sea. Overall, the results of this thesis do not provide evidence to support the economic rationale behind this proposal.

The findings also have a bearing on all other countries with an interest to the Arctic – and by extension the firms in those countries, which have aspirations to utilize the NSR for commercial or other types of shipping in the future. These countries naturally include Arctic Council members as well as South Korea, Japan, Singapore and China, which have an observer status on the Arctic Council (See Figure 15).

8.5 Further research

This thesis covers a variety of issues that do not only involve the maritime economics domain but relate also to the Arctic discourse in general. As such, it has brought up a number of potential new topics for future research.

The ambient conditions as well as the ship design aspects were considered in a rather general level in this thesis. Therefore, future studies could look more closely at ship design issues regarding economic performance in different operating conditions by employing the Comparative Ship Merit Factor (von Bock und Polach et al. 2014). In this respect, use of state of the art data on ice and other navigation condition parameters would enable the details of seasonal operations along the NSR to be taken into account in a more holistic manner.

The analysis in Article III did not assume any changes to the network configuration. In other words, the feasibility of transhipment hub alternatives in Europe – Asia trade was not tested. This may also be worth pondering when analysing the economic viability of an Arctic shuttle service as Niini et al. (2006) and PWC (2009) have suggested.

There is relatively limited knowledge about ships actual waiting times before they are allowed to enter the NSR. This information might be obtained directly from shipping companies, following the logic by Lee and Kim (2015). A continuation of this subject could be the construction of queuing models, for example, by employing discrete-event simulation.

The analysis of price sensitiveness of the Europe – Asia transport market offers another intriguing field for further research. There are some indications of price sensitivity in terms of Trans-Siberian Railroad (Hämäläinen 2007), but in the NSR context this has not been studied on a detailed level. Here, the intentions of cargo owners could be explored in terms of their interest of using the NSR.

In addition, a theoretical refinement of the Propeller Law to account for the deficiencies of the basic formula in low speeds could improve the validity of future cost analysis regarding Arctic shipping.

Finally, the application of system dynamics offers intriguing avenues for investigating the complexity of the shipping market, and provides a useful method for future studies in an environment, which an inherently limited capacity. In this regard, a practical solution could be the refinement of the supply capacity model, introduced in Article V, in a way which would also incorporate ship owners' financial considerations.

REFERENCES

Abdul Rahman, N. S. F – Saharuddin, A. H. – Rasdi, R. (2014) Effect of the Northern Sea Route Opening to the Shipping Activities at Malacca Straits. *International Journal of e-Navigation and Maritime Economy*, Vol. 1, 85–98. doi:10.1016/j.enavi.2014.12.008.

ACIA (2004) *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. ACIA Overview report. Cambridge University Press.

ACP – Panama Canal Authority (2015) Transit statistics. <https://www.pancanal.com/eng/op/transit-stats/index.html>, retrieved 23.11.2015.

Aguilar, F. J. (1967) *Scanning the Business Environment*. The Macmillan Company, New York, US.

AHDR (2015) *Arctic Human Development Report: Regional Processes and Global Linkages*. Larsen, J.N – Fondahl, G. (Eds.) Nordic Council of Ministers: Copenhagen, Denmark.

AMAP (2008) Arctic Oil and Gas 2007. Arctic Monitoring and Assessment Programme (AMAP) Oslo, Norway.

Appolonov, E. M. – Nesterov, A. B. – Paliy, O. M. – Timofeev, O. Y. (2007) A system of forming fundamental engineering solutions on assurance of ice strength and safe ship service in Russian Arctic and freezing seas. In: *Arctic Shipping 2007*. Lloyd's List events: London.

Appolonov, E. M. – Nesterov, A. B. – Sazonov, K. E. (2011) Regulation of extreme ice loads acting on hulls of azimuth propulsion systems for ice ships. *Ships and Offshore Structures*, Vol. 6 (3): 239–247. doi:10.1080/17445302.2010.548124.

Arbo, P. – Iversen, A. – Knol, M. – Ringholm, T. – Sander, G. (2013). Arctic futures: conceptualizations and images of a changing Arctic. *Polar Geography*, Vol. 36 (3), 163–182. doi:10.1080/1088937X.2012.724462.

Arbnor, I. – Bjerke, B. (1997) *Methodology for creating business knowledge*. 2nd ed. Sage Publications: Thousand Oaks, CA.

Arctic Council (2009) *Arctic Marine Shipping Assessment 2009 Report*. Arctic Council: Tromsø, Norway.

Arctic-info.com (2014) Putin: Russia needs a comprehensive project to develop the Northern Sea Route. <http://www.arctic-info.com/news/04-12-2014/putin--russia-needs-a-comprehensive-project-to-develop-the-northern-sea-route>, retrieved 8.9.2015.

Arctic Portal (2015) Arctic Portal Maps. <http://arcticportal.org/maps/download>, retrieved 2.12.2015.

Arlbjørn, J. S. – Halldórsson, A. (2002) Logistics knowledge creation: reflections on content, context and processes. *International Journal of Physical Distribution & Logistics Management*, Vol. 32 (1), 22–40. doi:10.1108/09600030210415289.

Armstrong, T. E. (1955) The Soviet Northern Sea Route. *The Geographical Journal*, Vol. 121 (2), 136–146.

Arpiainen, P. (1994) *The Northern Sea Route – A traffic Potential Study*. Publications from the Center for Maritime Studies University of Turku A 16.

Ashby, W. R. (1956) *An introduction to Cybernetics*. Chapman & Hall, London.

Baev, P. K. (2013) Sovereignty in the Key to Russia's Arctic Policy. *Strategic Analysis*, Vol. 37 (4), 489–493. doi:10.1080/09700161.2013.802523.

Barents Observer (2015) Northern Sea Route – focus on domestic projects. <http://barentsobserver.com/en/arctic/2015/10/northern-sea-route-focus-domestic-projects-17-10>, retrieved, 15.1.2016.

Baumgärtner, S. – Quaas, M. F. (2009) Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics*, Vol. 68, 2008–2020. doi:10.1016/j.ecolecon.2009.01.016.

Beary, B. (2008). Race for the Arctic. *CQ Global Researcher*, Vol. 2, 213–242. <http://library.cqpress.com/cqresearcher/cqrglobal2008080014>, retrieved 9.2.2016.

BEATA – Barents Euro-Arctic Area (2013) Joint Barents Transport Plan, September 2013. Barents Euro-Artic Region. <http://www.barentsinfo.fi/beac/docs/Joint_Barents_Transport_Plan_2013.pdf>, retrieved 30.11.2015.

Bekkers, E. – Francois, J. F. – Rojas-Romagosa, H. (2015) *Melting Ice Caps and the Economic Impact of Opening the Northern Sea Route*. CPB Discussion Paper | 307. CPB Netherlands Bureau for Economic Policy Analysis: Hague, The Netherlands.

Bendall, H. B. (2010) Cost of piracy: A comparative voyage approach. *Maritime Economics & Logistics*, Vol. 12 (2), 178–195. doi:10.1057/mel.2010.1.

Bergantino, A. S. – Bolis, S. (2008) Monetary values of transport service attributes: Land versus maritime ro-ro transport. An application using adaptive stated preferences. *Maritime Policy & Management*, Vol. 35 (2), 159–174. doi:10.1080/03088830801956821.

Bertalanffy, L. von (1969) General System theory: Foundations, Development, Applications. George Braziller, New York.

Beveridge, L. – Fournier, M. – Lasserre, F. – Huang, L. – Têtu, P.-L. (2016) Interest of Asian shipping companies in navigating the Arctic. *Polar Science*. doi:10.1016/j.polar.2016.04.004.

Bhaskar, R. (1979) *The Possibility of Naturalism: A Philosophical Critique of the Contemporary Human Science*. Humanities Press, Atlantic Highlands, NJ.

BIMCO – Baltic and International Maritime Council (2016) Dry Bulk Shipping: Poor freight rates despite strong demand growth from China. <https://www.bimco.org/Reports/Market_Analysis/2016/0901_DrybulkSMOO_2016-03.aspx>, retrieved 9.9.2016.

Bird, K. J. – Charpentier, R. R. – Gautier, D. L. – Houseknecht, D. W. – Klett, T. R. – Pitman, J. K. – Moore, T. E. – Schenk, C. J. – Tennyson, M. E. – Wandrey, C. J. (2008) Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle. U.S. Geological Survey Fact Sheet 2008, No. 3049. <http://pubs.usgs.gov/fs/2008/3049/>, retrieved 11.2.2016.

Bishop, A. – Bremner, C. – Laake, A. – Strobbia, C. – Parno, P. – Utskot, G. (2011) Petroleum Potential of the Arctic: Challenges and Solutions. *Oilfield Review*, Winter 2010/2011, Vol. 22 (2), 36–49.

Blaikie, N. (2000) *Designing Social Research: The Logic of Anticipation*. Polity Press, Cambridge.

Bloomberg (2016) Baltic Dry Index BDIY:IND. <http://www.bloomberg.com/quote/BDIY:IND>, retrieved 13.1.2016.

Blumberg, B. – Cooper, D. R. – Schindler P. S. (2011) *Business research methods.* 3rd edition. McGraw-Hill, Berkshire.

Bock und Polach, R. U. F., von – Ehlers, S. – Erikstad, S. O. (2014) A decision-based design approach for ships operating in open water and ice. *Journal of Ship Production and Design*, Vol. 30 (3), 1–11. doi:10.5957/JSPD.30.3.140001.

Bollen, K. A. (1989) *Structural Equations with Latent Variables*. John Wiley & Sons, New York.

Bourbonnais, P. – Lasserre, F. (2015) Winter shipping in the Canadian Arctic: toward year-round traffic? *Polar Geography*, Vol. 38 (1), 70–88. doi:10.1080/1088937X.2015.1006298.

Borgerson, S. (2008) Arctic Meltdown: The Economic and Security Implications of Global Warming. *Foreign Affairs*, Vol. 87 (2), 63–77.

Borgerson, S. (2013) The Coming Arctic Boom. *Foreign Affairs*, Vol. 92 (4), 76–89.

Brooks, M. R. – Frost, J. D. (2012) Providing freight services to remote arctic communities: Are there lessons for practitioners from services to Greenland and Canada's northeast? *Research in Transportation Business & Management*, Vol. 4, 69–78. doi:10.10167j.rtbm.2012.06.005.

Brosnan, I. G. – Leschine, T. M. – Miles, E. L. (2011) Cooperation or Conflict in a Changing Arctic? *Ocean Development & International Law*, Vol. 41 (1–2), 173–210. doi:10.1080/00908320.2011.543032.

Brubaker, R. D. – Ragner C. L. (2010) A review of the International Northern Sea Route Program (INSROP) – 10 years on. *Polar Geography*, Vol. 33 (1–2), 15–38. doi:10.1080/1088937X.2010.493308.

Buixadé Farré, A. – Stephenson, S. R. – Chen, L. – Czub, M. – Dai, Y. – Demchev, D. – Efimov, Y. – Graczyk, P. – Grythe, H. – Keil, K. – Kivekäs, N. – Kumar, N. – Liu, N. – Matelenok, I. – Myksvoll, M. S. – O'Leary, D. – Olsen, J. – Pavithran, S. A. P. – Petersen, E. – Raspotnik, A. – Ryzhov, I. – Solski, J. J. – Suo, L. – Troein, C. – Valeeva, V. – van Rijckevorsel, J. – Wighting, J. (2014) Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. *Polar Geography*, Vol. 37 (4), 298–324. doi:10.1080/1088937X.2014.965769.

Bukharin, O. (2006) Russia’s Nuclear Icebreaker Fleet. *Science & Global Security: The technical Basis for Arms Control, Disarmament, and Nonproliferation Initiatives*, Vol. 14 (1), 25–31. doi:10.1080./08929880600620559.

Bunkerworld (2016) BW380 Bunkerworld Index. <http://www.bunkerworld.com/prices/>, retrieved 21.9.2016.

Burrell, G. – Morgan, G. (1979) *Sociological Paradigms and Organisational Analysis*. Heinemann, London.

Business Wire (2016) Mission Accomplished: Crystal Serenity Completes 32-Day Northwest Passage Journey. <http://www.businesswire.com/news/home/20160916005705/en/Mission-Accomplished-Crystal-Serenity-Completes-32-Day-Northwest>, retrieved 27.9.2016.

Button, K. (2010) *Transport Economics*. 3rd Edition. Edward Elgar Publishing, Cheltenham, UK.

Button, K. – Kramberger, T. – Vizinger, T. – Intihar, M. (2015) Economic implications for Adriatic seaport regions of further opening of the Northern Sea Route. *Maritime Economics & Logistics*. doi:10.1057/mel.2015.25.

Cariou, P. – Faury, O. (2015) Relevance of the Northern Sea Route (NSR) for bulk shipping. *Transport Research Part A*, Vol. 78, 337–346. doi:10.1016/j.tra.2015.05.020.

Carmel, S. M. (2013) The Cold, Hard Realities of Arctic Shipping. *US Naval Institute Proceedings Magazine*, Vol. 139 (7), 1325.

Casti J. L. (1989) *Alternate realities: mathematical models of nature and man*. Wiley, New York, US.

Chang, K. Y. – He, S. S. – Chou, C. C. – Kao, S. L. – Chiou, A. S. (2015) Route planning and cost analysis for travelling through the Northeast Passage using public 3D GIS. *International Journal of Geographical Information Science*, Vol. 29 (8), 1375–1393.

Chen, S. – Frouws, K. – Van de Woorde, E. (2010) Technical changes and impacts on economic performance of dry bulk vessels. *Maritime Policy & Management*, Vol. 37 (3), 305–327. doi:10.1080/03088831003700710.

Chen, S – Meersman, H. – Van de Woorde, E. – Frouws, K. (2014) *Modelling and Forecasting in Dry Bulk Shipping*. Informa Law from Routledge, London, UK.

Chernova, S. – Volkov, A. (2010) *Economic feasibility of the Northern Sea Route container shipping development*. Master’s Thesis Business and Transportation, Bodø Graduate School of Economics.

Cho, Y. (2012) The melting Arctic changing the world: new sea route. *Paper presented at the Conference on Energy Security and Geopolitics in the Arctic: Challenges and Opportunities in the 21st Century*, Singapore, January 9–10, 2012, 1–24.

Cho, S-R. – Lee, S. (2015) A prediction method of ice breaking resistance using a multiple regression analysis. *International Journal of Naval Architecture and Ocean Engineering*, Vol. 7 (4), 708–719. doi:10.1515/ijnaoe-2015-0050.

Christiansen, M. – Fagerholt, K. – Nygreen, B. – Ronen, D. (2013). Ship routing and scheduling in the new millennium. *European Journal of Operational Research*, Vol. 228 (3), 467–483. doi:10.1016/j.ejor.2012.12.002.

Clark, A. M. (2008) Critical Realism. *The Sage Encyclopedia of Qualitative Research Methods*. SAGE Publications. 7.9.2011.

Cohen, J. – Screen, J. A. – Furtado, J. C. – Barlow, M. – Whittleston, D. – Coumou, D. – Francis, J. – Dethloff, K. – Entekhabi, D. – Overland, J. – Jones, J. (2014) Recent Arctic amplification and extreme mid-latitude weather. *Nature Geoscience*, Vol. 7, 627–637. doi:10.1038/ngeo2234.

Comtois, C. – Lacoste, R. (2012) Dry bulk shipping logistics. In: *Maritime logistics: a complete guide to effective shipping and port management*. eds. D-W. Song – P. Panayides, 163–176. Kogan Page Publishers, London, UK.

Corbett, J. J. – Lack, D. A. – Winebrake, J. J. – Harder, S. – Silberman, J. A. – Gold, M. (2010) Arctic shipping emissions inventories and future scenarios. *Atmospheric Chemistry and Physics*, Vol. 10, 9689–9704. doi:10.5194/acp-10-9689-2010.

Creswell, J. W. (2009) *Research Design: Qualitative and Quantitative and Mixed-Method Approaches*. Third edition. Sage Publications, Thousand Oaks, CA.

CRSL (2015) Clarksons World Fleet Registry. Clarkson Research Services Limited.

Cullinane, K. – Khanna, M. (2000) Economies of scale in large containerships: optimal size and geographical implications. *Journal of Transport Geography*, Vol. 8, 181–195. doi:10.1016/S0966-6923(00)00010-7.

Danermark, B. (2002). Interdisciplinary Research and Critical Realism The Example of Disability Research. *Alethia*, Vol. 5 (1), 56–64. doi:10.1558/aleth.v5i1.56.

DHL (2016) *Logistics Trend Radar. Delivering insight today. Creating value tomorrow!* DHL Customer Solutions & Innovation, Troisdorf, Germany.

Dinwoodie, J. – Tuck, S. – Rigot-Müller, P. (2013) Maritime oil freight flows to 2050: Delphi perceptions of maritime specialists. *Energy Policy*, Vol. 63, 553–561. doi:10.1016/j.enpol.2013.08.068.

Dinwoodie, J. – Landamore, M. – Rigot-Müller, P. (2014) Dry bulk shipping flows to 2050: Delphi perceptions of early career specialists. *Technological Forecasting & Social Change*, Vol. 88, 64–75. doi:10.1016/j.techfore.2014.06.010.

