FINANCIAL COST-BENEFIT ANALYSIS

Of Maritime Transport Through the Northern Sea Route

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Abstract

With the ever increasing warming of the Arctic, new attention to the Northern Sea Route has emerged creating the need for research into the feasibility of transporting goods through the Arctic Ocean. Transporting goods between Rotterdam and Yokohama using The Northern Sea Route as an alternative to the Suez Canal Route reduces travel distance and fuel expenses but requires the ship to have icebreaking capabilities.

This paper aims to examine when the investment in an ice-strengthened containership, using the Northern Sea Route when navigation in the Arctic is possible, and the Suez Canal Route when not, is an advantage to the investment in an ordinary containership of the same size, using only the Suez Canal Route. Several factors are taken into account, including variable and fixed operation costs, freight rates consumer demand. Due to the general uncertainty of the future impact of global warming on the sea-ice in the Artic Sea, three different navigation day scenarios are examined along with two versions of the Northern Sea Route.

A comparative analysis is conducted for each of the six scenarios using Monte Carlo simulation given the general uncertainty of future prices and navigation conditions. An additional comparative analysis is conducted, based on the same six scenarios but with the routes extended to the East Asian port cities of Busan, Shanghai, Qingdao and Tianjin.

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Introduction

The Arctic Ocean is melting at an alarming pace (Gupta, 2009) and the six years with the lowest observed summer sea ice extent have all occurred within the last decade (Smith & Stephenson, 2013). New forecast models are continuously bringing forward expectations of ice-free summers in the Arctic (Flake, 2013) creating a huge potential for shipping and resource extraction.

Due to these climatic changes, the reduction of the ice cover has made the Northern Sea Route (henceforth: NSR) more navigable (Kronbak & Liu, 2010), thus creating an alternative to the Suez Canal Route (henceforth: SCR) for seaborne trade between Europe and Asia. With close to three quarters of the world trade conducted through shipping (Khanna, 2008, p. 244), the increased availability of the NSR may affect 20-25 percent of ocean going container tonnage (Laulajainen, 2009). The prospect of using the NSR as an international transit lane for the shipment of goods is not, however, without problems. The volatility of the weather and ice cover in the Arctic creates a hazardous environment for maritime transport while the rights of navigation has yet to be determined politically by the Arctic Nation States. In addition navigating the NSR requires the vessel to be ice-strengthened increasing both the new building price and fuel consumption. Therefore, more research is needed in order to lay the ground for the investment in a new class of ice-reinforced transport ships.

Research question: *By performing a financial cost-benefit analysis on the economic feasibility of transporting containerized goods between Europe and Asia through the arctic sea, this master thesis will explore the economics possibilities and problems arising from utilizing such an alternative to the Suez Canal route. As an extension to the cost-benefit analysis, Monte Carlo simulations will be performed on several of the variables in order to include the general uncertainty of maritime transport in the arctic sea.*

This paper is divided into eight parts. The first part provides a general introduction of the NSR along with the environmental and juridical challenges arising from the rapid melting of the Arctic ice cover. The second part reviews the most relevant economic theories used for the calculations of the investment analysis. The third part contains the case study and defines the variables as well as explaining the general framework behind the conclusions drawn in this paper. The fourth and fifth parts combine the cost variables of part three and define the revenue, thus setting the framework for the calculations of part six. In the sixth part, the financial cost-benefit analysis is performed by estimating the year in which an investment in an ice-strengthened containership is favorable to an investment in an ordinary vessel using only the SCR, for the route between Rotterdam and Yokohama and given the variables and assumptions of the paper. Part seven examines the critical values of the NSR transit fee, that allows for the utilization of the NSR at present time while the eighth and last part extends the analysis of part six to cover a wider range of East Asian harbors.

Literature Review

Laulajainen (2009) reviews the potential of using the Arctic Sea as an international shipping lane incorporating several factors such as the physical setting, route options and the political issues of the sovereignty of the passageways in the Arctic Ocean. He concludes that a reduced ice cover in the Arctic presents several opportunities of resource extraction and reduced transport times but argues that ship owners and ship builders may face managerial problems with diminishing route distances.

Kronbak and Liu (2010) analyze the yearly costs of operating a 4300 twenty-foot equivalent unit (TEU) ice classed container ship between Rotterdam and Yokohama using a combination of the NSR and the SCR. The analysis uses three reduced levels of the highest official icebreaker fee set by the Northern Sea Route Administration under three levels of bunker fuel price. The authors compare these nine scenarios with an ordinary SCR containership by calculating the yearly profit for both types of vessels given an NSR service period of 90 days, 180 days and 270 days, respectively. By combining the various scenarios of the analysis, three main conclusions are drawn. Firstly, a reduction in the icebreaker fee of 50 percent causes the NSR to be unprofitable compared to the SCR for all fuel price and navigation day scenarios. Secondly, a reduction in the icebreaker fee of 85 percent and a bunker fuel price of 700 and 900 USD per ton cause the NSR to become advantageous when the NSR is open for more than 91 days. Lastly, if the icebreaker escort is free of charge the NSR yields a higher profit for all bunker fuel prices and all navigation day scenarios.

Similar to Kronbak and Liu (2010), Furuichi and Otsuka (2013) analyze the yearly costs (measured as yearly costs per TEU) of an ice-classed containership using a combination of the NSR and the SCR between North West Europe and East Asia. They use a 4000 TEU vessel and compare

the costs to ordinary SCR vessels with a container capacity of 4000, 6000, 8000 and 15,000 TEU. Unlike in the article by Kronbak and Liu (2010), an icebreaker fee based on recent transactions of five USD per gross ton is used, causing the NSR to be competitive to the SCR.
Furuichi and Otsuka find that an amount of five NSR trips per year (with eight SCR trips when the NSR is closed) makes the 4000 TEU ice-strengthened vessel advantageous to a 6000 TEU ordinary vessel for all levels of bunker fuel price examined. Additionally, the results suggest that a price of a ton of bunker fuel of 300 USD and 650 USD causes the NSR to be compatible to an 8000 TEU ordinary vessel.

Verny and Grigentin (2009) analyze the costs of transporting goods between Hamburg and Shanghai via the NSR using a 4000 TEU containership and compare it to transport using the SCR, the Trans-Siberian Railway and by air freight. They find that the costs per TEU are almost twice as high as that of the SCR vessel and significantly higher than transport by rail through Siberia. Furuichi and Otsuka (2013) note that the vessel purchase price of 180 million USD used by Verny and Grigentin exceeds the general new building price level of a containership and is the reason for the high costs of the NSR vessel presented in the paper.

Somanathan, Flynn and Szymanski (2008) simulate the transit of an ice-class ship from St. Johns, Newfoundland and New York to the port of Yokohama using the North West Passage in the Canadian Artic. This is done by dividing the Canadian Arctic into several segments with a stochastically generated level of ice conditions in each segment. From the simulations, they find that the route from St. Johns to Yokohama has a lower required freight rate relative to the Panama Canal Route although with a small margin. The authors conclude that further thinning of the ice cover on the North West Passage will reduce the costs relative to the Panama Canal Route and thereby make transit between New York and Yokohama via the Arctic economically feasible.