Dobie, G. – Kidtson, H. – Chamberlain, T. – Fields, C. (2015) *Safety and Shipping Review 2015: An annual review of trends and developments in shipping losses and safety*. Allianz Global Corporate & Specialty Report. <http://www.agcs.allianz.com/assets/PDFs/Reports/Shipping-Review-2015.pdf>, retrieved 26.2.2016.

Dobretsov, N. L. – Pokhilenko, N. P. (2010) Mineral resources and development in the Russian Arctic. *Russian Geology and Geophysics*, Vol. 51 (1), 98–111. doi:10.1016/j.rgg.2009.12.009.

Downward, P. – Hinch, J. H. – Ramsay, J. (2002) Critical realism, empirical methods and inference: a critical discussion. *Cambridge Journal of Economics*, Vol. 26, 481–500.

Doyle, A. (2013) China plans first commercial trip through Arctic shortcut in 2013. <http://www.reuters.com/article/2013/03/12/shipping-china-idUSL6N0C4F9720130312>, retrieved 21.6.2014.

Drent, J. (1993) Commercial shipping on the Northern Sea Route. *The Northern Mariner/Le Marin du nord*, Vol. III, (2) (April), 1–17.

Drewry (2012) *Ship Operating Cost Annual Review and Forecast. Annual Report 2012/2013*. Drewry Shipping Consultants, London.

Drost, E. A. (2011) Validity and Reliability in Social Science Research. *Education Research and Perspectives*, Vol. 38 (1), 105–123.

Dubois, A. – Gadde, L-E. (2002) Systematic combining: an abductive approach to case research. *Journal of Business Research*, Vol. 55, 553–560. doi:10.1016/S0148-2963(00)00195-8.

Dvorak, R. E. (2009) *Engineering and Economic Implications of Ice-Classed Containerships*. Master's Thesis. Naval Architecture and Marine Engineering, Massachusetts Institute of Technology (MIT).

Eger, M. K. – Mejlænder-Larsen, M. (2013) Arctic Marine Insurance. In: *Shipping in Arctic Waters. A comparison of the Northeast, Northwest and Trans Polar Passages*. eds. W. Østreng – K. M. Eger – B. Fløistad – A. Jørgensen-Dahl – L. Lothe – M. Mejlænder-Larsen – T. Wergeland, 331–332. Springer-Praxis, Chichester, UK.

EIA (2016) Petroleum & other liquids. Spot prices. United States Energy Information Administration. <https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm>, retrieved 5.2.2016.

Eide, L. I. – Eide, M. S. – Endresen, Ø. *Shipping Across the Arctic Ocean: A Feasible Option in 2030-2050 as a Result of Global Warming?* Research and Innovation, Position paper 04-2010. Det Norske Veritas: Høvik, Norway.

Emmerson, C. (2011) *The Future History of the Arctic: How Climate, Resources and Geopolitics are Reshaping the North and Why it Matters to the World*. Vintage Books, London.

Emmerson, C. – Lahn G. (2012) *Arctic opening: Opportunity and risk in the high north.* Lloyd's, London. <https://www.chathamhouse.org/publications/papers/view/182839>, retrieved 2.2.2016.

Erikstad, S. O. – Ehlers, S. (2012) Decision Support Framework for Exploiting Northern Sea Route Transport Opportunities. *Ship Technology Research*, Vol. 59 (2), 34–42. doi:10.1179/str.2012.59.2.003.

Ermida, G. (2014) Strategic decisions of international oil companies: Arctic versus other regions. *Energy Strategy Reviews*, Vol. 2, 265–272. doi:10.1016/j.esr.2013.11.004.

Esa, J. (2015) *Fuel and economic efficiency of an ice-going vessel on the Northern Sea Route*. Master's Thesis, Aalto University School of Engineering, Espoo, Finland.

Evans, J. J. – Marlow, P. B. (1990) *Quantitative Methods in Maritime Economics*. Second Edition. Fairplay Publications, Coulsdon, UK.

Falck, H. (2012) The Northern Sea Route: Market, Feasibility, Ship Requirement. *Paper presented at the Polyteknisk Forening Samferdsel*, Oslo, Norway, November 29, 2012, 1–26.

Fan, L. – Wilson, W. W. – Dahl, B. (2012) Impacts of new routes and ports on spatial competition for containerized import into the United States. *Maritime Policy & Management*, Vol. 39 (5), 479–501. doi:10.1080/03088839.2012.705027.

Faury, O. (2015) Risk Management in the Arctic from an Underwriter's Perspective. *Proceedings of the IAME 2015 Conference*. Kuala Lumpur, Malaysia.

Fayle, C. E. (2013) *A Short History of the World's Shipping Industry*. Abingdon, Oxon: Routledge.

Finland's Prime Minister's Office (2013) Finland's Strategy for the Arctic Region 2013. Government resolution 23.8.2013. Prime Minister's Office Publications 16/2013.

Flake, L. E. (2013) Navigating an Ice-Free Arctic. *The RUSI Journal*, Vol. 158 (3), 44–52. doi:10.1080/03071847.2013.807585.

Forrester, J. W. (1961) *Industrial Dynamics*. Massachusetts Institute of Technology Press, Cambridge, MA.

Frolov, I. E. – Gudkovich, Z. M. – Radionov, V. F. – Shirochkov, A. V. – Timokhov, L. A. (2005) *The Arctic Basin: Results from the Russian Drifting Stations*. Springer, Berlin.

Frolov, I. E. – Gudkovich, Z. M. – Karklin, V. P. – Kovalev, E. G. – Smolyanitsky, V. M. (2009) *Climate Change in Eurasian Arctic Shelf Seas. Centennial Ice Cover Observations*. Springer Praxis Publishing, UK.

Fu, X. – Ng, A. K. Y. – Lau, Y-Y. (2010) The impacts of maritime piracy on global economic development: the case of Somalia. *Maritime Policy & Management*, Vol. 37 (7), 677–697. doi:10.1080/03088839.2010.524736.

Furuichi, M. – Otsuka, N. (2013) Cost Analysis of the Northern Sea Route (NSR) and the Conventional Route Shipping. *Proceedings of the IAME 2013 Conference. Marseille, France*.

Furuichi, M. – Otsuka, N. (2014) Economic feasibility of finished vehicle and container transport by NSR/SCR-combined shipping between East Asia and Northwest Europe. *Proceedings of the IAME 2014 Conference. Norfolk, USA*.

Furuichi, M. – Otsuka, N. (2015) Proposing a common platform of shipping cost analysis of the Northern Sea Route and the Suez Canal Route. *Maritime Economics & Logistics*, Vol. 17 (1), 9–31. doi:10.1057/mel.2014.29.

Gautier D. L. – Bird K. J. – Charpentier R. R. – Grantz A. – Houseknecht D. W. – Klett T. R. – Moore T. E. – Pitman J. K. – Schenk C. J. – Schuenemeyer J. H. – Sørensen K. – Tennyson M. E. – Valin Z. C. – Wandrey C. J. (2009) Assessment of Undiscovered Oil and Gas in the Arctic. *Science*, Vol. 324, 1175–1179. doi:10.1126/science.1169467.

Gilabert, P. – Lawford-Smith, H. (2012) Political Feasibility: A Conceptual Exploration. *Political Studies*, Vol. 60, 809–825. doi:10.1111/j.1467-9248.2011.00936.x

Gilman, S. (1999) The size economies and network efficiency of large containerships. *International Journal of Maritime Economics,* Vol. 1 (1), 39–59. doi:10.1057/ijme.1999.4.

Goerlandt, F. – Montewka, J. – Zhang, W. – Kujala, P. (2016) An analysis of ship escort and convoy operations in ice conditions. *Safety Science*. doi:10.1016/j.ssci.2016.01.004.

Gold, E. (1999) Transiting the Northern Sea Route: Shipping and Marine Insurance interests. In: *The 21st century – Turning Point for the Northern Sea Route?,* ed. C. L. Ragner, 113–122. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Google Earth (2015) www.google.fi/intl/fi/earth/ (Accessed 14.12.2015).

Gorbachev, M. (1987) Speech at the ceremonial meeting on the occasion of the presentation of the order of Lenin and the gold star to the city of Murmansk. Murmansk, 1, October, 1987. <https://www.barentsinfo.fi/docs/Gorbachev_speech.pdf>, retrieved 11.1.2016.

Gorski, P. S. (2013) What is Critical Realism? And Why Should You Care? *Contemporary Sociology*, Vol. 42 (5), 658–670.

Graasberg, J. A. (1972) A Rational Approach to Feasibility Analysis. *The Appraisal Journal*, October, 513–521.

Granberg, A. G. (1998) The northern sea route: trends and prospects of commercial use. *Ocean & Coastal Management*, Vol. 41 (2–3), 175–207. doi:10.1016/S0964-5691(98)00064-7.

Griffiths, F. (2005) New illusions of a Northwest Passage. In: *International Energy Policy, the Arctic and the Law of the Sea.* eds. M. Nordquist – J. N. Moore – A. S. Skaridov, 303–309, Martinus Nijhoff Publishers, Leiden.

Gritsenko, D. – Kiiski, T. (2016) A review of Russian ice-breaking tariff policy on the northern sea route 1991–2014. *Polar Record*, Vol. 52 (2), 144–158. doi:10.1017/S0032247415000479.

Grix, J. (2002) Introducing Students to the Generic Terminology of Social Research. *Politics*, Vol. 22 (3), 175–186. doi:10.1111/1467-9256.00173.

Gunnarson, B. (2015) NSR's Search & Rescue. Presentation at 2nd Industry Seminar: NSR's Maritime Infrastructure, Høvik (Oslo), Norway, 15th of October 2015.

Gunnarson, B. (2016) Future Development of the Northern Sea Route. Maritime Executive 18.2.2016. <http://www.maritime-executive.com/editorials/future-development-of-the-northern-sea-route>, retrieved 14.9.2016.

Guy, E. – Lasserre, F. (2016) Commercial shipping in the Arctic: new perspectives, challenges and regulations. *Polar Record*, Vol. 52 (3), 294–304. doi:10.1017/S0032247415001011.

Haas, C. – Howell, S. E. L. (2015) Ice thickness in the Northwest Passage. *Geophysical Research Letters*, Vol. 42, 7673–7680. doi:10.1002/2015GL065704.

Hakkinen, S. – Proshutinsky, A. – Ashik, I. (2008) Sea ice drift in the Arctic since the 1950s. *Geophysical Research Letters*, Vol. 35, L19704. doi:10.1029/2008GL034791.

Haley, S. – Klick, M. – Szymoniak, N. – Crow, A. (2011) Observing trends and assessing data for Arctic mining. *Polar Geography*, Vol. 34 (1–2), 37–61. doi:10.1080/1088937X.2011.584449.

Harsem, Ø. – Eide, A. – Heen, K. (2011) Factors influencing future oil and gas prospects in the Arctic. *Energy Policy*, Vol. 39, 8037–8045. doi:10.1016/j.enpol.2011.09.058.

Headland, R. K. (2015) Transits of the Northwest Passage to end of the 2015 Navigation Season. <http://www.americanpolar.org/wp-content/uploads/2015/11/NWP-2015.pdf>, retrieved 21.3.2016.

Heylighen, F. – Joslyn, C. (1992) What is Systems Theory? Principia Cybernetica Web. <http://pespmc1.vub.ac.be/systheor.html>, retrieved 10.2.2016.

Hill, E. – LaNore, M. – Véronneau, S. (2015) Northern sea route: an overview of transportation risks, safety, and security. *Journal of Transportation Security*. doi:10.1007/s12198-015-0158-6.

Hintikka, J. (1998) What is abduction? The Fundamental Problem of Contemporary Epistemology. *Transaction of the Charles S. Peirce Society*, Vol. 34 (3), 503–533.

Ho, J. (2010) The implications of Arctic sea ice on shipping. *Marine Policy*, Vol. 34, 713-715. doi:10.1016/j.marpol.2009.10.009.

Hong, N. (2012) The melting Arctic and its impact on China’s maritime transport. *Research in Transportation Economics*, Vol. 35, 50–57. doi:10.1016/j.retrec.2011.11.003.

HSBC (2015) Trade forecast report: Global. 2H 2015. <https://globalconnections.hsbc.com/global/en/tools-data/trade-forecasts/global>, retrieved 23.1.2016.

Hua, X. – Dong, Y. (2014) Sailing on Top of the World: The coming Artic Container Shuttle Lane. *Proceedings of the IAME 2014 Conference. Norfolk, USA*.

Hughes, C. N. (1996) *Ship Performance: Technical, Safety, Environmental and Commercial Aspects*. Business of Shipping Series. 2nd edition. LLP, London.

Humpert, M. – Raspotnik, A. (2012) The future of Arctic shipping along the transpolar sea route. In: *Arctic Yearbook 2012*, ed. L. Heininen, 281–307. Northern Research Forum, Akureyri, Iceland.

Humpert, M. (2015) Frozen waters: Northern Sea Route traffic boosted by internal traffic, while transits fall sharply. High North News 15.12.2015. <http://www.highnorthnews.com/frozen-waters-northern-sea-route-traffic-boosted-by-internal-traffic-while-transits-fall-sharply/>, retrieved 17.12.2015.

Hämäläinen, E. (2007) Impacts of Price Revisions on the Trans-Siberian Railway Logistics. In: *Third Research Meeting Held at Kouvola – Value Adding Role of Logistics in Northern Europe*, ed. O-P. Hilmola, 15–24. Research Report 183. Lappeenranta University of Technology, Lappeenranta.

Ibisonin, D. (2007) Shippers chart polar bypass for clogged global trade routes. Financial Times, August 11, 2007. <http://www.ft.com/intl/cms/s/0/38053730-47a4-11dc-9096-0000779fd2ac.html?siteedition=intl#axzz3zfhJkyXy>, retrieved 9.1.2016.

Iceland Ministry of Foreign Affairs (2005) *North Meets North. Navigation and the Future of the Arctic.* Report of a working group of the Ministry for Foreign Affairs. Iceland Ministry of Foreign Affairs, Reykjavik.

IEA – International Energy Agency (2008) World Energy Outlook. OECD/IEA, Paris.

IMO – International Maritime Organization. (2002) *Guidelines for ships operating in Arctic ice covered waters*. International Maritime Organisation, London.

IMO – International Maritime Organisation (2010a) *Shipping in Polar Waters*. International Maritime Organisation, London.

IMO – International Maritime Organisation (2010b) *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers*. International Maritime Organisation, London.

IMO – International Maritime Organisation (2014) *Consideration and adoption of amendments to mandatory instruments*. Technical background to POLARIS. Maritime Safety Committee. MSC 94/INF.13. International Maritime Organisation, London.

IMO – International Maritime Organisation (2016) *International Code for Ships Operating in Polar Waters (Polar Code)*. International Maritime Organisation, London.

IPCC (2001) *Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. eds. J. T. Houghton – Y. Ding – D. J. Griggs – M. Noguer – P. J. Van der Linden – X. Dai – K. Maskell – C. A. Johnson. Cambridge University Press, Cambridge.

IPCC (2007) *Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. eds. S. Solomon – D. Qin – M. Manning – Z. Chen – M. Marquis – K. B. Averyt – M. Tignor – H. L. Miller. Cambridge University Press, Cambridge.

IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* eds. R. K. Pachauri – L. A. Meyer IPCC, Geneva, Switzerland.

Jakobsson, M. – Mayer, L. A. – Coakley, B. – Dowdeswell, J. A. – Forbes, S. – Fridman, B. – Hodnesdal, H. – Noormets, R. –Pedersen, R. –Rebesco, M. – Schenke, H.-W. – Zarayskaya, Y. – Accettella, A, D. – Armstrong, A. – Anderson, R. M. – Bienhoff, P. – Camerlenghi, A. – Church, I. – Edwards, M. – Gardner, J. V. – Hall, J. K. – Hell, B. – Hestvik, O. B. – Kristoffersen, Y. – Marcussen, C. – Mohammad, R. – Mosher, D. – Nghiem, S. V. – Pedrosa, M. T. – Travaglini, P. G. – Weatherall, P. (2012) The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0. *Geophysical Research Letters*, Vol. 39, L12609. doi:10.1029/2012GL052219.

JHC – Joint Hull Committee (2012) *The Northern Sea Route. An information paper*. JH2012/004 2nd March 2012. London, England: Lloyd's Marketing Association and International Underwriting Association.

Johnson, G. – Scholes, K. – Whittington, R. (2011) *Exploring strategy: text & cases*. 9th edition. Essex, England: Financial Times Prentice Hall.

Juurmaa, K. (2006) *Arctic Operational Platform: Integrated Transport System*. ARCOP Final Report. Aker Finnyards Inc., Helsinki.

Kamesaki, K. – Kishi, S. – Yamauchi, Y. (1999). Simulation of NSR Navigation Based on Year Round and Seasonal Operation Scenarios. INSROP Working Paper 164 – 1999. Fridtjof Nansen Insitute, Lysaker, Norway.

Kao, S-M. – Pearre, N. S. – Firestone, J. (2012) Adoption of the arctic search and rescue agreement: A shift of the arctic regime towards a hard law basis? *Marine Policy*, Vol. 36, 832–838. doi:10.1016/j.marpol.2011.12.001.

Kasanen, E. – Lukka, K. – Siitonen, A. (1991) Konstruktiivinen tutkimusote liiketaloustieteessä, *Liiketaloudellinen Aikakauskirja*, No. 3, 301–329.

Khon, V. C. – Mokhov, I. I. – Latif, M. – Semenov, V. A. – Park, W. (2010) Perspectives of Northern Sea Route and Northwest Passage in the twenty-first century. *Climate Change*, Vol. 100, 757–768. doi:10.1007/s10584-009-9683-2.

Kiiski, T. (2012) Northern Sea Route -potentiaalinen konttikuljetusreitti Euroopan ja Aasian välillä [engl. Northern Sea Route a potential container shipping route between Europe and Asia]. Master's thesis. Turku School of Economics at the University of Turku.

Kim, H. J. (2015) Success in heading north?: South Korea's master plan for Arctic Policy. *Marine Policy*, Vol. 61, 264–272. doi:10.1016/jmarpol.2015.08.002.

Klimenko, E. (2014) *Russia's evolving Arctic Strategy: Drivers, Challenges and New Opportunities*. SIPRI Policy Paper 42 September 2014. Stockholm International Peace Research Institute, Stockholm.

Klimenko, E. (2016) *Russia's Arctic Security Policy: Still Quiet in the High North?* SIPRI Policy Paper 45 February 2016. Stockholm International Peace Research Institute, Stockholm.

Kolstad, E. W. – Bracegirdle, T. J. (2008) Marine cold-air outbreaks in the future: an assessment of IPCC AR4 model results for the Northern Hemisphere. *Climate Dynamics*, Vol. 30, 871–885. doi:10.1007/s00382-007-0331-0.

Kontorovich, A. E. –Epov, M. I. – Burshtein, L. M. – Kaminskii, V. D. – Kurchikov, A. R. – Malyshev, N. A. – Prischepa, O. M. – Safronov, A. F. – Stupakova, A. V. – Suprunenko, O. I. (2010) Geology and hydrocarbon resources of the continental shelf in Russian Arctic seas and the prospects of their development. *Russian Geology and Geophysics*, Vol. 51, 3–11. doi:10.1016/j.rgg.2009.12.003.

Koskinen, M-M. – Hilmola, O-P. (2005) Investment Cycles in the Newbuilding Market of Ice-Strengthened Oil Tankers. *Maritime Economics & Logistics*, Vol. 7, 173–188. doi:10.1057/palgrave.mel.9100128.

Kovács, G. – Spens, K. M. (2005) Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management*, Vol. 35 (2), 132–144. doi:10.1108/09600030510590318.

Knol, M. – Arbo, P. (2014) Oil spill response in the Arctic: Norwegian experiences and future perspectives. *Marine Policy*, Vol. 50, 171–177. doi:10.1016/j.marpol.2014.06.003.

Korolkov, A. (2014) 'Soviet Union' to replace 'Russia' by the end of the year. Russia Beyond The Headlines 26.6.2014. <http://rbth.com/defence/2014/06/26/soviet_union_to_replace_russia_by_the_end_of_the_year_37735.html>, retrieved 14.10.2015.

Kumar, S. – Hoffmann, J. (2002) Globalization: the Maritime Nexus. In: *Handbook of Maritime Economics and Business*, ed. C. Grammenos, 35–62. Informa, Lloyds List Press, London.

Lack, D. A. – Corbett, J. J. (2012) Black carbon from ships: a review of the effects of ship speed, fuel quality and exhaust gas scrubbing. *Atmospheric Chemistry and Physics*, Vol. 12, 3985–4000. doi:10.5194/acp-12-3985-2012.

Laine, J. – Vepsäläinen, A. P. J. (1994) Economies of Speed in Sea Transportation. *International Journal of Physical Distribution & Logistics Management*, Vol. 24 (8), 33–41. doi:10.1108/09600039410071280.

Lalonde, S. – Lasserre, F. (2013) The Position of the United States on the Northwest Passage: Is the Fear of Creating a Precedent Warranted? *Ocean Development & International Law*, Vol. 44 (1), 28–72, doi:10.1080/00908320.2012.726832.

Lammers, L. P. (2010) *The possibilities of container transit shipping via the Northern Sea Route*. Port Research Centre Rotterdam-Delft, Rotterdam.

Lasserre, F. – Pelletier, S. (2011) Polar super seaways? Maritime transport in the Arctic: an analysis of ship-owners intentions. *Journal of Transport Geography*, Vol. 19, 1465–1473. doi:10.1016/j.trangeo.2011.08.006.

Lasserre, F. (2014) Case studies of shipping along the Arctic routes. Analysis and profitability perspectives for container sector. *Transportation Research Part A*, Vol. 66, 144–161. doi:10.1016/j.tra.2014.05.005.

Laulajainen, R. (2009) The Arctic Sea Route. *International Journal of Shipping and Transport Logistics*, Vol. 1 (1), 55–73. doi:10.1504/IJSTL.2009.021976.

Lawrence, S. A. (1972) *International Sea Transport: The Years Ahead*. Lexington Books, Lexington.

Lee, T. – Kim, H. J. (2015) Barriers of voyaging on the Northern Sea Route: A perspective from shipping companies. *Marine Policy*, Vol. 62, 264–270. doi:10.1016/j.marpol.2015.09.006.

Lei, R. – Xie, H. – Wang, J. – Leppäranta, M. – Jónsdóttir, I. – Zhang, Z. (2015) Changes in sea ice conditions along the Northeast Passage from 1979 to 2012. *Cold Regions Science and Technology*, Vol. 119, 132–144. doi:10.1016/j.coldregions.2015.08.004.

Lim, S-M. (1998) Economies of Scale in container shipping. *Maritime Policy & Management*, Vol. 25 (4), 361–373. doi:10.1080/03088839 800000059.

Lin, J. Y. (2003) Development Strategy, Viability and Economic Convergence. *Economic Development and Cultural Change*, Vol. 51 (2), 277–308. doi:10.1086/367535.

Lindholt, L. – Glomsrød, S. (2012) The Arctic: No big bonanza for the global petroleum industry. *Energy Economics*, Vol. 34, 1465–1474. doi:10.1016/j.eneco.2012.06.020.

Lindstad, H. – Bright, R. M. – Strømman, A. H. (2016) Economic savings linked to future Arctic shipping trade are at odds with climate change mitigation. *Transport Policy*, Vol. 45, 24–30. doi:10.1016/j.tranpol.2015.09.002.

Liu, M. – Kronbak, J. (2010) The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe. *Journal of Transport Geography*, Vol. 18, 434–444. doi:10.1016/j.trangeo.2009.08.004.

Liu, Q. – Wilson, W. W. – Luo, M. (2016) The impact of Panama Canal expansion on the container-shipping market: a cooperative game theory approach. *Maritime Policy & Management*, Vol. 43 (2), 209–221, doi:10.1080/03088839.2015.1131863.

Lloyd, T. (1950) The Northern Sea Route. *The Russian Review*, Vol. 9 (2), 98–111.

Lloyd’s Register – Qinetiq – Strathclyde University (2013). *Global Marine Trends 2030*. London.

Loughnane, D. – Judson, B. –Reid J. (1995). Arctic Tanker Risk Analysis Project. *Maritime Policy & Management*, Vol. 22 (1), 3–12. doi:10.1080/03088839500000028.

Lu, D. – Park, G-K., Choi, K. – Oh, S. (2014) An Economic Analysis of Container Shipping through Canadian Northwest Passage. *International Journal of e-Navigation and Maritime Economy*, Vol. 1, 60–72. doi:10.1016/jj.enavi.2014.12.001.

Lukka, K. (1991) Laskentatoimen tutkimuksen epistemologiset perusteet. [in English: Epistemological foundations in management accounting research]. *Liiketaloudellinen Aikakauskirja*, No. 2, 160–186.

Majoni, G. (1975) The Feasibility of Social Policies. *Policy Sciences*, Vol. 6, 49–69.

Maloni, M. – Paul, J. A. – Gligor, D. M. (2013) Slow steaming impact on ocean carriers and shippers. *Maritime Economics & Logistics*, Vol. 15, 151–171. doi:10.1057/mel.2013.2.

MAN – MAN Diesel & Turbo (2011) *Basic Principles of Ship Propulsion*. MAN Diesel & Turbo, Copenhagen, Denmark.

Marken, V. B. – Ehlers, S. – Khan, F. (2015) Delay risk analysis of ship sailing the northern sea route. *Ship Technology Research*, Vol. 62 (1), 26–35. doi:10.1179/0937725515Z.0000000007.

Martikainen, T. – Pynnöniemi, K. – Saari, S. – Ulkopoliittisen instituutin työryhmä. *Venäjän muuttuva rooli Suomen lähialueilla*. [in English: Russia's changing role in Finland's neighbourhood]. Publications of the Government´s analysis, assessment and research activities 34/2016. Prime Minister's Office Finland.

Martinez-Zarzoso, I. (2013) Alternative Sea routes: What Effects on Maritime Trade? *SAIS Review of International Affairs*, Vol. 33 (2), 61–74. doi:10.1353/sais.2013.0020.

Maslanik, J. – Stroeve, J. – Fowler, C. – Emery, W. (2011) Distribution and trends in Arctic sea ice age through spring 2011. *Geophysical Research Letters*, Vol. 38, LI3502. doi:10.1029/2011GK047735.

McCulley, R. (2013) Aker Arctic announces heavy-duty Oblique icebreaker. *Offshore*, Vol. 73 (6), 26. June 2013.

MDPM – Marine Department Peninsular Malaysia. (2016) List of statistics. <http://www.marine.gov.my/jlmeng/Contentdetail.asp?article_id=245&category_id=4&subcategory_id=42&subcategory2_id=0#.VrMLgkagSFI>, retrieved 21.1.2016.

Mills, W. J. (2003) *Exploring Polar Frontiers: A Historical Encyclopedia.* Vol. 1, A–L. ABC CLIO, Santa Barbara, CA.

Modell, S. (2009) In defence of triangulation: A critical realist approach to mixed methods research in management accounting. *Management Accounting Research*, Vol. 20, 208–221. doi:10.1016/j.mar.2009.04.001.

Moe, A. – Jensen, Ø. (2010) *Opening of the new Arctic shipping routes*. Standard Briefing, Directorate-General for External Policies of the Union. European Parliament, Brussels.

Moe, A. (2012) Potential Arctic Oil and Gas Development: What are Realistic Expectations? In: *The Arctic in World Affairs: A North Pacific Dialogue on Arctic Marine Issues*, eds. by O. R. Young – J. D. Kim – Y. H. Kim, 227–251. 2012 North Pacific Arctic Conference Proceedings. Korean Maritime Institute, Seoul, South Korea.

Moe, A. (2014) The Northern Sea Route: Smooth Sailing Ahead? *Strategic Analysis*, Vol. 38 (6), 784–802. doi:10.1080/09700161.2014.952940.

Molenaar, E. J. (2014) Options for Regional Regulation of Merchant Shipping Outside IMO, with particular Reference to the Arctic Region. *Ocean Development & International Law*, Vol. 45, 272–298. doi:10.1080/00908320.2014.929474.

Moon, D-S. – Kim, D-J. – Lee, E-K. (2015) A Study on Competitiveness of Sea Transport by Comparing International Transport Routes between Korea and Europe. *The Asian Journal of Shipping and Logistics*, Vol. 31 (1), 1–20. doi:10.1016/j.ajsl.2015.03.001.

Mostafa, M. M. (2004) Forecasting the Suez Canal traffic: a neural network analysis. *Maritime Policy & Management*, Vol. 31 (2), 139–156. doi:10.1080/0308883032000174463.

Mulherin, N. D. (1996) *The Northern Sea Route Its Development and Evolving State of Operations in the 1990s*. CRREL Report 96-3. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Murphy, K. (2009) As Arctic ice melts, a vast frontier opens. Los Angeles Times 9.2.2009. <http://www.latimes.com/nation/la-na-new-arctic-frontier-20091011-story.html>, retrieved 1.2.2016.

Narvik Havn (2016) Narvik Havn KF – Pris och vilkår 2016. Narvik Havn KF.

Neilimö, K. – Näsi, J. (1980) *Nomoteettinen tutkimusote ja suomalaisen yrityksen taloustiede. Tutkimus positivismin soveltamisesta.* Tampere: Tampereen yliopisto: yrityksen taloustieteen ja yksityisoikeuden laitoksen julkaisuja, A2/12.

New World Encyclopedia (2016) Bering Strait. <http://www.newworldencyclopedia.org/entry/Bering_Strait>, retrieved 11.2.2016.

Niini, M. – Arpiainen, M. – Kiili, R. (2006) *Arctic Shuttle Container Link from Alaska, US to Europe*. AARC K63. Aker Arctic Technology Inc. Report K63.

Niiniluoto, I. (1984) *Tiede, filosofia ja maailmankatsomus filosofisia esseitä tiedosta ja sen arvosta* [In Finnish: Science, philosophy and worldview. Philosophical essays about knowledge and its value]. Otava, Helsinki.

Notteboom, T. E. (2006) The Time Factor in Liner Shipping Service. *Maritime Economics & Logistics*, Vol. 8, 19–39. doi:10.1057/palgrave.mel.9100148.

Notteboom, T. E. – Vernimmen, B. (2009) The effect of high fuel costs on liner service configuration in container shipping. *Journal of Transport Geography*, Vol. 17, 325–337. doi:10.1016/j.trangeo.2008.05.0

Notteboom, T. E. (2012) Towards a new intermediate hub region in container shipping? Relay and interlining via the Cape route vs. the Suez route. *Journal of Transport Geography*, Vol. 22, 164–178. doi:10.1016/j.trangeo.2012.01.003.

NSIDC (2016) Sea Ice Index. National Snow & Ice Data Center. <ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/data/>, retrieved 8.2.2016.

NSRA – Northern Sea Route Administration (2016) Object of activity and functions of NSRA. <http://www.nsra.ru/en/celi_funktsii/>, retrieved 4.4.2016.

NSRIO – Northern Sea Route Information Office (2013) The tanker “Nordvik” left the NSR water area. <http://www.arctic-lio.com/node/206, retrieved 14.3.2016.

NSRIO – Northern Sea Route Information Office (2016a) Transit statistics. <http://www.arctic-lio.com/nsr_transits>, retrieved 3.4.2016.

NSRIO – Northern Sea Route Information Office (2016b) Search and Rescue. <http://www.arctic-lio.com/nsr_searchandrescue>, retrieved 3.1.2016.

NSRIO – Northern Sea Route Information Office (2016c) Legislation. <http://www.arctic-lio.com/nsr_legislation>, retrieved 15.1.2016.

NSRIO – Northern Sea Route Information Office (2016d) Arctic Ports. <http://www.arctic-lio.com/arcticports>, retrieved 9.1.2016.

NSRIO – Northern Sea Route Information Office (2016e) Ice Concentration. <http://www.arctic-lio.com/nsr_ice>, retrieved 19.2.2016.

OAO Novatek (2014) Yamal LNG infrastructure. <http://www.novatek.ru/en/business/yamal-lng/yamal_infrastructure/>, retrieved 11.2.2016.

Offerdal, K. (2014) Interstate relations: the complexities of Arctic politics. In: *Geopolitics and Security in the Arctic: Regional Dynamics in a Global World*. eds. by R. Tamnes – K. Offerdal, 73–96. Routledge, London.

Omre, A. (2012) *An Economic Transport System of the Next Generation – Integrating the Northern And Southern Passages*. Master's Thesis. Norwegian University of Science and Technology (NTNU).

Paris, C. – Chiu, J. (2015) Chinese Shipping Group Cosco Planning Regular Trans-Arctic Sailings. The Wall Street Journal, 29.10. <http://www.wsj.com/articles/chinese-shipper-cosco-to-schedule-regular-trans-arctic-sailings-1446133485>, retrieved 11.11.2015.

Parmentier, F-J. W. – Zhang, W. – Mi, Y. – Zhu, X. – van Huissteden, J. – Hayes, D. J. – Zhuang, Q. – Christensen, T. R. – McGuire, A. D. (2015) Rising methane emissions from northern wetlands associated with sea ice decline. *Geophysical Research Letters*, Vol. 42, 7214–7222. doi:10.1002/2015GL065013.

Parsons, J. – Dinwoodie, J. – Roe, M. (2011) Northern opportunities: A strategic review of Canada's Arctic icebreaking services. *Marine Policy*, Vol. 35, 549–556. doi:10.1016/j.marpol.2011.01.017.

Paxian, A. – Eyring, V. – Beer, W. – Sausen, R. – Wright, C. (2009) Present-Day and Future Global Bottom-Up Ship Emission Inventories Including Polar Routes. *Environmental Science and Technology*, Vol. 44, 1333–1339. doi:10.1021/es9022859.

Peirce, C. S. (1960) In: *Collected Papers of Charles Sanders Peirce*. eds. C. Hartshorne, C. – P. Weiss, Belknap Press of Harvard University Press, Cambridge MA.

Pelletier, J-F. – Guy, E. (2015) Supply and demand for the Eastern Canadian Arctic Sealift. *Maritime Policy & Management*, Vol. 42 (7), 669–681. doi:10.1080/03088839.2014.925594.