Part I: New Opportunities, New Challenges

1.1: The Northern Sea Route

The NSR is by Russian law defined as the shipping lane from the Barents Sea to the Behring Strait through the Arctic Sea (Arctic Council, 2009, p. 23). The NSR is not a specific route but a multitude of passageways along the Arctic Sea (Kronbak & Liu, 2010, p. 435). With shifting ice conditions, severe weather patterns in the winter and vast distances to nearby emergency responds, in the case of accidents, sailing on the NSR makes a challenging voyage. The Arctic Ocean between the Northern Russian coast along the Siberia and the Arctic Ocean Basin is generally quite shallow and further adds difficulty and draft restrictions to the voyage. The NSR along the Russian North coast is divided into five Seas: The Barents Sea, the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea (ibid.). Figure 2 shows a map of the five Russian Arctic Seas along with a few NSR shipping lanes.

Figure 1: The Russian Arctic and the Northern Sea Routes
Source: Arctic Econ (2012)

Along the Russian coast, the Barents Sea is generally quite shallow with depths averaging between 10 and 100 meters. The Barents Sea is the only one of the Arctic Seas that are not totally covered in ice during winter and is generally sheltered from severe ice conditions due to Islands around the

Barents Sea perimeter (Mulherin, Sodhi, & Smallidge, 1994, p. 17). The Southern route from the Barents Sea to the Kara Sea requires the crossing of the Kara Gate, which is the main shipping route south of Novaya Zemlya and with an established traffic scheme and a minimum depth of 21 meters (Arctic Council, 2009, p. 23). The average depth of the Kara Sea is 90 meters but ice and climate conditions are more severe. Due to lying between the islands of Novaya Zemlya to the west and Severnaya Zemlya to the east, the Kara Sea mostly receives cold water and ice from the Arctic Sea in the north (Mulherin, et al., 1994, p. 18). The Vilkitskiy Strait south of the Severnaya Zemlya islands that separates the Kara Sea and the Laptev Sea is quite deep, not restricting draft but is covered in ice most of the year requiring icebreaker assistance (Arctic Council, 2009). The southern part of the Laptev Sea has a depth of less than 100 meters and the eastern part of the Sea around the New Siberian Islands is even shallower. The Laptev Sea experiences less summer ice than the Kara Sea due to the warm water influx of several of the rivers running into the ocean but winter ice cover is severe, with first year ice reaching up to two and a half meter in thickness (Mulherin, et al., 1994, p. 18). The Sannikov Strait, from the Laptev to the East Siberian Sea, causes the major draft restrictions on the NSR along the Russian coast with a maximum depth of 13 meters, challenging the navigation of the ships crossing into the East Siberian Sea. The East Siberian Sea averages a depth of 58 meters and is the shallowest of the five Seas traversing the NSR. In addition to being the shallowest, the East Siberian Sea faces the most severe ice conditions and ocean currents resulting in an influx of drifting ice, causing parts of the ice cover to persist through the summer months (ibid., p. 19). The Long Strait south of Wrangel Island links the East Siberian Sea to the Chukchi Sea while routes north of the island are in open waters. The Long strait spans 120 nautical miles, has a depth of minimum 20 meters, and leads into the Chukchi Sea with an average depth of 88 meters.

Summer Ice conditions in the Chukchi Sea resemble those in the Barents Sea due to the influx of warmer waters from the Pacific Ocean through the Behring Strait but faces more severe ice conditions in the winter (ibid.).

1.2: A Brief History of the Northern Sea Route

The following is a brief review of the history of the NSR, for a more in depth review see Arctic Council (2009). The diplomat Gerasimov was the first Russian to officially mention the idea of an

NSR connection between the Atlantic and the Pacific Ocean, in 1525, even though Russian settlers had been exploring the Arctic Seas as early as the start of the millennium. In a grand expedition in 1648, Semyon Dezhnev crossed the Behring Strait from the Pacific with seven ships but after heavy losses eventually sailed into the Anadyr River in the Chukchi Peninsula, concluding that no such North East Passage existed. From 1725 to 1742, the Great Northern expeditions were launched to map the areas north of the Pacific Ocean. The Danish Sailor Vitus Behring led the expeditions to the Behring Strait where he discovered Alaska and The Aleutians until his death on Behring Island in 1741. A complete passage of the NSR was not achieved before 1878, when Swedish-Finnish Baron Adolf Erik Nordenskjöld, after a winter spent locked in ice in the Behring strait, crossed through to Europe the following summer. Following the success of Nordenskjöld, several eastbound transits of the NSR were achieved, and in 1934, the Russian Glavnoye Upravleniye Severnogo Morskogo Puti in the icebreaker, Fedor Litke, accomplished the first one-season transit. After the Russian October Revolution in 1917, the Soviet Union started using the NSR as an internal transport route for goods, restricting foreign access, except during the Second World War, when Britain and America aided the Soviet Union by shipping supplies to Soviet harbors. From 1932 to its fall, the Soviet Union kept developing infrastructure and transport on the NSR resulting in regular summer and autumn shipping being possible. In 1959, the world’s first nuclear icebreaker was launched, expanding the possibility of navigation in the region and achieving all-year shipping on the western part of the NSR from the port cities Murmansk to Dudinka. The cargo flows on the NSR kept increasing throughout the years of the Soviet Union, from 300,000 tons annually before The Second World War to 6.6 million tons annually in the mid-eighties. After the fall of the Soviet Union, the NSR was

Year:	1945	1960	1970	1980	1987	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Volume:	0,44	0,96	2,98	4,95	6,58	5,51	4,80	3,91	2,97	2,30	2,36	1,64	1,95	1,46	1,58

Figure 2: Total cargo volumes transported along the NSR (1945-1999)

Measured in megaton. Source: Ragner (2000)

officially made accessible by foreign shipping creating the Northern Sea Route Administration and started leasing the nuclear icebreaker service to foreigners. Even though the NSR was commercialized, the flows of cargo dropped significantly in the years of the newly established Russian Republic (see figure 2) due to the decline in population and economic activity (Kronbak & Liu, 2010, p. 438). Recently, shipping has once again emerged in the Arctic, and in September 2013, the Chinese vessel Yong Sheng was the first containership in history to transit the NSR (Staalesen, 2013). The Yong Sheng was one of the 71 large ships navigating the NSR in 2013, and the Russian authorities expect this number to increase 30-fold by 2020 (Vidal, 2014).

1.3: Geopolitics

With global warming increasingly changing the landscape of the Arctic Ocean, the need for clearly defined boundaries and navigation rights have arisen, previously made obsolete by the ice cover. Therefore, the countries in the Arctic Circle, Denmark, Canada, Norway, the United States and Russia, have started laying claims of sovereignty on parts of the Arctic Ocean sparking huge attention by the international community (Gupta, 2009, pp. 174-175). The planting of a Russian Flag on the seabed of the North Pole in 2007 and the Russian air force performing strategic bombing runs over the Arctic have caused several scholars and media commentators to warn of a risk of military conflict over the disputed segments of the Arctic Ocean (Flake, 2013, p. 146). Despite the military buildups in the Arctic, the five Arctic countries signed the Ilulissat declaration in 2008 stating that the overlapping claims and navigation rights will be resolved by diplomacy in accordance with the United Nations Convention on the Law of the Sea of 1982 (UNCLOS), article 234 (Gupta, 2009, p. 176).