Peters, G. P. – Nilssen, T. P. – Lindholt, L. – Eide, M. S. – Glomsrød, S. – Eide, L. I. – Fuglestvedt, J. S. (2011) Future emissions from shipping and petroleum activities in the Arctic. *Atmospheric Chemistry and Physics*, Vol. 11, 5305–5320. doi:10.5194/acp-11-5305-2011.

Pettersen, T. (2011) Russia to have ten Arctic rescue centers by 2015. <http://barentsobserver.com/en/topics/russia-have-ten-arctic-rescue-centers-2015>, retrieved 6.2.2016.

Pettersen, T. (2013) Northern Sea Route no alternative to Suez – Deputy Minister. <http://barentsobserver.com/en/business/2013/12/northern-sea-route-no-alternative-suez-deputy-minister-19-12>, retrieved 3.2.2016.

Pharand, D. (2007) The Arctic Waters and the Northwest Passage: A Final Revisit. *Ocean Development & International Law*, Vol. 38 (1–2), 3–69, doi:10.1080/00908320601071314.

Pizzolato, L. – Howell, S. E. L. – Derksen, C. – Dawson, J. – Copland, L. (2014) Changing sea ice conditions and marine transportation activity in Canadian Arctic waters between 1990 and 2012. *Climatic Change*, Vol. 123, 161–173. doi:10.1007/s10584-013-1038-3.

Portworld Distance Calculator (2015) <http://www.portworld.com/map>, retrieved 3.10.2015.

Pruyn, J. F. J. (2016) Will the Northern Sea Route ever be a viable alternative? *Maritime Policy & Management.* doi:10.1080/03088839.2015.1131864.

Putin, V. (2011) Speech at the International Arctic Forum: The Arctic – Territory of Dialogue in Arkhangelsk. Arkhangelsk, September 28, 2011. <http://www.rusembassy.ca/node/607>, retrieved 11.1.2016.

PWC – PricewaterhouseCoopers (2009) Northern Sea Route <http://library.arcticportal.org/1566/1/Skyrsla_um_Nordurishafssiglingar_2_feb_2009.pdf>, retrieved 29.1.2016.

PWC – PricewaterhouseCoopers (2011) Future of the world trade: Top 25 sea and air freight routes in 2030. <http://www.pwc.com/gr/en/publications/future-of-world-trade.html>, retrieved 30.10.2015.

Qu, X. – Meng, Q. (2012) The economic importance of the Straits of Malacca and Singapore: An extreme-scenario analysis. *Transportation Research Part E*, Vol. 48, 258–265. doi:10.1016/j.tre.2011.08.005.

Ragner, C. L. (2000a) *Northern Sea Route cargo flows and infrastructure – present state and future potential*. FNI report 13. Lysaker: Fridtjof Nansen Institute.

Ragner, C. L. (2000b) The Northern Sea Route – Commercial Potential, Economic Significance, and Infrastructure Requirements. *Post-Soviet Geography and Economics*, Vol. 41 (8), 541–580. doi:10.1080/10889388.2000.10641157.

Rahmstorf, S. – Box, J. E. – Feulner, G. – Mann, M. E. – Robinson, A. – Rutherford, S. – Shaffernicht, E. J. (2015) Exceptional twenthieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change*, Vol. 5, 475–480. doi:10.1038/NCLIMATE2554.

Rajkumar, C. – Kavin, L. – Luo, X. – Stentoft, J. (2016) Doctoral dissertations in logistics and supply chain management: a review of Nordic contributions from 2009 to 2014. *Logistics Research*, Vol. 9 (5), 1–18. doi:10.1007/s12159-016-0132-0.

Raza, Z. – Schøyen, H. (2014) The Commercial Potential for LNG Shipping Between Europe And Asia Via the Northern Sea Route. *Journal of Maritime Research*, Vol. 11 (2), 67–79.

Riska, K. (2009) *Definition of the new ice class IA Super+*. Research Report No 60. Winter Navigation Research Board, Helsinki.

Riska, K. (2010) *Design of ice breaking ships*. Technical Report. ILS Oy, Helsinki, Finland & University of Science and Technology, Trondheim, Norway.

Rodemann, H. – Templar, S. (2014) The enablers and inhibitors of intermodal rail freight between Asia and Europe. *Journal of Rail Transport Planning & Management*, Vol. 4, 70–86. doi:10.1016/j.jrtpm.2014.10.001.

Rodrigue, J-P. – Ashar, A. Transshipment hubs in the New Panamax Era: The role of the Caribbean. *Journal of Transport Geography*, Vol. 51, 270–279. doi:10.1016/j.jtrangeo.2015.10.002.

Rodrigues, J. (2009) The increase in the length of the ice-free season in the Arctic. *Cold Regions Science and Technology*, Vol. 59, 78–101. doi:10.1016/j.coldregions.2009.05.006.

Rottem, S. V. (2015) A Note on the Arctic Council Agreements. *Ocean Development & International Law*, Vol. 46 (1), 50–59. doi:10.1080/00908320.2015.988940.

Røseth, T. (2014) Russia's China Policy in the Arctic. *Strategic Analysis*, Vol. 38 (6), 841–859. doi:10.1080/09700161.2014.952942.

Ruksha, V. (2014) Atomic Icebreaking Fleet and Development of the Northern Sea Route. Viacheslav Ruksha, Director General, Rosatomflot. <https://blog.canpan.info/oprf_en/img/Mr.20Vyacheslav20V.20Ruksha20%28Rosatomflot%2920E8AC9BE6BC94.pdf>, retrieved 10.1.2016.

Russian Federation (2012) Federal Law N 132-F3 on amendments to specific legislative acts of the Russian federation related to governmental regulation of merchant shipping in the water area of the Northern Sea Route.

Ruth, M. – Hannon, B. (2012) *Modeling Dynamic Economic Systems*. Springer Science+Business Media. doi:10.1007/978-1-4614-2209-9_1.

Ryan, B. – Scapens, R. W. – Theobald, M. (2002) *Research Method & Methodology in Finance & Accounting*. 2nd edition. Thomson, London.

Safonov, Y. G. (2010) Mineral potential of the Russian Arctic: state and efficient development. *Russian Geology and Geophysics*, Vol. 51, 112–120. doi:10.1016/j.rgg.2009.12.013.

Sakhuja, V. (2013) Sailing through the Northern Sea Route: Opportunities and Challenges. *Strategic Analysis*, Vol. 37 (4), 494–498. doi:10.1080/09700161.2013.802524.

Sakhuja, V. (2014) The Polar Code and Arctic Navigation. *Strategic Analysis*, Vol. 38 (6), 803–811. doi:10.1080/09700161.2014.952943.

Sand, M. – Berntsen, T. K. – Seland, Ø. – Kristjánsson, J. E. (2013) Arctic Surface Temperature Change To Emissions Of Black Carbon Within Arctic Or Midlatitudes. *Journal of Geophysical Research: Atmospheres*, Vol. 118, 7788–7798. doi:10.1002/jgrd.50613.

Sander, G. – Gille, J. – Stepien, A. – Koivurova, T. – Thomas, J. – Gascard, J-C. – Justus, D. (2014) *Changes in Arctic Maritime Transport*. Strategic Assessment of Development of the Arctic. Assessment conducted for the European Union. European Commission.

Sarrabezoles, A. – Lasserre, F. – Hagouagn'rin, Z. (2014) Arctic shipping insurance: towards a harmonisation of practices and costs? *Polar Record*, doi:10.1017/S0032247414000552.

Sawhill, S. – Ragner, C. L. (2002) Shipping nuclear cargo via the Northern Sea Route. *Polar Record*, Vol. 38 (204), 39–52. doi:10.1017/S0032247400017289.

Sayer, A. (2000) *Realism and Social Science*. Sage Publications, London.

Sazonov, K. E. (2011) Navigation challenges for large-size ships in ice conditions. *Ships and Offshore Structures*, Vol. 6 (3): 231–238. doi:10.1080/17445302.2010.548123.

SCA – Suez Canal Authority (2015) Suez Canal Traffic Statistics. <http://www.suezcanal.gov.eg/TRstat.aspx?reportId=1>, retrieved 23.11.2015.

Scarsi, R. (2007) The bulk shipping business: market cycles and shipowners' biases. Maritime Policy & Management, 34 (6), 577–590, doi:10.1080/03088830701695305.

Schøyen, H. – Bråthen, S. (2011) The Northern Sea Route versus the Suez Canal: cases from bulk shipping. *Journal of Transport Geography*, Vol. 19, 977–983. doi:10.1016/j.trangeo.2011.03.003.

Serreze, M. C. – Barry, R. G. (2011) Processes and impacts of Arctic amplification: A research synthesis. *Global and Planetary Change*, Vol. 77 (1–2), 85–96. doi:10.1016/j.gloplacha.2011.03.004.

Smith, L. C. (2011) *The World in 2050: Four Forces Shaping Civilization's Northern Future*. Penguin Group (USA) Inc., New York.

Smith, L. C. – Stephenson, S. R. (2013) New Trans-Arctic shipping routes navigable by mid-century. *Proceedings of the National Academy of Sciences Plus*, Vol. 110, 4871–4872.

Solli, P. E. – Rowe, E. W. – Lindgren W. Y. (2013) Coming into the Cold: Asia's Arctic interests. *Polar Geography*, Vol. 36 (4), 253–270. doi:10.1080/1088973X.2013.825345.

Solski, J. J. (2013) New Developments in Russian Regulation of Navigation on the Northern Sea Route. *Arctic Review on Law and Politics*, Vol. 4 (1), 90–119.

Somanathan, S. – Flynn, P. – Szymanski, J. (2007) Feasibility of a Sea Route through the Canadian Arctic. *Maritime Economics & Logistics*, Vol. 9, 324–334. doi:10.1057/palgrave.mel.9100185.

Somanathan, S. – Flynn, P. – Szymanski, J. (2009) The Northwest Passage: A simulation. *Transportation Research Part A*, Vol. 43, 127–135. doi:10.1016/j.tra.2008.08.001.

Spanos, G. – Angelis, L. (2016) The impact of information security events to the stock market: A systematic literature review. *Computers & Security*, Vol. 58, 216–229. doi:10.1016/j.cose.2015.12.006.

Spens, K. M. – Kovács, G. (2006) A content analysis of research approaches in logistics research. *International Journal of Physical Distribution & Logistics Management*, Vol. 36 (5), 374–390. doi:10.1108/09600030610676259.

Staalesen, A. (2016) Upcoming chair of Arctic Council hints focus on railway, Northern Sea Route. Independent Barents Observer, 31.3.2016. <http://thebarentsobserver.com/industry/2016/03/upcoming-chair-arctic-council-hints-focus-railway-northern-sea-route>, retrieved, 25.4.2016.

Stamatopoulou, I. V. – Psaraftis, H. N. (2013) Northern Sea Route: Effect on Modal Shift & Modal Choice. *Proceedings of the IAME 2013 Conference*. Marseille, France.

Stephenson, S. R. – Smith, L. C. – Agnew, J. A. (2011) Divergent long-term trajectories of human access to the Arctic. *Nature Climate Change*, Vol. 1 (3), 156–160. doi:10.1038/nclimate1120.

Stephenson, S. R. – Smith, L. C. – Brigham, L. W. – Agnew, J. A. (2013) Projected 21st-century changes to Arctic Marine access. *Climate Change*, Vol. 118 (3–4), 885–899. doi:10.1007/s10584-012-0685-0.

Stephenson, S. R. – Brigham, L. W. – Smith, L. C. (2014) Marine accessibility along Russia's Northern Sea Route. *Polar Geography*, Vol. 37 (2), 111–133. doi:10.1080/1088937X.2013.845859.

Sterman, J. D. (2000) *Business Dynamics: Systems thinking and modelling for a complex world*. McGraw-Hill Higher Education, USA.

Stopford, M. (1988) *Maritime Economics*. First Edition. Routledge, London.

Stopford, M. (2009) *Maritime Economics*. Third Edition. Routledge, London.

Stroeve, J. – Serreze, M. C. – Holland, M. M. – Kay, J. E. – Maslanik, J. – Barrett, A. P. (2012) *Climate Change*, Vol. 110, 1005–1027. doi:10.1007/s10584-011-0101-1.

Sørstrand, S. S. (2012) *A Decision Support Model for Merchant Vessels Operating on the Arctic Sea*. Master's Thesis. Norwegian University of Science and Technology (NTNU).

Tavasszy, L. – Minderhoud, M. – Perrin, J–F. – Notteboom, T. (2011) A strategic network choice model for global flows: specification, estimation and application. *Journal of Transport Geography*, Vol. 19, 1163–1172. doi:10.1016/j.trangeo.2011.05.005.

Têtu, P-L. – Pelletier, J-F. – Lasserre, F. (2015) The mining industry in Canada north of the 55th parallel: a maritime traffic generator? *Polar Geography*, Vol. 38 (2), 107–122. doi:10.1080/1088937X.2015.1028576.

Tikka, K. – Riska, K. – Liu, S. (2008) Tanker Design Considerations for Safety and Environmental Protection of Arctic Waters: Learning from Past Experience. *WMU Journal of Maritime Affairs*, Vol. 7 (1), 189–204. doi:10.1007/BF03195131.

Tonami, A. (2014) The Arctic policy of China and Japan: multi-layered economic and strategic motivations. *The Polar Journal*, Vol. 4 (1), 105–126. doi:10.1080/2154896X.2014.913931.

UK P&I Club (2014) Arctic Shipping: P&I Insurance FAQs. <http://www.ukpandi.com/knowledge/article/arctic-shipping-p-i-insurance-faqs-130451/>, retrieved 1.2.2016.

UNCLOS – United Nations Convention on the Law of the Sea. (1982) <http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm>, retrieved 12.2.2016.

UNCTAD – United Nations Conference on Trade and Development (2015) *Review of Maritime Transport 2014*. United Nations Publications, New York.

Ungo, R. – Sabonge, R. (2012) A competitive analysis of Panama Canal routes. *Maritime Policy & Management*, Vol. 39 (6), 555–570. doi:10.1080/03088839.2012.728727.

Vafidis, D. (2007) *Approaches for Knowledge and Application Creation in Logistics. An empirical Analysis Based on Finnish and Swedish Doctoral Dissertations Published Between 1994 and 2003*. Publications of the Turku School of Economics. Series A-3:2007.

Valsson, T. – Ulfarsson G. F. (2011) Future changes in activity structures of the globe under a receding Arctic ice scenario. *Futures*, Vol. 43, 450–459. doi:10.1016/j.futures.2010.12.002.

VanderZwaag, D. L. – Chircop, A. – Franckx, E. – Kindred, H. – MacInnis, K. – McConnell, M. – McDonald, A. – McDorman, T. L. – Mills, S. – Puthucherril, T. – Rolston, S. – Saunders, P. – Spears, K. J. (2008) *Governance of Arctic Marine Shipping*. Marine and Environmental Law Institute, Dalhousie University, Halifax.

Veenstra, A. W. – Ludema, M. W. (2006) The relationship between design and economic performance of ships. *Maritime Policy & Management*, Vol. 33 (2), 159–171. doi:10.1080/03088830600612880.

Verny, J. – Grigentin, C. (2009) Container shipping on the Northern Sea Route. *International Journal of Production Economics*, Vol. 122, 107–117. doi:10.1016/j.ijpe.2009.03.018.

Way, B. – Veitch B. – Khan, F. (2015) The Northern Sea Route vs. the Suez Canal Route – an Economic analysis incorporating probabilistic simulation optimization of vessel speed. OMAE2015-42054. *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015*, May 31–June 5, 2015, St. John's, Newfoundland, Canada.

Wergeland, T. (2013) Commercial comparisons of Arctic transit routes In: *Shipping in Arctic Waters: A Comparison of the Northeast, Northwest and Trans Polar Passages*. eds. W. Østreng – K. M. Eger – B. Fløistad – A. Jørgensen-Dahl – L. Lothe – M. Mejlænder-Larsen – T. Wergeland, 340–353. Springer-Praxis, Chichester, UK.

Wijnolst, N. – Wergeland, T. (2009) *Shipping Innovation*. IOS Press, Amsterdam, The Netherlands.

WMO – World Meteorological Organization (2013) Implementation plan for the evolution of global observing systems (EGOS-IP) Technical Report No.2013-4. <http://www.wmo.int/pages/prog/www/OSY/Publications/EGOS-IP-2025/EGOS-IP-2025-en.pdf>, retrieved 8.1.2016.

WTO – World Trade Organization (2014) International Trade Statistics 2014. <www.wto.org/statistics>, retrieved 2.4.2016.

Xu, M. – Yin, Z. – Jia, D. – Jin, F. – Ouyang, H. (2011) The potential seasonal alternative of Asia-Europe container service via Northern sea route under the Arctic sea ice retreat. *Maritime Policy & Management*, Vol. 38 (5), 541–560. doi:10.1080/03088839.2011.597449.

Yang, M. – Khan, F. I. – Lye, L. – Sulistiyono, H. – Dolny, J. – Oldford, D. (2013) Risk-based Winterization for Vessel Operations in Arctic Environments. *Journal of Ship Production and Design*, Vol. 29 (4), 199–210. doi:10.5957/JSPD.29.4.120059.

Yenikeyeff, S. M. – Krysiek, T. F. (2007) *The Battle for the Next Energy Frontier: The Russian Polar Expedition and the Future of Arctic Hydrocarbons.* Oxford Energy Comment August 2007. Oxford Institute for Energy Studies.

Yin, R. K. (1994) *Case Study Research – Design and Methods*. SAGE Publications, Newbury Park, CA.

Yip, T. L. – Wong, M. C. (2015) The Nicaragua Canal: scenarios of its future roles. *Journal of Transport Geography*, Vol. 43, 1–13. doi:10.1016/j.trangeo.2015.01.002.

Young, G. I. M. (1970) Feasibility Studies. *The Appraisal Journal*, July, 376–383.

Young, O. R. (2010) Arctic Governance – Pathways to the Future. *Arctic Review on Law and Politics*, Vol. 1 (2), 164–185.

Zelasney, J. – Huppert, D. – Leschine, T. (2011) The influence of oil price on maritime routing of containerized imports from China. *Maritime Economics & Logistics*, Vol. 13, 298–318. doi:10.1057/mel.2011.13.

Zhang, Z. (2011) China's energy security, the Malacca dilemma and responses. *Energy Policy*, Vol. 39, 7612–7615. doi:10.1016/j.en.pol.2011.09.033.

Østhagen, A. (2015) The Arctic Coast Guard Forum: Big Tasks, Small Solutions. <http://www.thearcticinstitute.org/2015/11/the-arctic-coast-guard-forum-big-tasks.html>, retrieved 4.1.2016.

Østreng, W. (2013) Introduction: An operational view of Arctic waters. In: *Shipping in Arctic Waters: A Comparison of the Northeast, Northwest and Trans Polar Passages*. eds. W. Østreng – K. M. Eger – B. Fløistad – A. Jørgensen-Dahl – L. Lothe – M. Mejlænder-Larsen – T. Wergeland, 1–45. Springer-Praxis, Chichester, UK.

APPENDICES

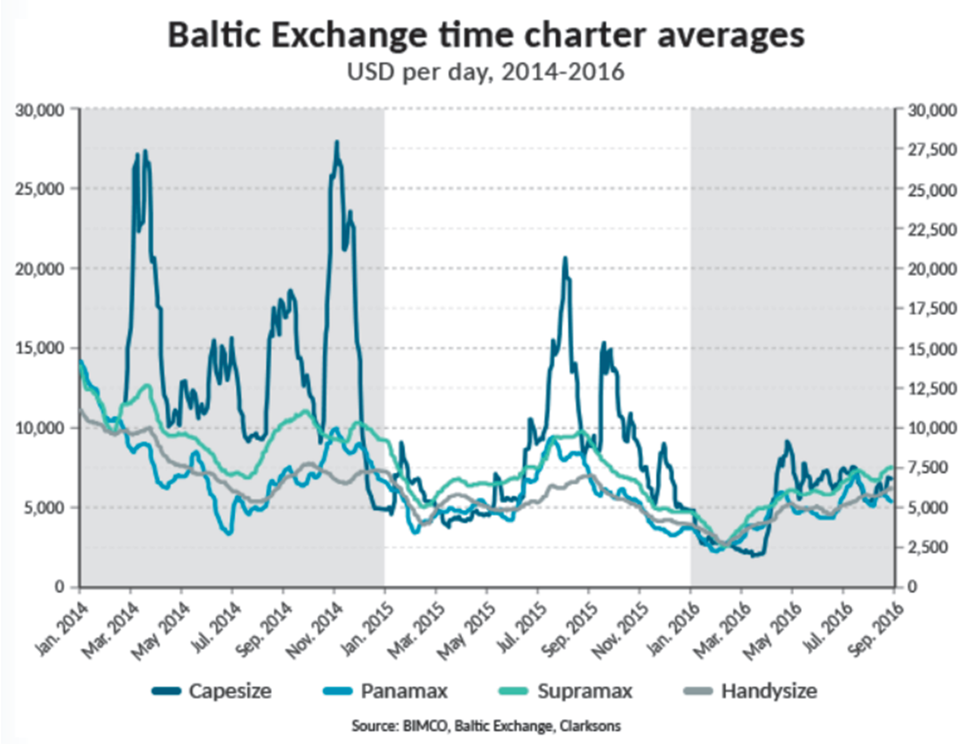
Appendix 1 Basic assumptions and parameters of containerships used in the sensitivity analysis comparing economic viability of the NSR relative to the SCR

COST PARAMETERS FOR CONTAINERSHIPS ON ANNUAL LINER SERVICE BASIS			
Route	Suez Canal Route		Northern Sea Route
Containership evolution category	ULCS	Panamax	
Cargo carrying capacity (TEU)	18 000	4 000	
Port calls	5		
Average sailing speed (knots)	18		12 *)
Nominal speed	24		20
NSR area (NM)	–		2 200
NSR annual navigational season length (days)			150
Days in port	7	3	3
Ship particulars based on ships	*Maersk Majestetic*	*ANL Warringa*	*N/A*
Load Factor (%)	65		
Main engine power (kWh)	59 360	36 560	
SFOC (g/kWh)	180		
Engine load (%)	80		
Sea margin (%)	15		
Fuel consumption estimation basis	Propeller Law		Propeller Law **)
CAPITAL COST			
Newbuilding price (Million USD)	185	72	90
Ice-class premium (%)			25
Depreciation (years)	20		
Interest p.a. (%)	3		
VOYAGE COST			
Suez Canal Net Tonnage	195 149	44 367	44 367
Container handling cost per TEU (USD)	100		
Suez Canal tolls per transit (USD)	976 300	361 147	361 147
NSR icebreaking cost per transit (USD)	–		375 000
Port fees per port (USD) Source: Stopford (2009)	98 746	35 768	35 768
HFO price (USD/tonne) High scenario	600		
HFO price (USD/tonne) Low scenario	250		
MDO price (USD/tonne)	800		
MDO consumption in ports (%) of the HFO	10		
DAILY COST			
Total operating cost (USD) per day (Drewry 2012)	10 461	7 229	8 288
Manning (USD)	3 340	2 749	3 024
Insurance (USD)	1 698	803	1 123
Hull & machinery	678	232	348
Protection & indemnity	754	407	611
Miscellaneous incl. brokerage	267	164	164
Stores	491	406	406
Spares	926	608	608
Lubes	2 703	1 652	1 652
R&M	552	465	931
Management	752	545	545
Shipping line administration cost (USD) per roundtrip (Stopford 2009)	2 226 656	517 969	517 969
Cost per employee (USD/p.a.)	60 000	60 000	60 000
Productivity per employee (TEU/p.a.)	640	640	640
*) inside NSR boundaries and elsewhere 18 knots			
**) For sensistivity analysis purposes daily fuel consumption at 5 knots assumed as 61.3 tonnes; 1 knots as 124.6 tonnes			

Appendix 2 Basic assumption and parameters of dry bulkers used in the sensitivity analysis comparing economic viability of the NSR relative to the SCR

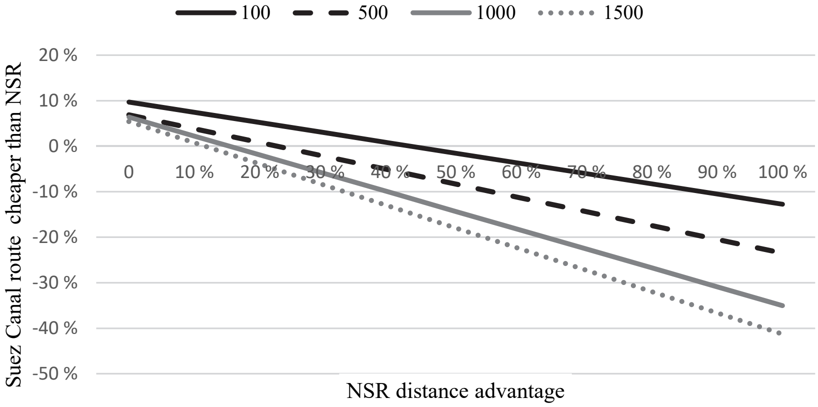
COST PARAMETERS FOR TIME-CHARTERED DRY BULKERS			
Route	Suez Canal Route		Northern Sea Route
Dry bulker evolution category	Capesize	Panamax	
Cargo carrying capacity (DWT)	150 000	75 000	
Port calls	3		
Average sailing speed (knots)	14		12 *)
Nominal speed	16		
NSR area (NM)	–		2 200
Days in port	5	3	3
Ship particulars based on ships	*Ocean Trinity*	*Morning Cloud*	*Nordic Orion*
Load Factor (%)	90		
Main engine power (kWh)	15 662	11 060	15 886
SFOC (g/kWh)	180		
Engine load (%)	80		
Sea margin (%)	15		
Fuel consumption estimation basis	Propeller Law		Propeller Law **)
Time-charter rate per day (USD) High scenario	50 000	25 000	25 000
Time-charter rate per day (USD) Low scenario	7 500	5 000	5 000
Suez Canal Net Tonnage	83 536	38 570	40 142
Suez Canal tolls per transit (USD)	307 287	203 611	208 123
NSR icebreaking cost per transit (USD)	–		277 620
Port fees (USD) per port (Narvik Havn 2016)	68 650	33 579	33 579
HFO price (USD/tonne) High scenario	600		
HFO price (USD/tonne) Low scenario	250		
MDO price (USD/tonne)	800		
MDO consumption in ports (%) of the HFO	10		
*) inside NSR boundaries and elsewhere 14 knots			
**) For sensitivity analysis purposes daily fuel consumption at 5 knots assumed as 37 tonnes; 1 knots as 52 tonnes			

Appendix 3 Time-charter rates 2014–2016 for various dry bulker sizes (BIMCO 2016)

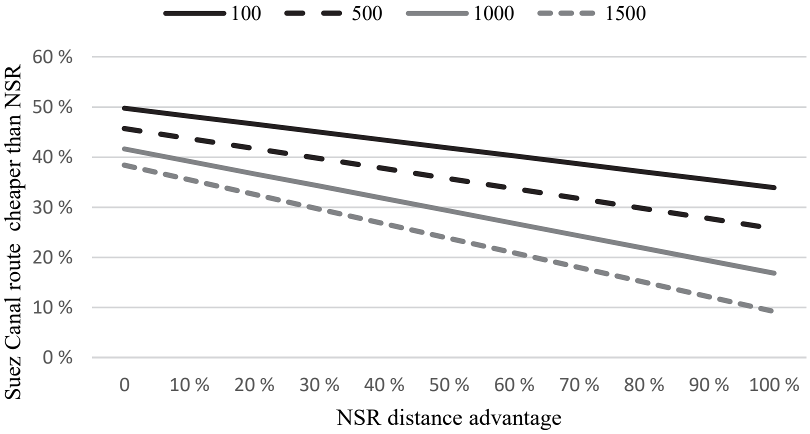


Source: BIMCO, Baltic Exchange, Clarksons

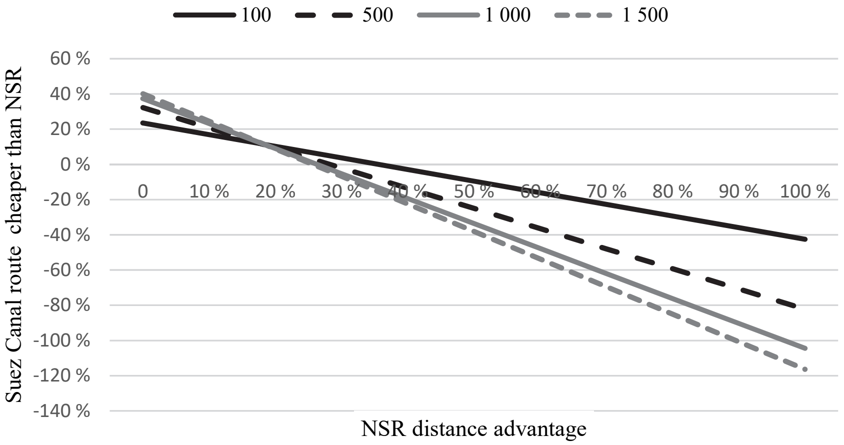
Appendix 4 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



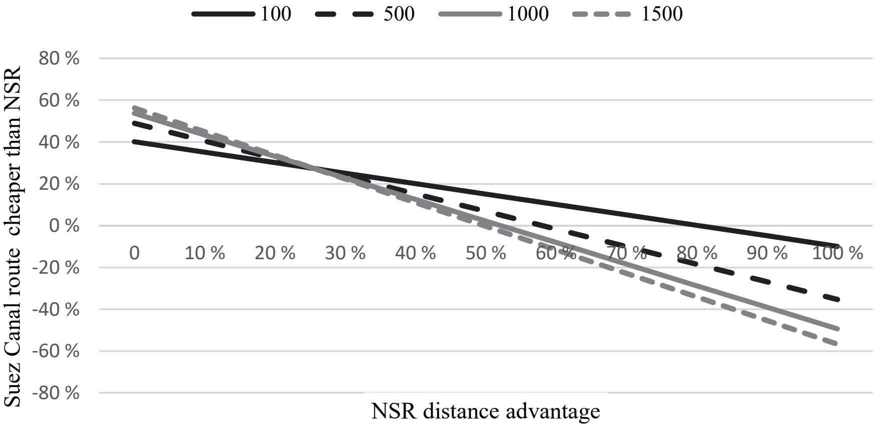
Appendix 5 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



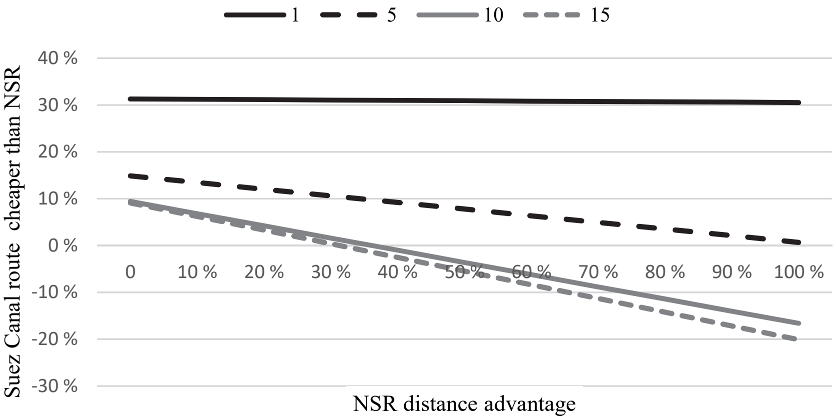
Appendix 6 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



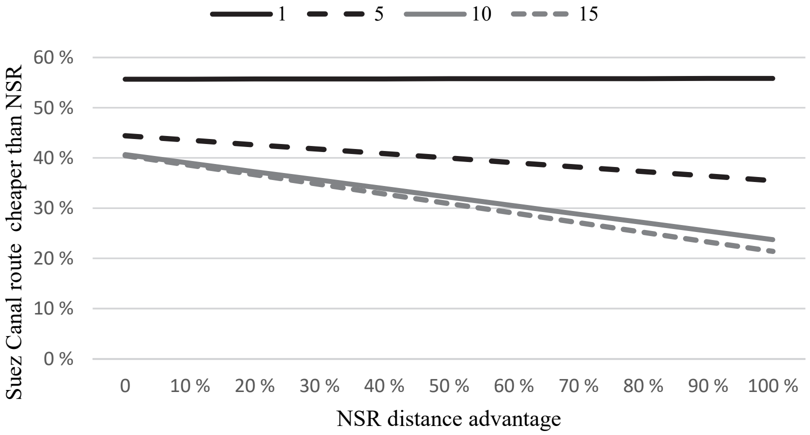
Appendix 7 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



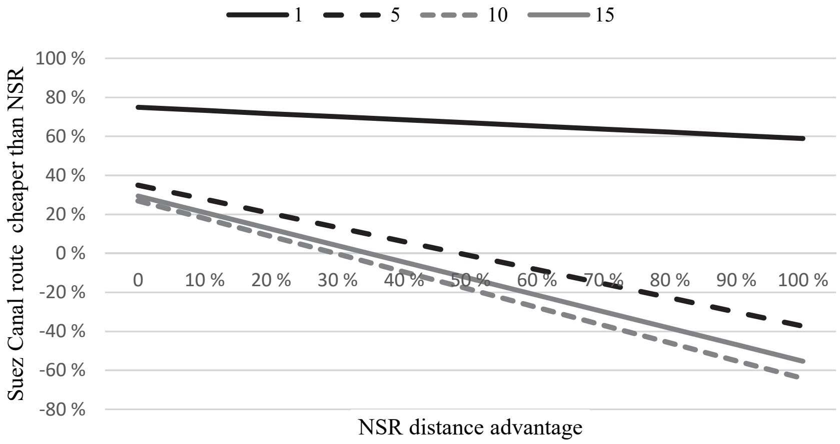
Appendix 8 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