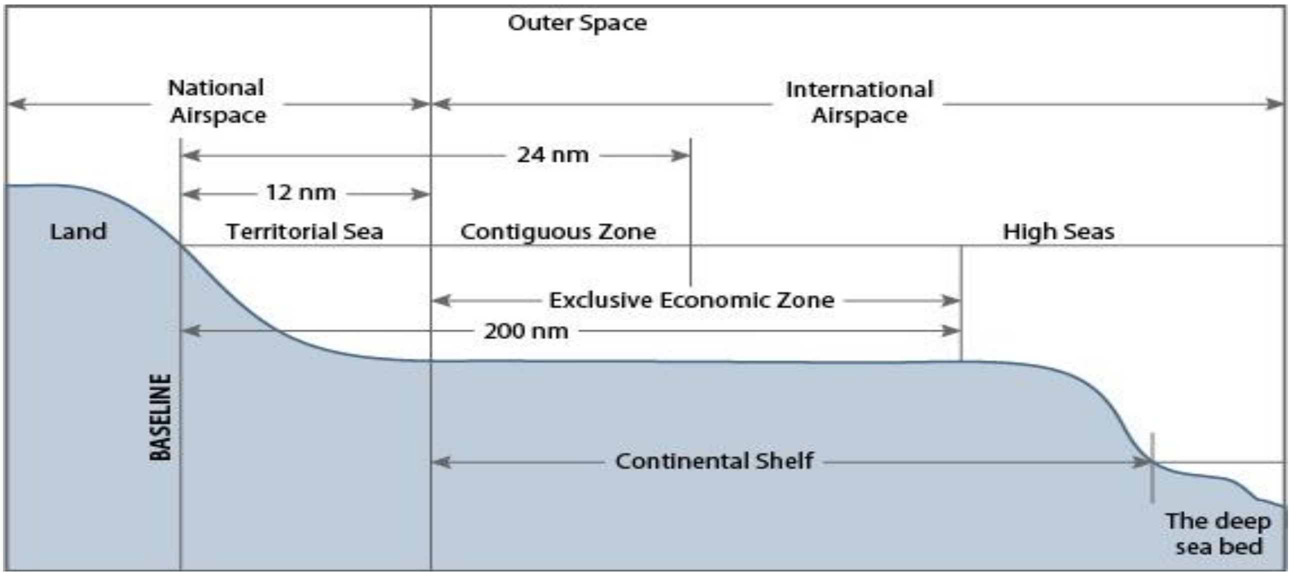

Figure 3: The maritime definitions of the UN Law of the Sea Convention Article 234

Distances measured in nautical miles.

Source: U.S Military (2007)

The UNCLOS sets up the political framework, of which countries have jurisdiction over resource extraction and international shipping in maritime zones divided into internal waters, territorial waters, the exclusive economic zone (henceforth: EEZ) and the high seas (Arctic Council, 2009, pp. 50-52). In addition, coastal states can in some cases claim sovereign rights over resource extraction on continental shelves extending from the EEZ, being the main cause of overlapping claims by the coastal nations (Kullerod, et al., 2013).

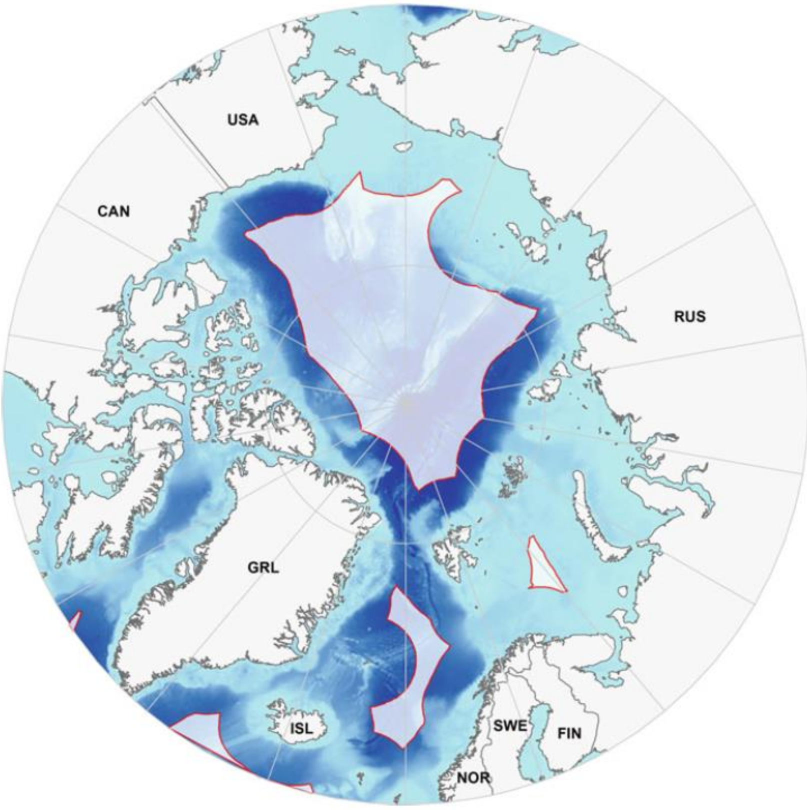

Figure 4: Arctic Ocean territories not included in the EEZ

Source: Kullerod, et al., (2013)

According to the UNCLOS, internal waters are defined as waters in deeply indented coastlines and waters between the coast and near surrounding islands, all part of the same nation, as well as historically recognized internal national waters. The internal waters are a sovereign part of the coastal state, which therefore has the right to exercise full jurisdiction over ships crossing its internal waters. This has major implications for shipping in such waters, and both Canada and Russia are insisting that their Arctic Straits are internal waters to the disagreements of several other countries (Flake, 2013, p. 44). The territorial waters extend from 12 to 24 nautical miles from the coast, and the coastal state has full sovereignty and the right to adopt the domestic laws on foreign ships traversing the territorial waters. Under the UNCLOS, foreign ships have the right of innocent passage, i.e. continuous passage without presenting a security or environmental risk, through the territorial waters.

The EEZ ranges from the territorial waters to 200 nautical miles from the shore giving the coastal nations right over the natural resources, although with a limited power of enforcement on international shipping. In the EEZ, the coastal country has, however, the right to regulate international shipping by enforcing standards to reduce pollution, especially if the zone in question is covered in ice throughout most of the year (Arctic Council, 2009, pp. 51-52). These standards allow the coastal state to enforce strict environmental rules in its EEZ, as stated in Article 234 of the UNCLOS, and *"[...] (t)oday, Russia employs this single UNCLOS provision to effectively control* *all maritime traffic within 200 nautical miles of its Arctic coastline"* (Flake, 2013, p. 45). Since the Russian EEZ covers such a large area, staying away from the zone makes arctic shipping impossible with the current ice cover, effectively forcing shipping to follow rules set by the Russian Northern Sea Route Administration. Flake (2013) projects that even after the melting ice-cover makes article 234 redundant, Russia will persist on controlling maritime traffic in its EEZ. He also projects, however, that despite Russian control over its arctic waters recent doctrines have promoted and welcomed the prospect of the NSR as an international shipping lane as a mean to spur economic growth in Northern Russia. Infrastructure development has already started along the Russian Arctic Coast, and in September 2013, Russian president Vladimir Putin predicted the NSR to rival the Suez Canal and stressed the *"[…] Northern Sea Route as an international transport artery that will rival traditional trade lanes in service fees, security and quality"* (Bryanski, 2013).

1.4: NSR Transit Regulations

The newly created Russian Federal State institution, The Northern Sea Route Administration (henceforth: NSRA), administers the organization of navigation along the NSR. According to the NSRA, the main goals of the institution are to ensure safe navigation and protection of the marine environment in the area around the NSR.

The following is a simplified extract of the NSRA regulations related to Arctic shipping along the NSR:

- The vessel operating on the NSR must have an ice-strengthened hull sufficient for the ice conditions along the route.
- Applications for a permit to enter the NSR shall be submitted a maximum of 15 days before entering NSR.
- The vessel is only allowed to stay on the NSR for the duration of the permit.
- The NSRA dictates the necessities of using icebreakers depending of the ice conditions on the NSR.
- An ice pilot is to be present on the vessel unless an equally experienced navigator is already present on the ship.
- The icebreaker fee depends on the ship size and load, and it is, along with the ice pilot fee, determined by the Russian Federation.

- Storage tanks for the collection of waste are to be present on the ship, and the discharge of oil residuals into the ocean is prohibited.
- Along the NSR, short and long run ice and weather forecasts are provided by the NSRA.

(The Northern Sea Route Administration, 2013)

1.5: Climate Change and Ice Cover

Few places on planet earth are affected by global warming at the magnitude of the Arctic. Temperatures in the Arctic have risen by four degrees in the last fifty years (ACIA, 2004, p. 23). Consequently, the Arctic mean temperature increase is projected to rise by five to seven degrees by the end of the century, which is twice that of the global mean temperature increase projected in the same period (Solomon, et al., 2007, pp. 904-908). Because of the global warming, the ice cover on the Arctic Ocean is ever retreating north and further away from the Russian northern coast, and in 2008, for the first time in recorded history, the NSR along the Russian northern coast was completely ice-free (Ho, 2010, p. 714). Between 1979 and 2001, the September ice cover saw a reduction of 6.5 percent per decade, increasing to 8.5 percent by 2005, 10.2 percent by 2007 and a further increase to a 12 percent reduction per decade up to September 2011 (Maslowski, et al., 2012, p. 629). This could indicate an increase in the rate of reduction of the Arctic ice cover, and Rodrigues (2008, p. 124) notes that the decline in Arctic sea-ice between 2001 and 2006 has reached the highest points since 1979 when recordings began. The increased absorption of sun radiation by the darker water surface and subsequent increased warming of the ocean can explain one of the factors influencing the increasing rate of melting in the Arctic Ocean. The result is a further increase in ice melting called the positive feedback phenomenon (Walsh, 2013, p. 172). The winter ice cover has experienced a significantly lesser reduction than observed during the summer months, and observations of the March ice cover show only a three percent reduction per decade (Laulajainen, 2009, p. 56), with winter ice cover not projected to disappear during the next century (Arctic Council, 2009, p. 25).

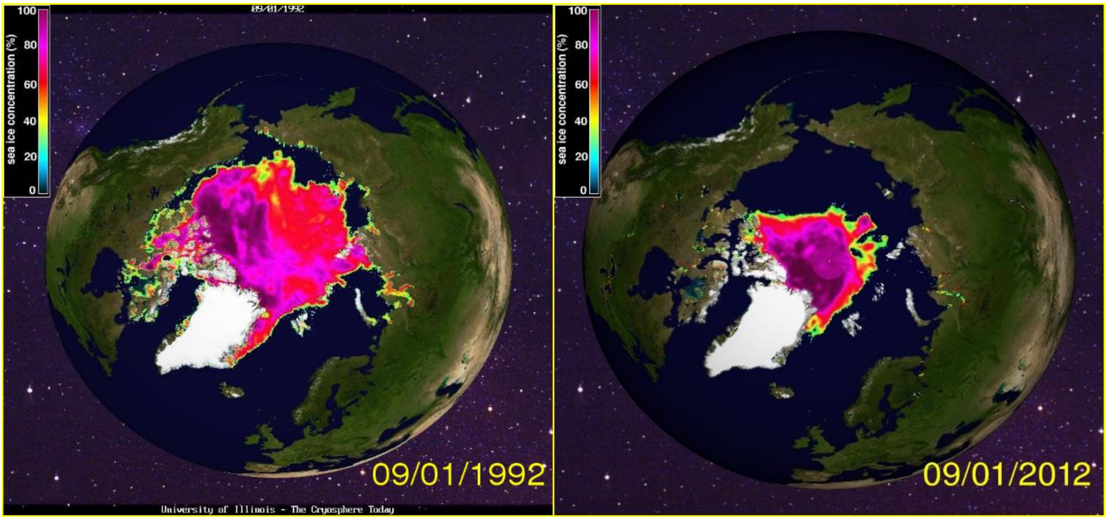

Figure 5: September ice concentration in the Arctic Ocean

Darker colors indicate larger sea ice concentrations with left (1992) and right (2012)

Source: University of Illinois (2014)

Figure 5 shows the September sea ice extent (yearly lowest ice cover) in 1992 and 2012. The difference in September sea ice extent in the 20 years between 1992 and 2012 is clearly significant with the northern sea route being completely ice free in the summer of 2012. The March ice cover difference during the same period presented in figure 6 shows that, despite the rapidly melting Arctic, ice still covers the majority of the ocean during the winter months.

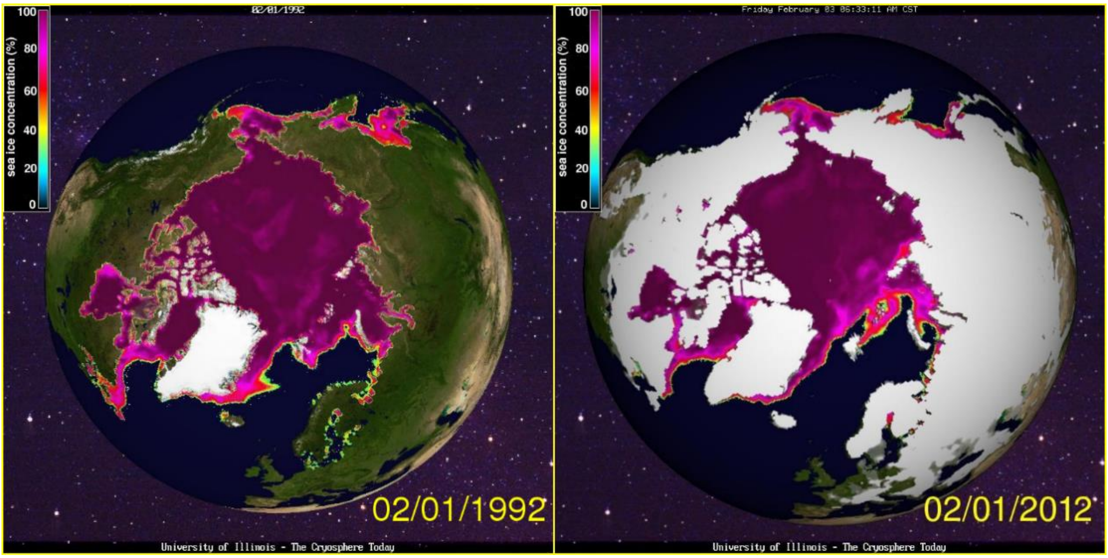

Figure 6: March ice concentration in the Arctic Ocean

Darker colors indicate larger sea ice concentrations with left (1992) and right (2012)

Source: University of Illinois (2014)

The future pace, at which the ice cover in the Arctic Ocean is melting, is subject to debate, and the global circulation models used to forecast the future ice cover are constantly being updated. Based on several global climate models, the Arctic Climate Impact Assessment (henceforth: ACIA) (2004, p. 83) projects a continuous decline in sea ice cover with ice-free September months within this century. The ACIA also projects the number of navigable days along the NSR, estimating a total of up to 150 days of possible navigation along the NSR in 2080 from an amount of 80 days in 2010.