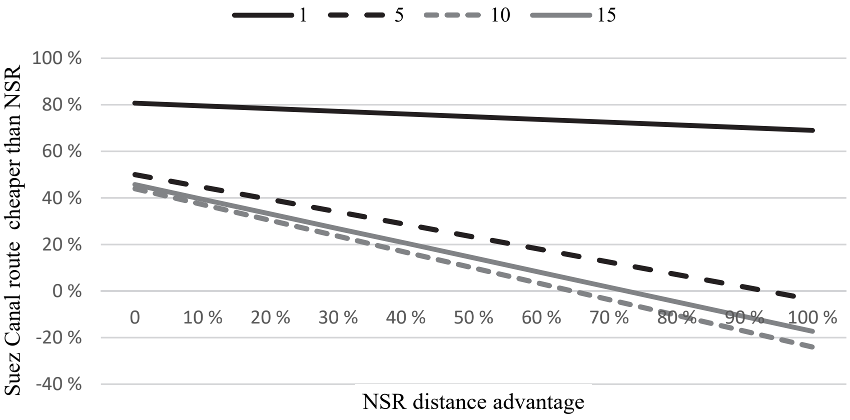
Appendix 9 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



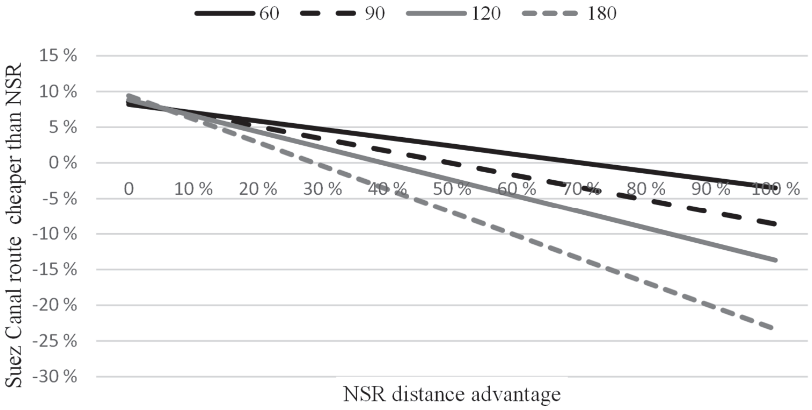
Appendix 10 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



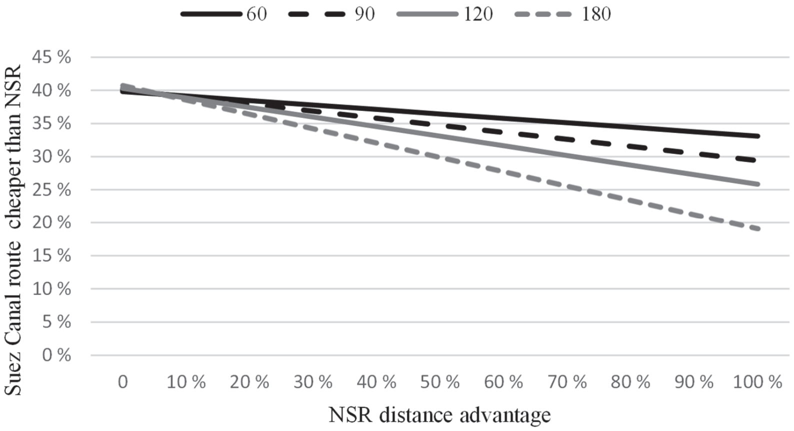
Appendix 11 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



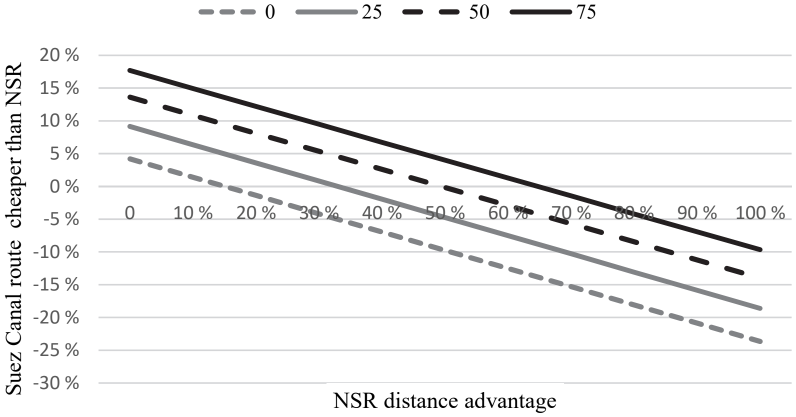
Appendix 12 Impact of NSR navigational season length (days) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



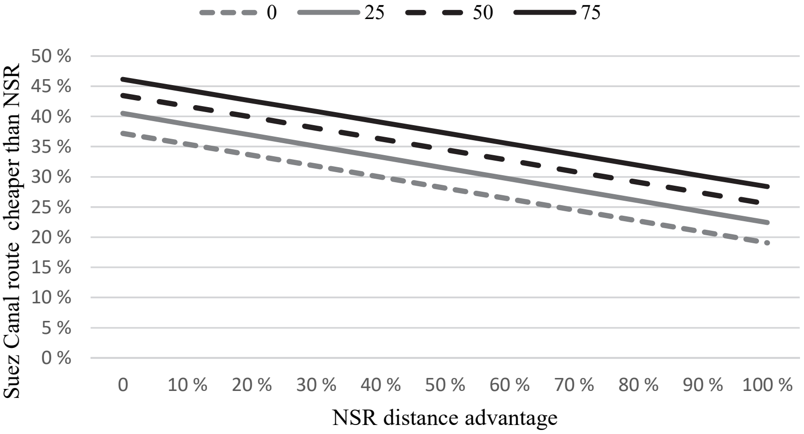
Appendix 13 Impact of NSR navigational season length (days) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



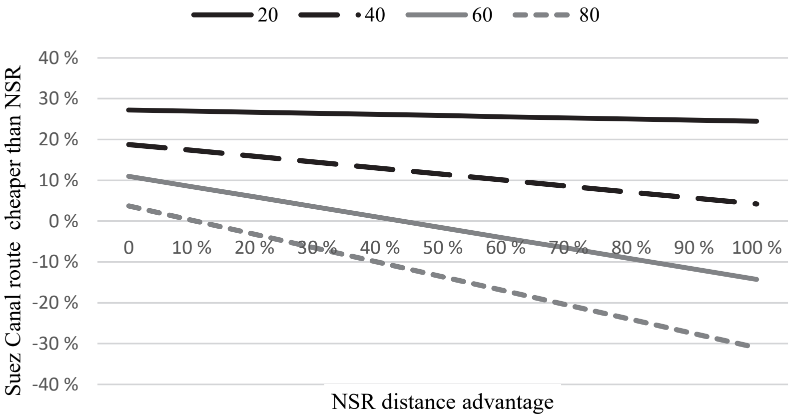
Appendix 14 Impact of ice-class building cost differential (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



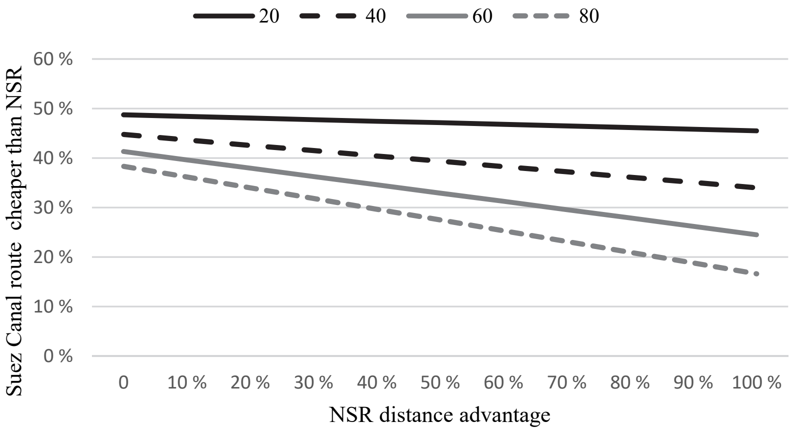
Appendix 15 Impact of ice-class building cost differential (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



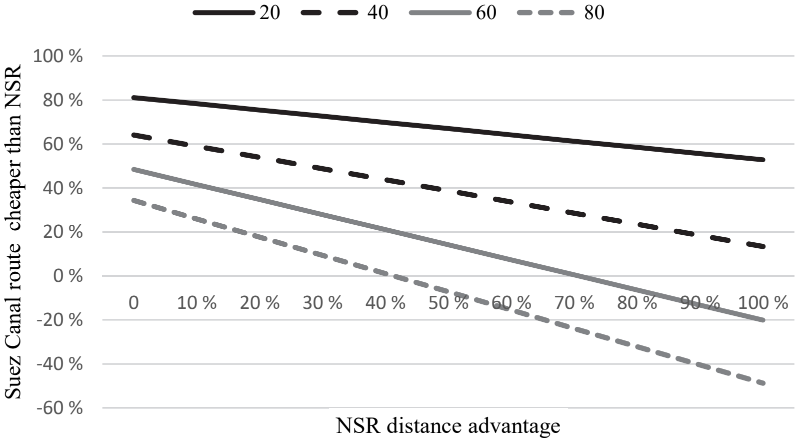
Appendix 16 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



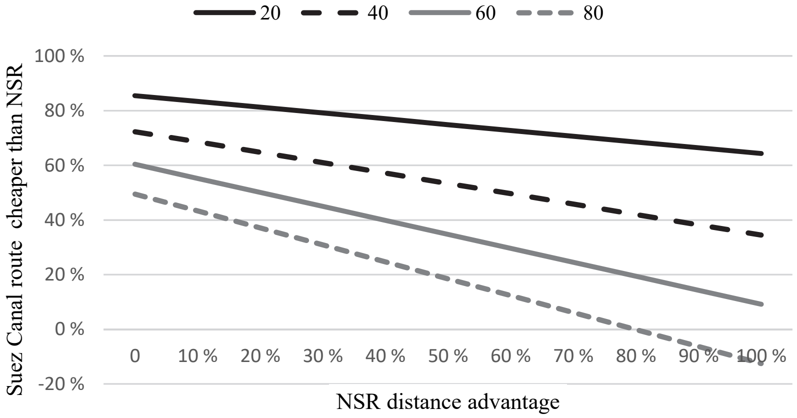
Appendix 17 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



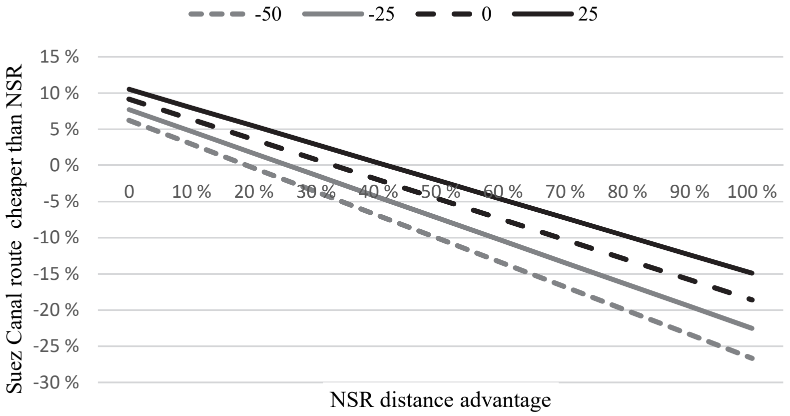
Appendix 18 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



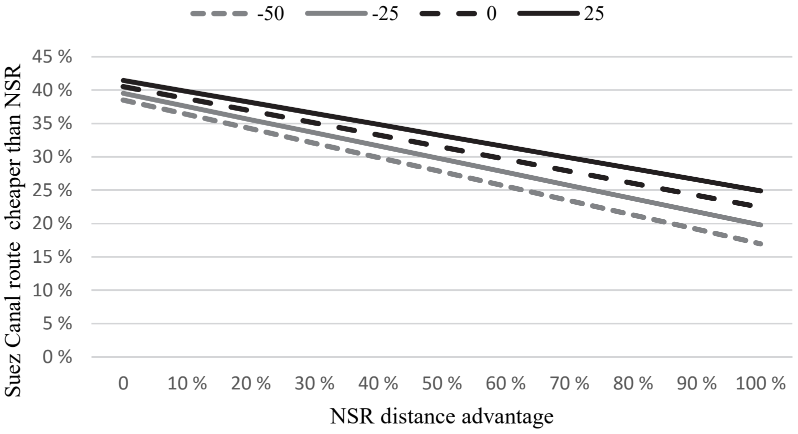
Appendix 19 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



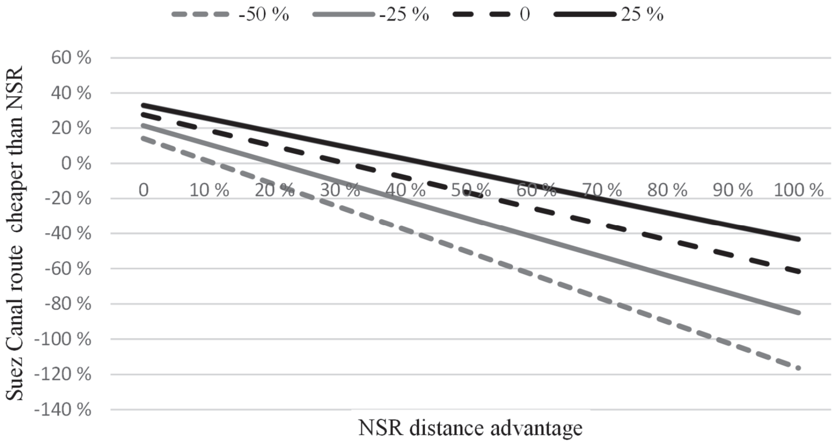
Appendix 20 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



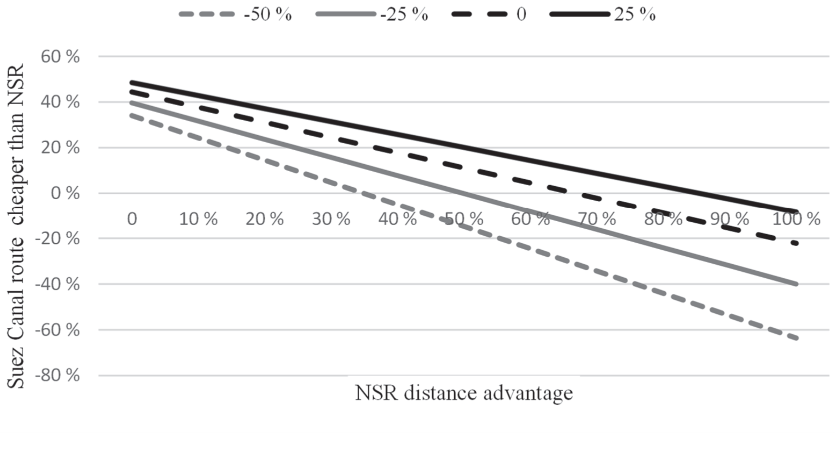
Appendix 21 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



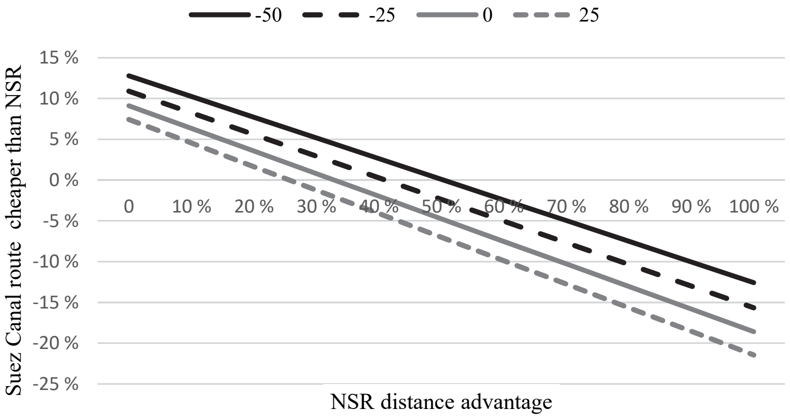
Appendix 22 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



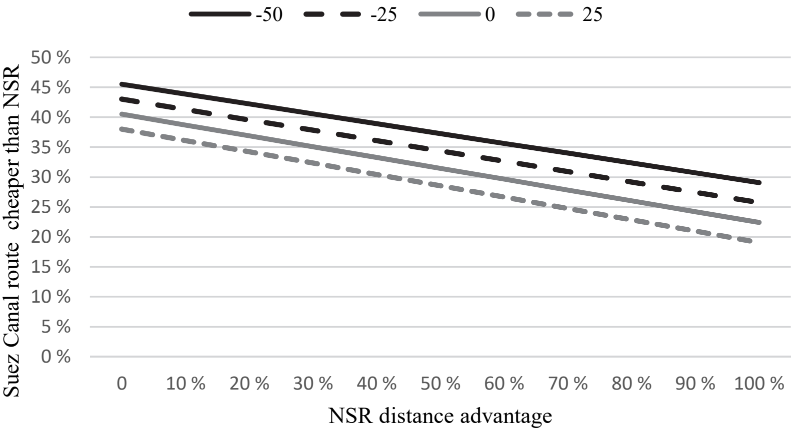
Appendix 23 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



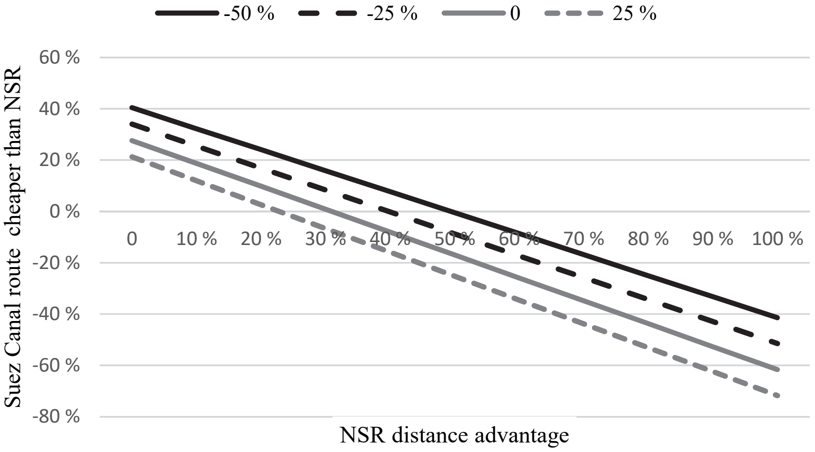
Appendix 24 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (Low scenario)



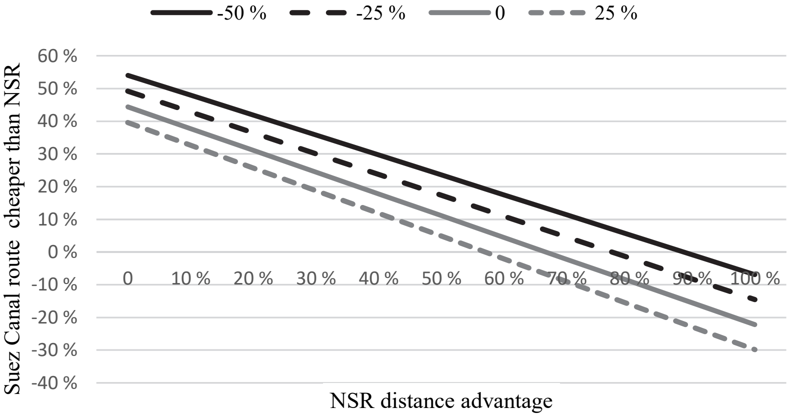
Appendix 25 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (Low scenario)



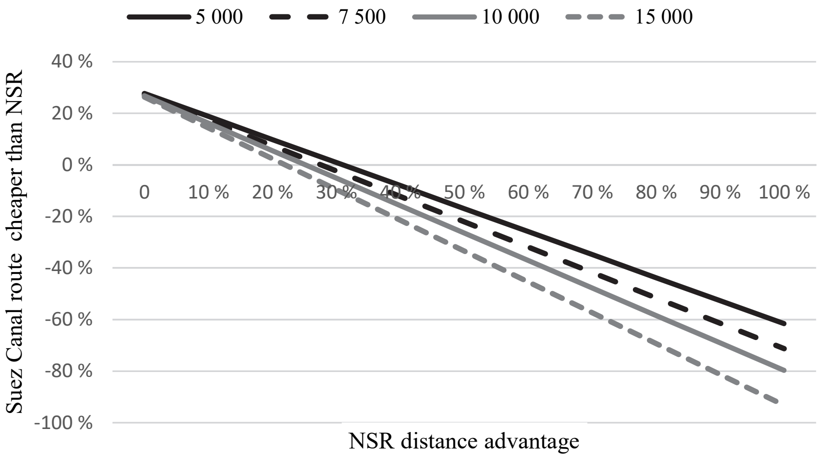
Appendix 26 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



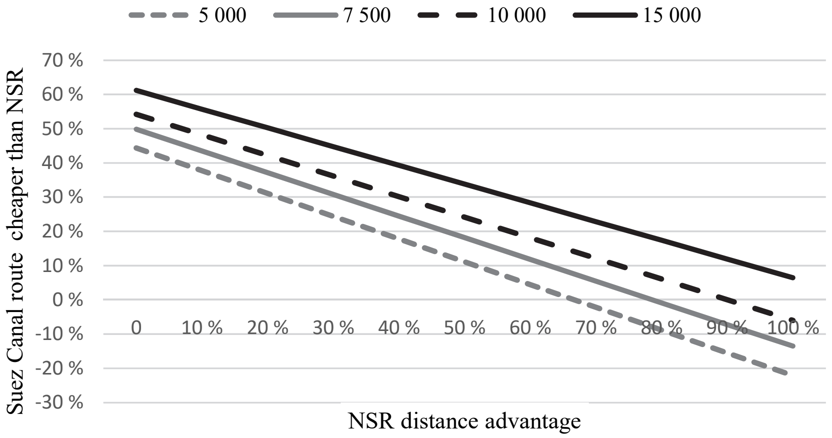
Appendix 27 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



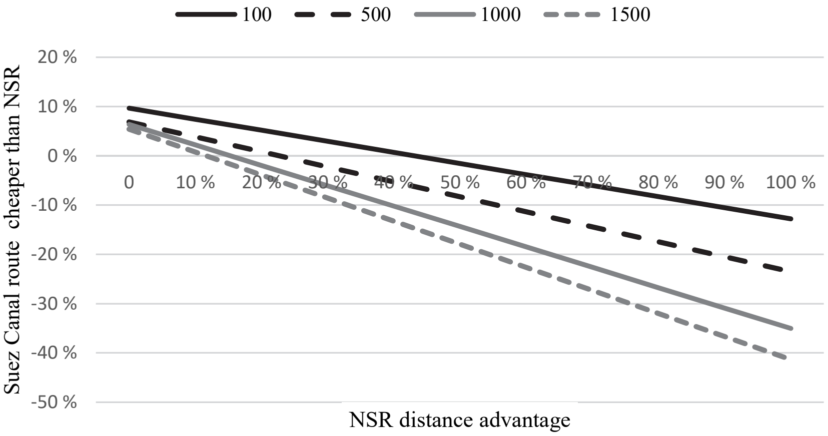
Appendix 28 Impact of various time-charter rate levels (USD per day) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (Low scenario)



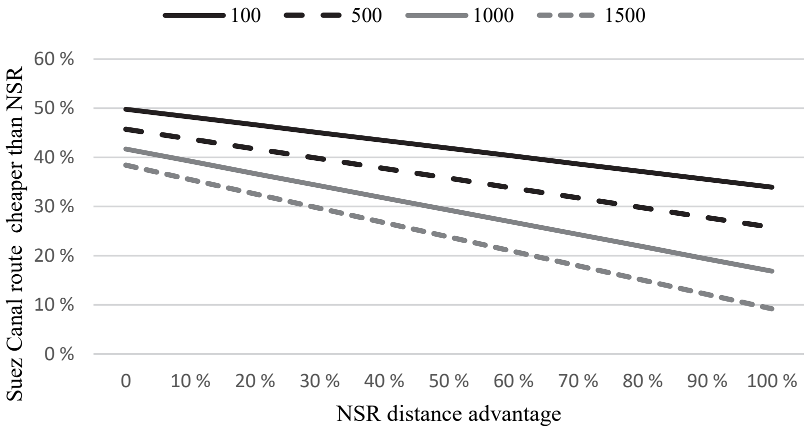
Appendix 29 Impact of various time-charter rate levels (USD per day) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (Low scenario)



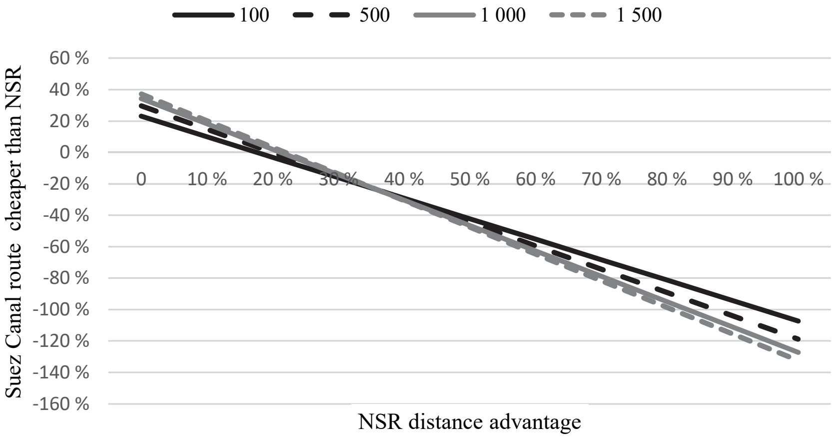
Appendix 30 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



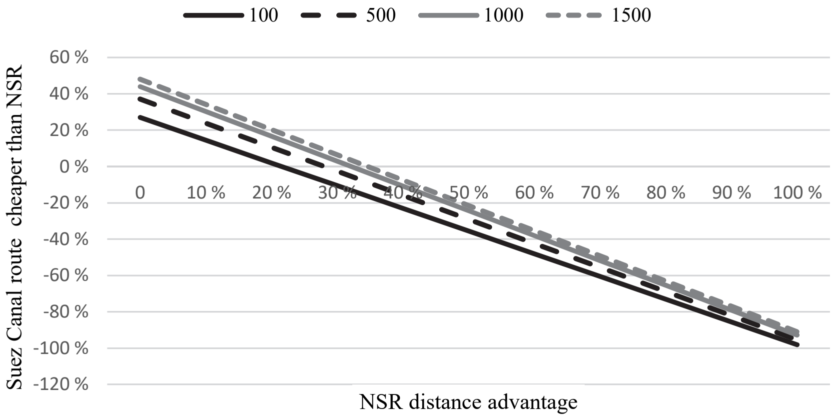
Appendix 31 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



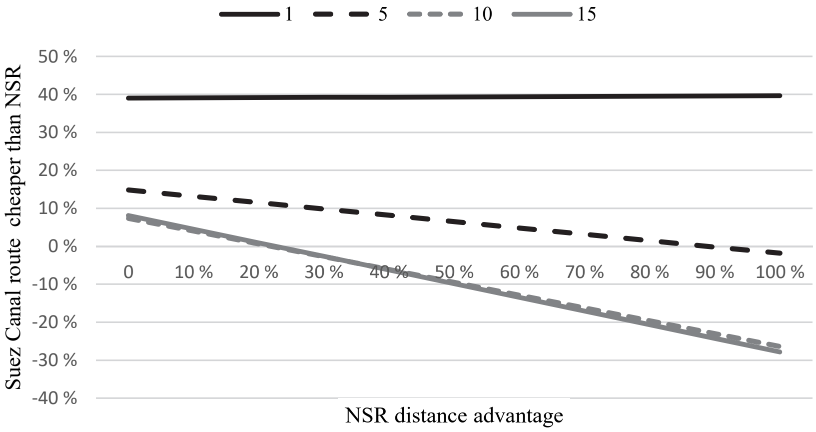
Appendix 32 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



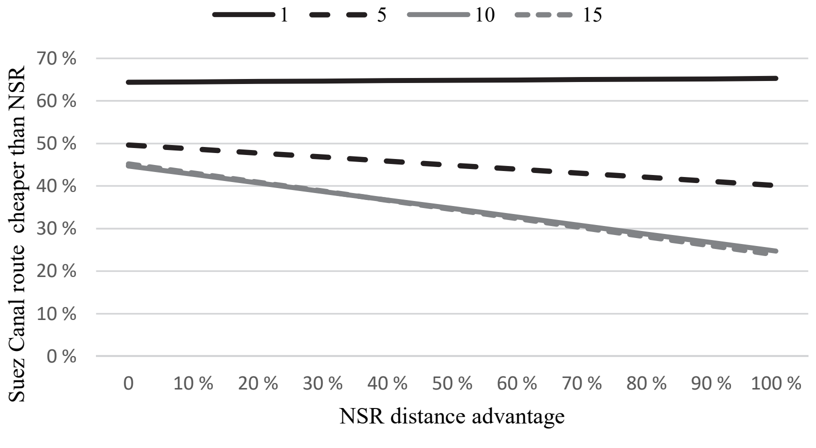
Appendix 33 Impact of various fuel prices (USD/tonne) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)



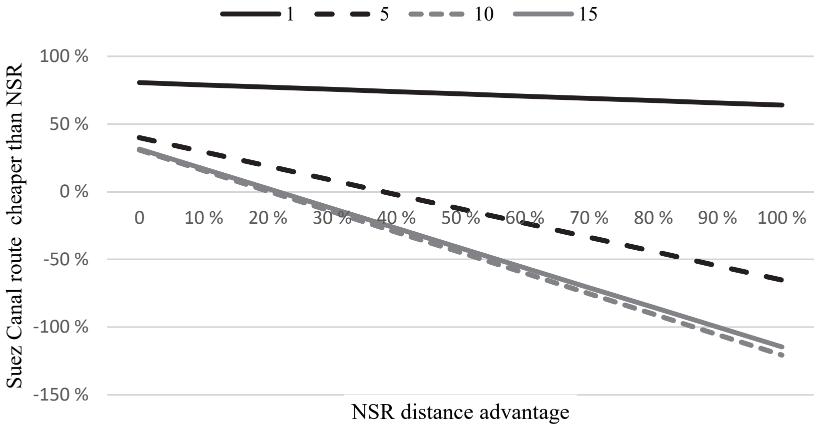
Appendix 34 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



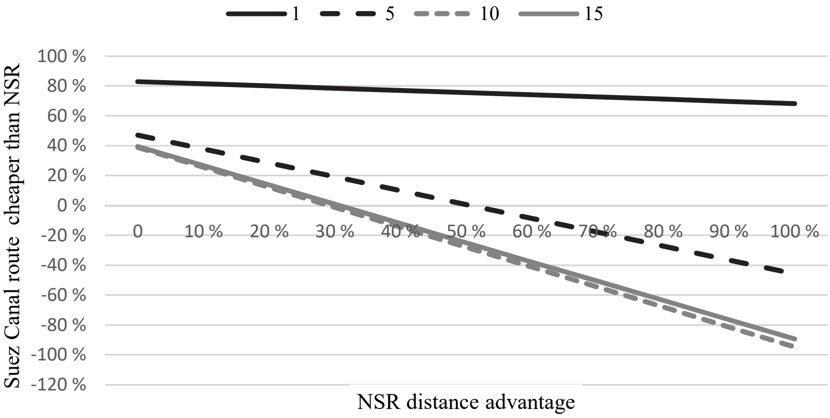
Appendix 35 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



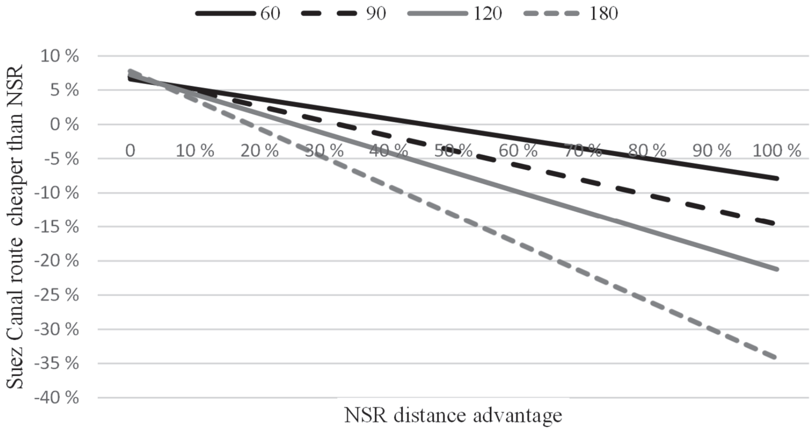
Appendix 36 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



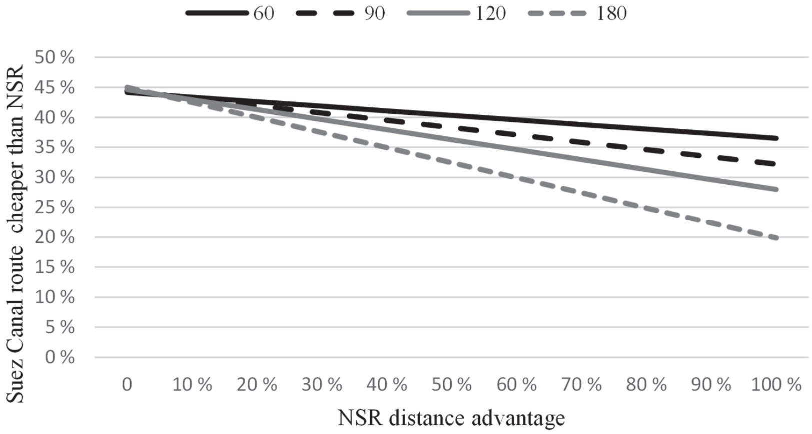
Appendix 37 Impact of NSR sailing speeds (knots) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)



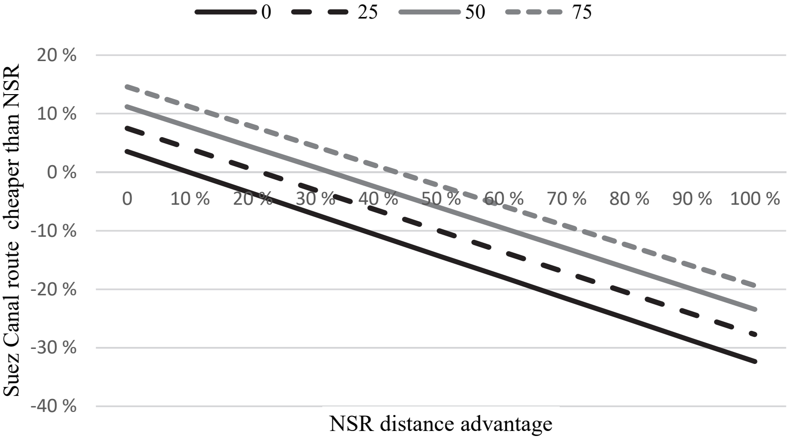
Appendix 38 Impact of NSR navigational season length (days) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