The International Panel on Climate Change, using the AR4 GCM criticized by Wang & Overland (2013, p. 2097) and the Arctic Council (2009, p. 30) for being far too conservative, projects a more rapidly melting ice cover compared to the ACIA forecasts, with an almost ice free Arctic Ocean as soon as September 2050. Since a completely ice free Ocean on the northern hemisphere is not achievable due to ice formations between the northern part of Greenland and the Canadian Archipelago, most sources define an ice free Arctic Ocean as an ice-cover below one million square kilometers (Wang & Overland, 2013, p. 2097). An almost ice-free ocean by 2040 will have significant implications on the possibility of sailing along the NSR. The strongest, and most hazardous, form of ice cover is the ice that is formed over several years, turning into hardened ice, effectively negating the possibility of traversing the ice cover for even the strongest icebreakers (Arctic Council, 2009, p. 22). If an ice-free ocean were to occur just once a year, it would result in only first year ice to be generated through the colder months, effectively removing the risk of encountering the hard multiyear ice. First year ice does not generally reach above two meters in thickness and rarely damages ice-strengthened vessels traversing the Arctic Sea, even though caution and expertise is needed in order to secure a safe voyage (ibid.).

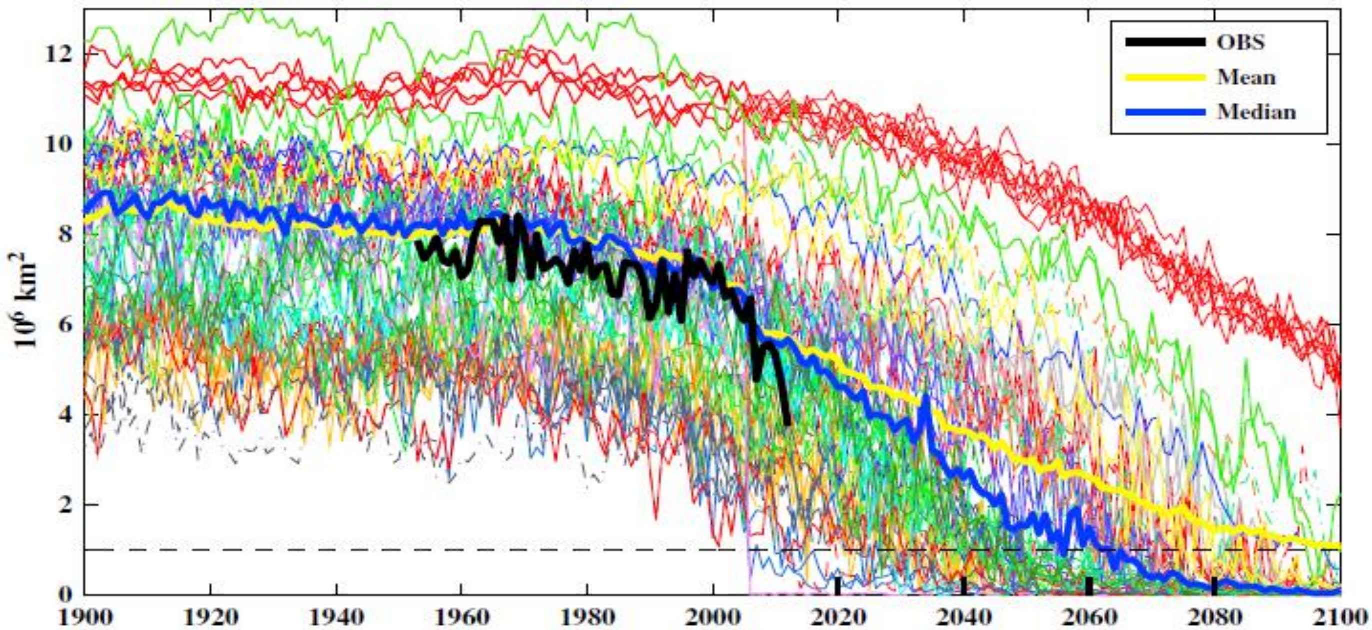

Figure 7: Observed and projected September sea ice extent

The observed sea ice extent is compared with 36 GCM's from Coupled Model Intercomparison Project 5. The yellow and blue lines shows the mean and median projected ice cover extend of the various GCM's respectively in million square miles while the black line shows the observed ice cover extent. Source: Wang & Overland (2013)

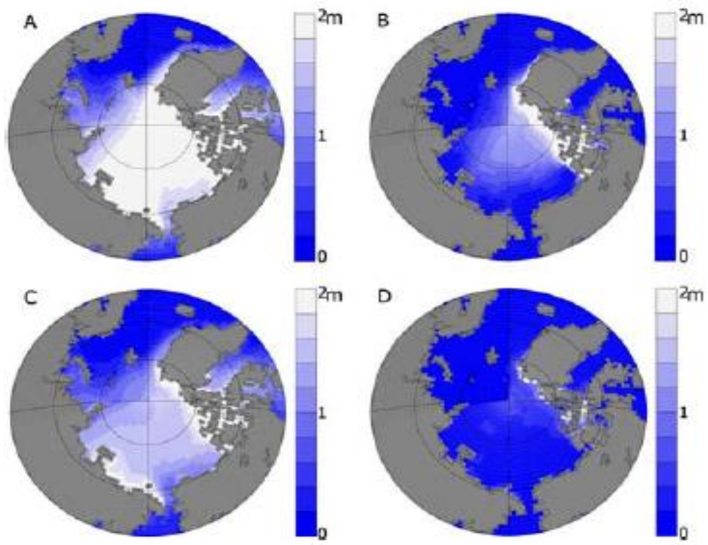

Figure 8: Projected mean sea ice thickness
Projections for March (left) and September (right) are aggregated from six climate models. A and B are from a September ice cover extent of 4.6 million square kilometers (reached in 2007) while C and D show the same, given a year with an ice-free September. Source: Wang & Overland (2009)

Wang and Overland (2009) use existing GCM's to estimate the number of years it takes to reach a September ice free Arctic Ocean from a base September ice extent of 4.6 million square kilometers and note that such an extent was reached in 2007, which is 30 years ahead of the projections done by the IPPC. This results in a projection of an ice-free Arctic Ocean in September 2028 with a winter ice thickness of less than two meters (figure 8).

In a recent study, Maslowski, et al. (2012) argue that the September volume of Arctic sea ice correlates with the ice cover extent and follows a negative trend of $-1.120 km^3 \cdot year^{-1}$ with a standard deviation of $2.235 km^3 \cdot year^{-1}$ using ice volume data starting in the mid-nineties. Given current data Maslowski, et al. (2012) calculate that a nearly ice-free Arctic Ocean can be reached already by 2016.

Using recently updated climate models Smith and Stephenson (2013) simulate the optimal sailing routes for polar class 6 ice reinforced vessels (PC6 see part 3.2) and non-ice-reinforced vessels over the arctic Sea from the projected sea-ice cover during the years from 2040 to 2059. They end up concluding that as early as between 2040 and 2059, a PC6 vessel can use the direct route across the North Pole, and a non-ice-reinforced vessel will be able to use the NSR along the Russian coast, both without the need for icebreaker Assistance (figure 9). The possibility of utilizing the most direct route in the Arctic Sea by sailing directly over the North Pole would not only shorten the travel distance by a significant margin but also keep the vessel well away from the Russian EEZ and therefore transit fees.

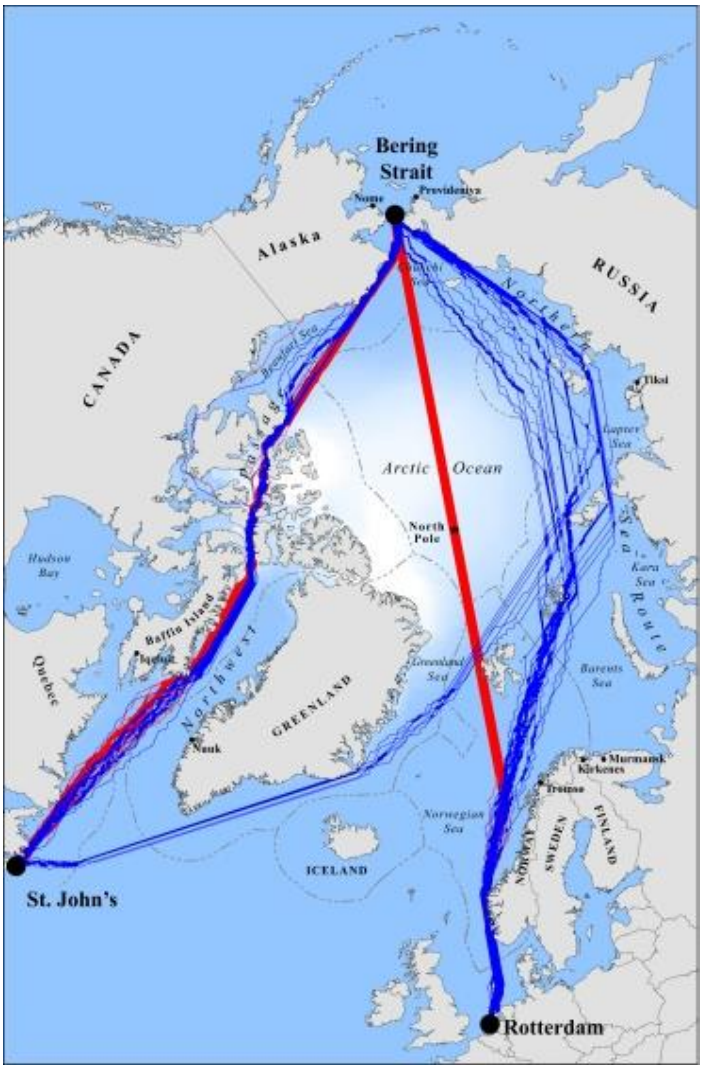

Figure 9: Projected fastest shipping lanes
The fastest possible shipping lanes between the Atlantic to the Pacific Ocean during September, from 2040 to 2059 based on the findings of the Smith & Stephenson (2013) study. Red and blue lines indicate the fastest routes for PC6 and non-ice reinforced vessels respectively.
Source: Smith & Stevenson (2013)

1.6: Environmental Concerns

When activists of the Green Peace Organization boarded the Russian Oil Drilling platform Prirazlomnaya on the 18th of September, 2013, it was to prevent the drilling of oil in the Arctic Ocean in order to preserve the fragile ecosystem (BBC News, 2013; NBC News, 2013). The Arctic Ocean and its surroundings are a pristine and fragile environment that are, so far, mostly left untouched by human interference. With a rapid melting of the Arctic ice cover, the possibilities of shipping and extraction of resources on the seabed are becoming possible, which poses a threat to the abundant wildlife living in the Arctic (ACIA, 2004, p. 84). The Arctic is a rich migration corridor for various bird species while the Arctic Ocean is teeming with abundant fish stocks and mammal life (ibid.).

The threats to the marine life in the Arctic Ocean posed by shipping are numerous and ranging from ships colliding with whales to the introduction of invasive species from the hulls and ballast water of the ships transiting the area (Arctic Council, 2009, pp. 145-150). Major oil pollution has the potential to destroy Arctic environment as seen during the Exxon Valdez oil spill in Prince Williams Sound in Alaska that inflicted major damage to the environment, with an estimated quarter of a million bird deaths. Due to the hostile climate and the lack of infrastructure, cleaning up oil spills poses a challenge, and fourteen years after the Exxon Valdez accident, oil was still found around Price Williams Sound (ACIA, 2004, p. 85). Emissions from the engines of shipping, adversely affecting the environment, include carbon dioxide (CO_2,) Nitrogen oxide (NO_x), Sulphur Oxide (SO_x) and black carbon. While the emission of the above mentioned particles is a product of shipping in all the World's oceans, black carbon darkens the surface of the ice-cover in the Arctic Ocean reducing the amount of sunlight reflected by the ice (Arctic Council, 2009, p. 144). This reduction in the albedo has the potential to speed up the melting of the Arctic ice cover as mentioned in the previous section.

Part II: Economic Theory

2.1: Net Present Value

In the analysis section of this paper, the net present value (henceforth: NPV) method is used to evaluate the financial cost-benefit analysis on the economic feasibility of investing in container ships transporting goods over the NSR as an alternative to the normal SCR. The NPV method is used for evaluating an investment running over several future periods, where these future values of cost and benefits are discounted for the opportunity costs of initiating the investment (see Christensen & Sorensen, 2005, chapter 3). The NPV of an investment, running over a duration of n years and initiated in year zero, is calculated using equation 2.1.1.

$$NPV = \sum_{t=0}^{n} \frac{TR_t - TC_t}{(1+r)^t} \qquad (2.1.1)$$

$TR_t = Total\ revenue\ in\ year\ t$

$C_t = Total\ costs\ in\ year\ t$

$r = Yearly\ depreciation\ rate$

$n = Duration\ of\ the\ invenstment\ in\ years$

The yearly depreciation rate consists of a nominal depreciation rate, as well as a fixed depreciation rate. Because of inflation, the value of 100 US dollars in one year is rarely worth the same as 100 US dollars in the present, and the annual nominal depreciation rate is therefore equal to the annual rate of inflation, denoted as π throughout this paper. The real depreciation rate, and with real meaning discounted for inflation, equals the opportunity cost of initiating the investment, which is denoted by δ. The opportunity cost is defined as the rate of return yielded by investing the capital alternatively. Denoting the yearly depreciation rate as $r = \pi + \delta$ and inserting into equation 2.1.1 yields equation 2.1.2, used in the analysis section of this paper.

$$NPV = \sum_{t=0}^{n} \frac{TR_t - TC_t}{(1+\pi+\delta)^t} \qquad (2.1.2)$$

$\pi = Annual\ rate\ of\ inflation$

$\delta = Discount\ factor\ (real\ depreciation\ rate)$

2.2: Probability Functions

Unlike a frequency distribution, where the vertical axis denotes the frequency of the given value, the probability density function denotes the relative frequency of the given value. By using relative frequency, the probability density function describes the probability, $P(x)$, that a random value from the distribution equals of x (Vose, 1996, p. 13). The definitions of a probability density function are that the total area under the curve equals one and is the derivative of the cumulative distribution function. The cumulative distribution function describes the probability, $P(x)$, that a random value in the distribution is equal to or less than a x.

A wide range of different distributions exists, but throughout this paper, only the normal and uniform distributions are used to explain the probabilistic uncertainty of the variables.