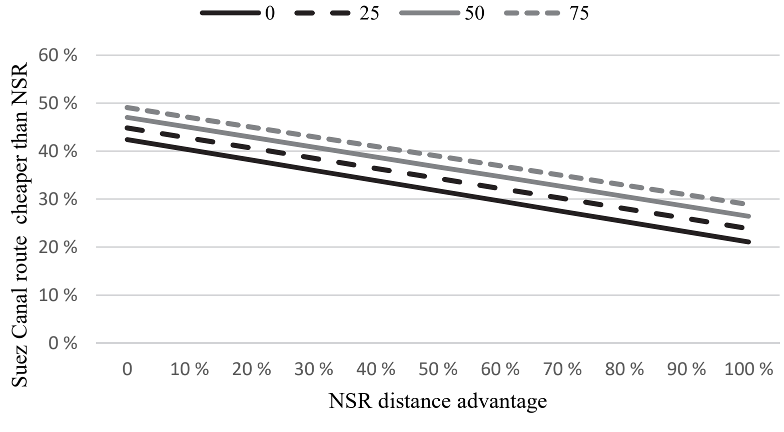
Appendix 39 Impact of NSR navigational season length (days) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



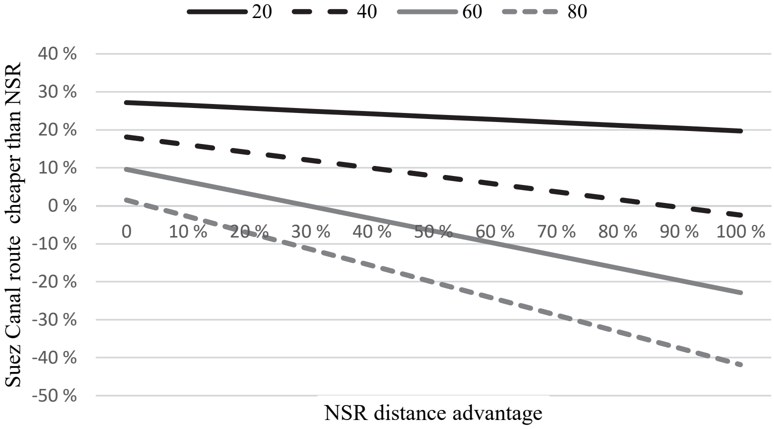
Appendix 40 Impact of ice-class building cost differential (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



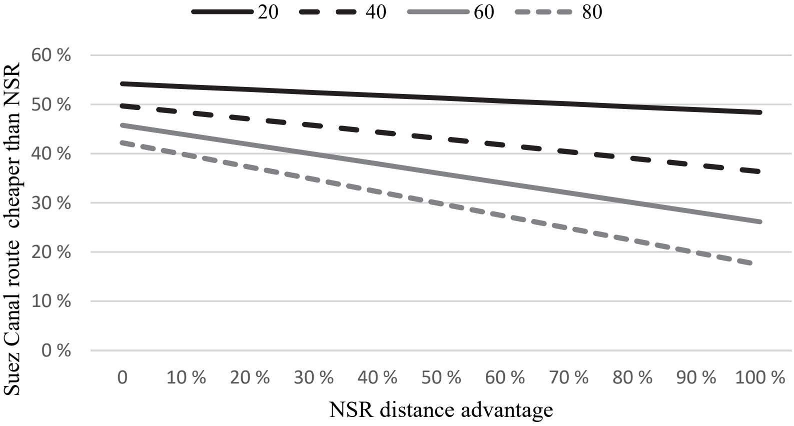
Appendix 41 Impact of ice-class building cost differential (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



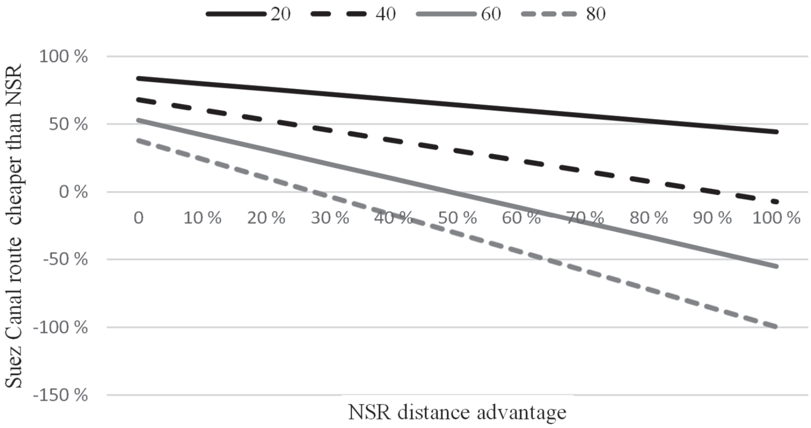
Appendix 42 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



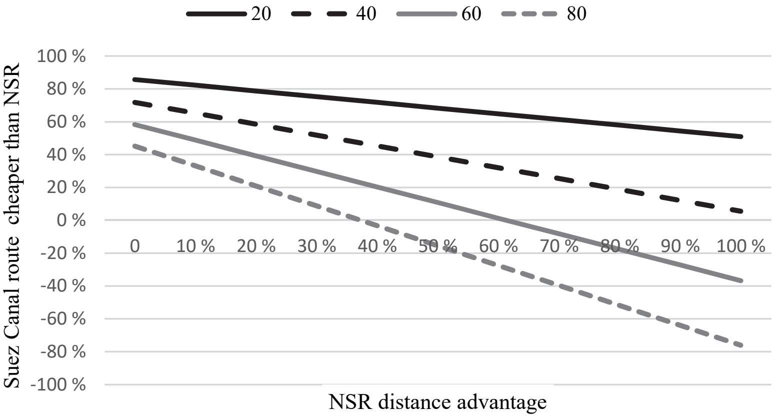
Appendix 43 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



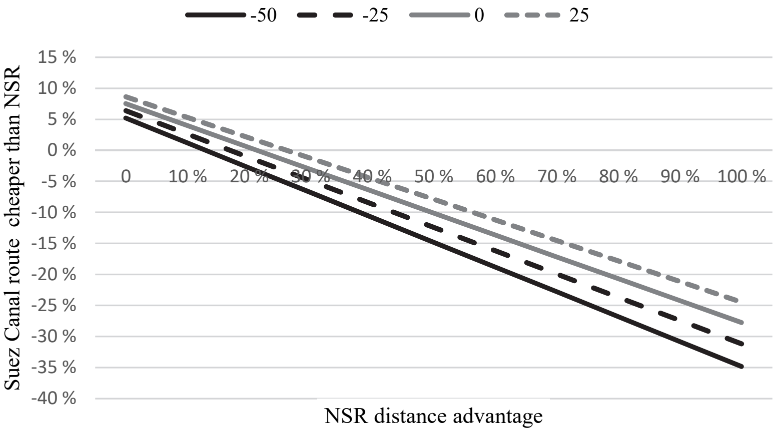
Appendix 44 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



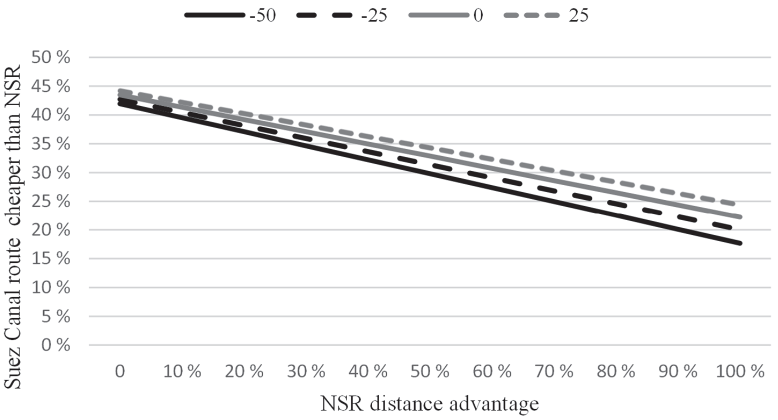
Appendix 45 Impact of NSR load factors (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)



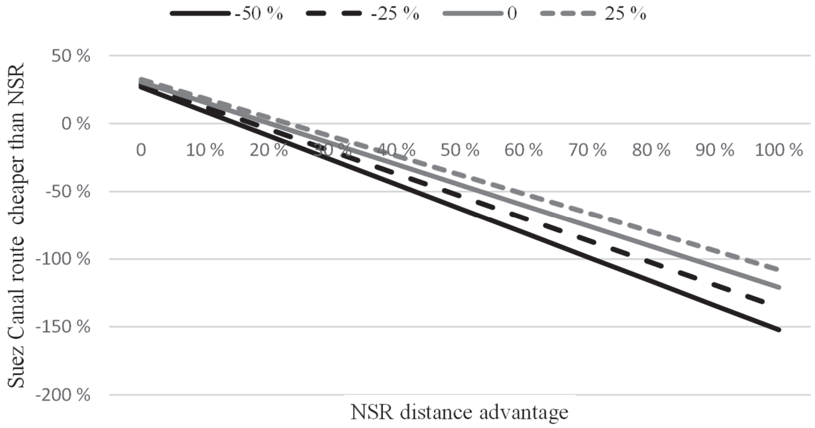
Appendix 46 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



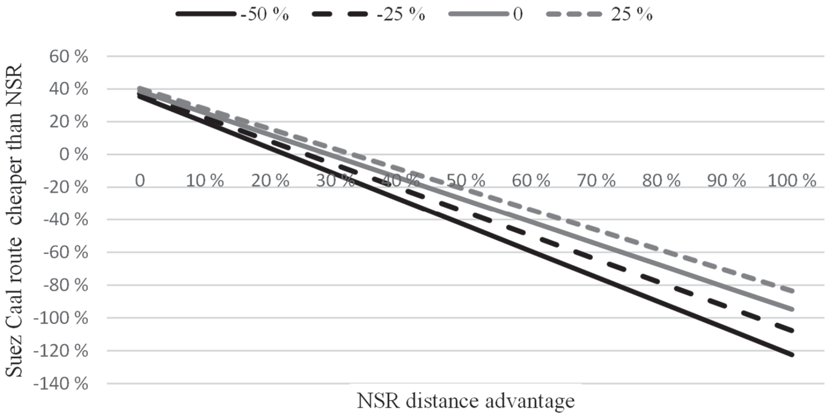
Appendix 47 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



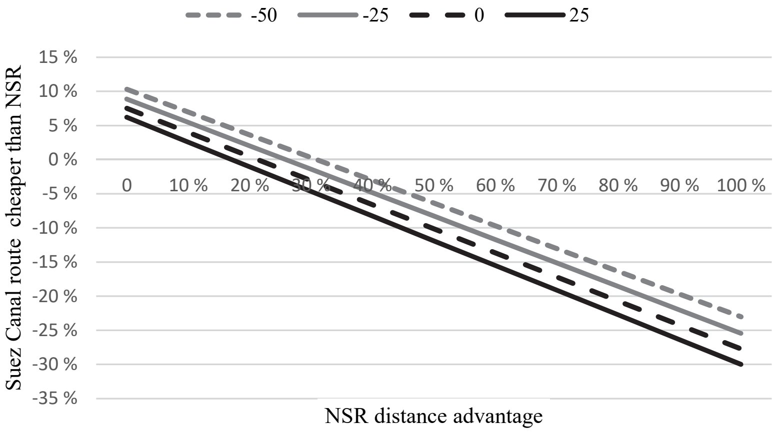
Appendix 48 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



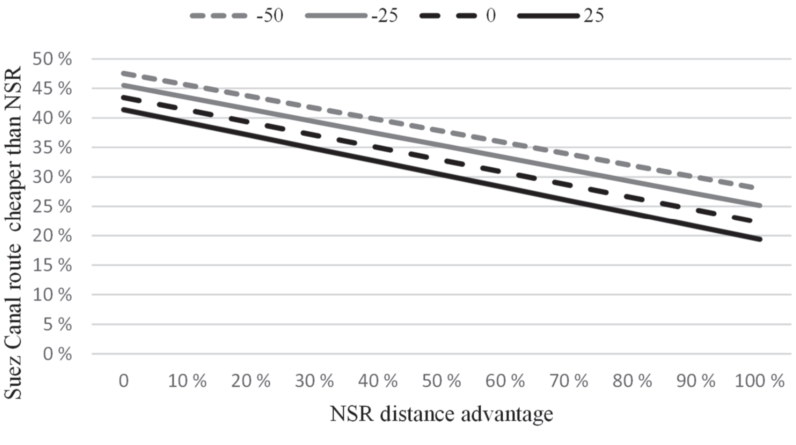
Appendix 49 Impact of icebreaking fee changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)



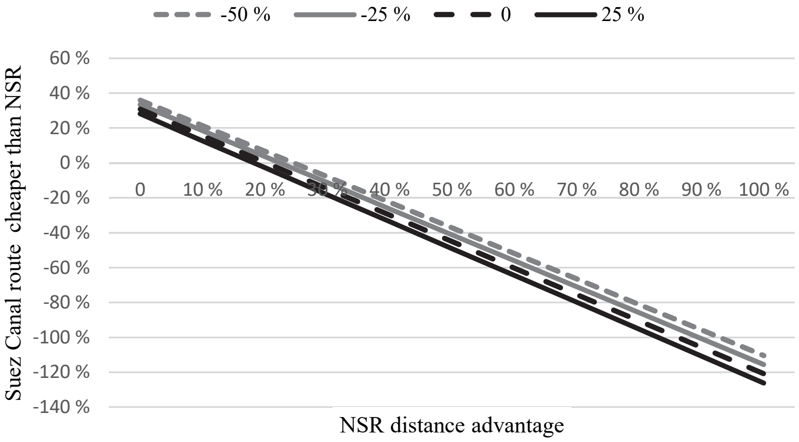
Appendix 50 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and in the SCR (High scenario)



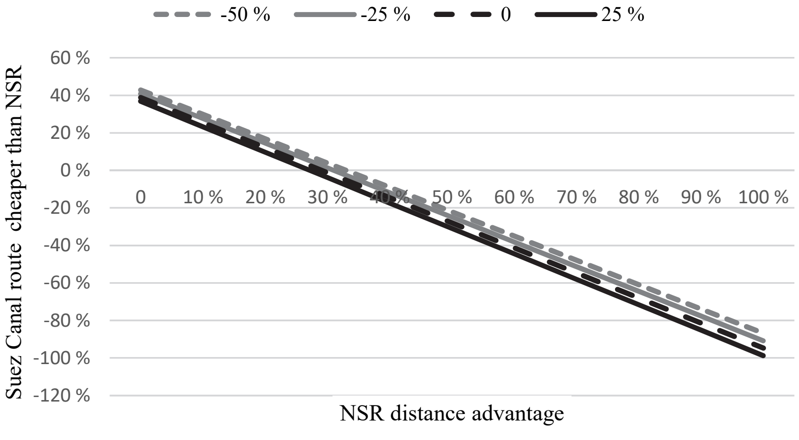
Appendix 51 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in containerships with capacity of 4,000 TEU deployed in the NSR and 18,000 TEU in the SCR (High scenario)



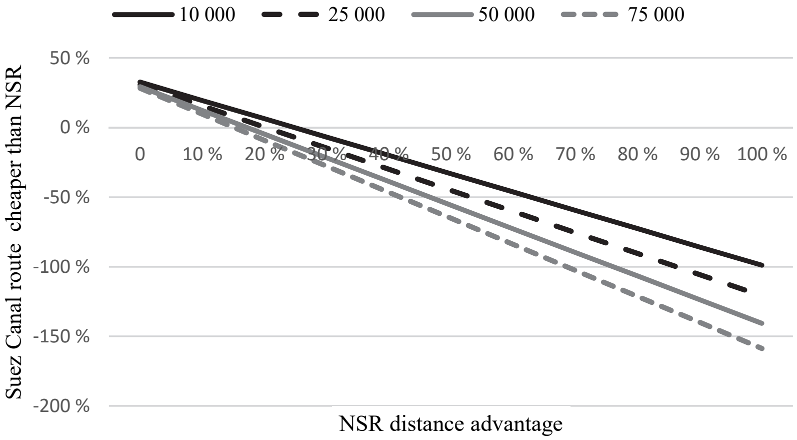
Appendix 52 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



Appendix 53 Impact of Suez Canal toll changes (per cent) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)



Appendix 54 Impact of various time-charter rate levels (USD per day) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and in the SCR (High scenario)



Appendix 55 Impact of various time-charter rate levels (USD per day) on NSR's required distance advantage relative to the SCR in dry bulkers with capacity of 75,000 DWT deployed in the NSR and 150,000 DWT in the SCR (High scenario)