The continuous normal distribution is a bell shaped curve symmetrical about the mean value with tails to each side defined by the standard deviation. The normal distribution is one of the most widely used distributions due to the central limit theorem. It states that conducting a large number of independent samples of a variable causes the results to be normally distributed (ibid., p. 83). The probability density function of a normal distribution as a function of x given the mean μ and standard deviation σ is presented in equation 2.2.1 (Weisstein, 2014).

$$\mathcal{N}(x) = \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{(x-\mu)^2}{2 \cdot \sigma^2}} \qquad (2.2.1)$$

$\mathcal{N}(x) = Normal\ distributed\ probability\ density\ function$

$\sigma = standard\ deviation$

$\mu = mean$

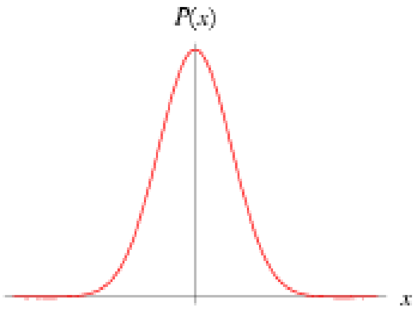

Figure 10: The normal distribution

Source: Weisstein (2014)

The probability, $\mathcal{N}(x)$, that x is less than, or equal to, y in the normally distributed probability density functions, is found by calculating the integral (the cumulative probability function) of the probability density function in the domain of $-\infty$ to y presented by equation 2.2.2.

$$\int_{-\infty}^{y} \mathcal{N}(x)\, dx = \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot \int_{-\infty}^{y} e^{-\frac{(x-\mu)^2}{2 \cdot \sigma^2}} \qquad (2.2.2)$$

The continuous uniform distribution sets an equal probability over a continuous span of two values. The uniform distribution is good for approximations when actual data is scarce but is rarely a good reflection of the actual distribution (Vose, 1996, p. 90). The probability density function and the cumulative probability function for the continuous uniform distribution are presented in equation 2.2.3 and 2.2.4 respectively (Weisstein, 2014).

$$u(x) = \begin{cases} 0 & for\ x < a \\ \frac{1}{b-a} & for\ a \le x \le b \\ 0 & for\ x > b \end{cases} \qquad (2.2.3)$$

$$U(x) = \begin{cases} 0 & for\ x < a \\ \dfrac{x-a}{b-a} & for\ a \le x \le b \\ 1 & for\ x > b \end{cases} \qquad (2.2.4)$$

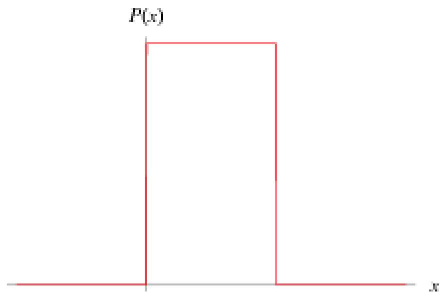

Figure 11: The uniform distribution

Source: Weisstein (2014)

2.3: Monte Carlo Simulation

Monte Carlo simulation is a technique used to perform quantitative risk analysis (see Vose, 1996, chapter 2).

When one or several variables, used in a calculation, can take multiple values and therefore yield no fixed result, quantitative analysis is needed in order to find reliable results. Simply letting the uncertain variables take one of the possible values and calculating once will rarely reach a reliable result due to the high amount of combination of values that the result can take. This is exemplified by looking at an equation taking the form of $y = a + b + c$ where the three independent variables each can take different ranges consisting of five values with equal probability. The result in the above equation alone has $5^3 = 125$ outcomes causing a simple guess to only have less than one percent chance of reaching the actual result. If, instead, the independent variables in the above equation each take their five different values with uneven probability, the chance of reaching the actual results diminishes even further. The Monte Carlo simulation method, a widely recognized technique, takes into account the probability distributions of the variables, and calculates and samples the results hundreds or even thousands of times, depending on the number of iterations set by the user (ibid., p. 11). The Monte Carlo simulation results take the forms of probability density functions allowing for a probabilistic and more precise and interpretation of the results.

Part III: Case Study

3.1: Framework for the Analysis

In contrast to most recent studies on the economic possibilities of transporting goods through the NSR using static costs and revenues, this paper aims to create a financial cost-benefit analysis over time, allowing for the gradual changes in ice cover and fuel prices. In the analysis section, the ratio of the NPV of the investment, in a containership designed for the use on the NSR, to the NPV of an investment in an ordinary vessel using the SCR – both initiated in the same year – is calculated in order to compare the investment returns.

The NPV ratios are calculated for each of the two different vessel sizes, relative to an SCR vessel of the same size, and three different ice-cover scenarios. The containerships used for the analysis are a 4300 TEU vessel using a southern draft restricted version of the NSR and an 8000 TEU vessel using a northern open water version of the NSR. The three ice cover scenarios are divided into a low, medium and high Arctic warming scenario.

In the following section, the routes and scenarios are further examined and explained. Additionally, the section will describe and quantify the various costs encountered when operating a container ship. Stopford (2009, p. 225) lists the five major cost components of running a ship as operating costs, periodic maintenance, voyage costs, cargo-handling costs and capital costs, described as follows:

- Operating costs consists of crew costs, stores and lubricants, repairs and maintenance, insurance and general costs.
- Periodic maintenance consists of dry-docking of the ship every two years and a special survey every four years in order to verify the sea worthiness of the vessel.
- Voyage costs consists of the price for bunker fuel, oil, port dues and canal dues.
- Cargo handling costs consists of the loading and discharging of containers when visiting a port.
- Capital costs is the repayment of the debt incurred from financing the purchase of the ship as well as the interest payments of the debt.

Due to the scope of this assignment, some of the less significant operating costs are excluded. These consist of stores, lubricants, crew supplies and dry docking maintenance.

The majority of the cost components examined in this paper is set to follow the general annual rate of inflation and therefore take non-static values. Throughout the rest of this paper most of these cost components along with several other variables therefore use the denotation *t* to describe the value of the given variable depending on the year. The first year possible to conduct an investment given the framework set up is the year 2014. For simplicity the year 2014 is denoted as $t = 0$ such that $t = 1 \; for \; 2015, t = 2 \; for \; 2016,,, t = n \; for \; 2014 + n$.

- ***Assumption 1:*** *Variables changing value through time use the denotation t such that* $t = 0$ *is year 2014,* $t = 1$ *is 2015 and* $t = n$ *is year* $2014 + n$.

3.2: Two Northern Sea Routes

In this section, the two versions of the NSR used to calculate the feasibility of sailing containerized goods through the Arctic Sea instead of the standard SCR are presented. The two Northern Sea Routes examined here are illustrated in figure 12 while the SCR is presented in figure 13.

Standard Northern Sea Route: From measurements using Google Earth the Standard NSR has a length of 7378 nautical miles from Rotterdam in The Netherlands to Yokohama in Japan. The standard NSR is the route that follows the Russian Northern Coast through the Arctic Sea and is currently the route with the least extent of sea ice due to the greater distance from the multi-year ice cover of the Northern Pole. The Route takes the vessel north of Novaya Zemlya through the Kara Sea and then into the Laptev Sea through the Vilkitskiy Strait south of Severnaya Zemlya. From the Laptev Sea, the Route follows the coast along the East Siberian Sea, the Chukchi Sea and through the Sannikov Strait south of the New Siberian Islands to the Behring Strait.

The High Northern Sea Route: From the observed ice cover data and the various global circulation models presented in section 1.4, it is clear that the global warming is causing the sea ice in the Arctic Sea to recede north at a rapid pace. The possibility of using a more direct northern version of the NSR seems ever more likely in the near future and is therefore subsequently studied in this paper. The high NSR runs north of the various islands in the proximity of the Russian northern coast (Novaya Zemlya, Severnaya Zemlya and New Siberian Islands) and is therefore not subject to the restrictions the shallow waters around the Russian Coast place on the potential size of the vessel. It is clear that, due to the higher latitudes of the route in question, ice conditions are more severe, which currently and in the near future lowers the amount of days possible to navigate along the route. From measurements using Google Earth, the high NSR spans a length of 6998 nautical miles from Rotterdam, Netherlands to Yokohama, Japan.

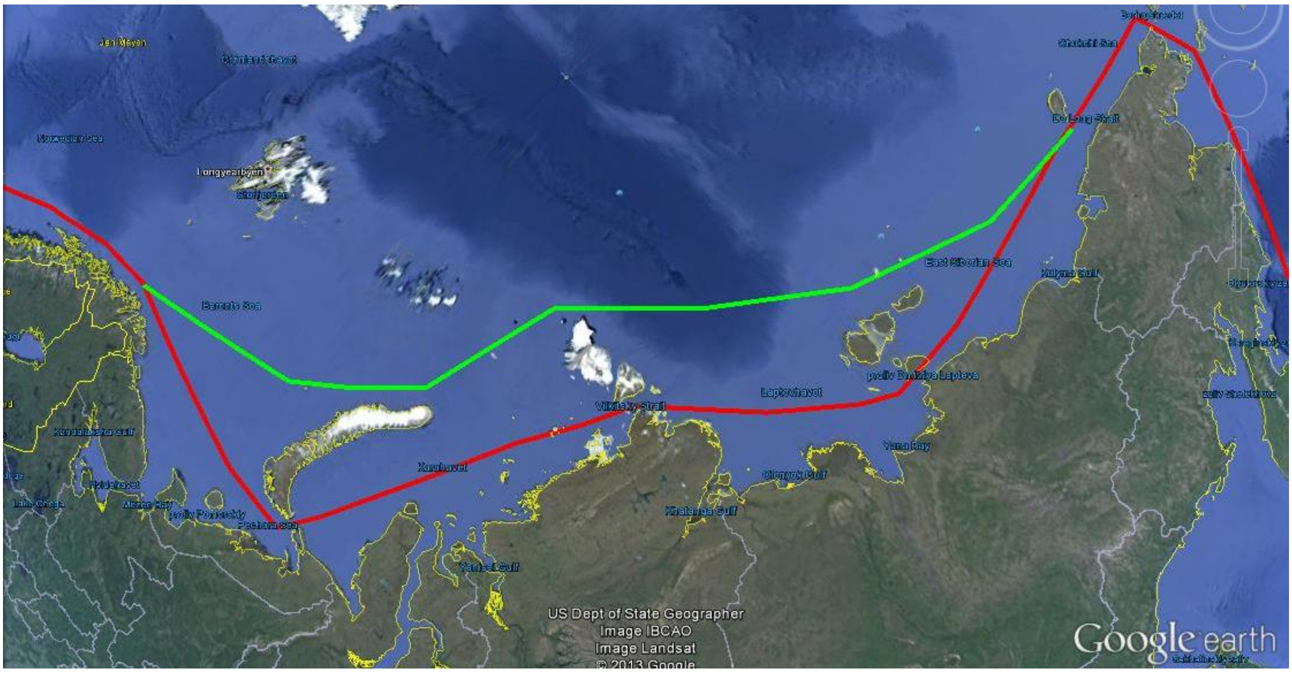

Figure 12: The two northern Sea Routes used for the analysis in this paper

The green and red line illustrates the standard and high NSR respectively.

Source: Own calculations using Google Earth

The Suez Canal Route: The SCR from Rotterdam to Yokohama spans approximately 11.400 nautical miles (Kronbak & Liu, 2010 p. 441) and therefore increases the travel distance by close to 55 percent compared to the NSRs. From Rotterdam the Suez Canal Route sails south around the Iberian Peninsula, through Strait of Gibraltar and into the Mediterranean Sea. From there the route crosses the Suez Canal between the Eastern Mediterranean Sea, through the Red Sea, the Gulf of Aden and east over the Indian Ocean crossing the Strait of Malacca to Singapore. From the Strait of Malacca the Suez Canal Route turns north through the Yellow Sea and the East Chinese Sea, finally arriving in Yokohama on the Japanese Island of Honshu.

Figure 13: The Suez Canal Route

Source: The Arctic Institute (2011)

3.3: Vessel Specifications and Acquisition

Transporting goods using the NSR requires the vessel to have an ice-reinforced double hull for the safety of the crew as well as to prevent oil spills .The Russian NSRA and the International Maritime Organization (henceforth: IMO) use the polar class index to categorize the ice breaking capabilities of the vessel. The Polar Class index goes from one to seven where a class index of one allows for all-year operation in all Arctic waters (IMO, 2010, p. 11). In the two comparative scenarios analyzed in this thesis, ice-reinforced containerships of Polar Class six are used for the vessels sailing on the NSR during the navigation period, and on the SCR the rest of the year, are compared to an ordinary blue water container ship solely using the SCR. Vessels of the Polar Class six classification are able to sail through first year ice of up to 120 cm without an icebreaker escort (Smith & Stephenson, 2013 p. 4), reducing the amount of time needed for the hiring of icebreaker assistance.

International shipping uses several internationally defined measurements of the size and capacity of maritime vessels, amongst them Dead Weight Ton (DWT) and Gross Ton (G). DWT measures the total cargo weight and supplies (including fuel and ballast weight) that the vessel can support

(Stopford, 2009, p. 752). Gross ton is an international type of measurement of the volume of a vessel, which is calculated from a standard formula set by the IMO (ibid.), and both the Suez Canal and NSR fees are based on the gross tonnage of the ship seeking passage. Equation 3.3.1 shows the formula used to calculate the gross ton of a vessel (IMO, 1982, p. 20).

$$Gt = V \cdot \left(0.2 + 0.02 \cdot log_{10}(V)\right) \qquad (3.3.1)$$

$V = Total\ volume\ of\ all\ enclosed\ spaces\ on\ the\ ship\ (m^3)$

Apart from the requirements of an ice-strengthened hull, when sailing along the Standard NSR, the shallow waters of the southern part of the Arctic Ocean impose draft restrictions (maximum depth) upon the vessel as well as the breadth restriction presented by the icebreaker escort size. The Sannikov Strait south of the New Siberian Islands has a maximum depth of 13 meters while the maximum breadth of the icebreaker escorts are 33-49 meters (Furuichi & Otsuka, 2013 p. 10). From the shipbuilding specification spreadsheet from the Danish Ship Owners' Association the maximum container capacity of the ship, given the above restrictions, is found to be 4300 TEU. The containership with a capacity of 4300 TEU has a maximum draft of 12.92 meters, a breadth of 32.22 meters and a DWT of 55,754.

The vessel using the High NSR is not subject to any draft restrictions, besides the one presented by the Suez Canal and the harbors visited and therefore only faces the restriction imposed by the icebreaker escort of a maximum of 33-49 meters along with the reinforced hull. In order to realistically be able to acquire icebreaker escort whenever needed and not only when the largest of the nuclear icebreakers are available, a breadth significantly lower than 49 meters are used in the analysis. For the transport along the high NSR, a vessel with a container capacity of 8000 TEU is used, utilizing the positive effects of economics of scale associated larger vessels (Stopford, 2009, p. 545). From the above-mentioned spreadsheet the measurements of an 8000 TEU containership is a breadth of 42.91 meters, a draft of 14.33 meters and a maximum DWT of 95,782.

According to the Suez Canal authorities, the Suez Canal is restricted to a maximum draft of 20.11 meters and a DWT of 240,000. The two container ships used in the calculations of the economic feasibility of transporting goods using the NSR are all well within these bonds. Despite the thicker hull of the ice-strengthened vessels, throughout this paper the assumption is that the vessels operating solely using the SCR are subject to the same dimensions as the NSR vessels.

Table 1: Physical vessel descriptions

	4300 TEU Vessel (Suez)	*4300 TEU Vessel (NSR/SCR)*	*8000 TEU Vessel (SCR)*	*8000 TEU Vessel (NSR/SCR)*
DWT	*55,754*	*55,754*	*95,782*	*95,782*
Draft (meters)	*12.92*	*12.92*	*14.33*	*14.33*
Breadth (meters)	*32.22*	*32.22*	*42.91*	*42.91*
Length (meters)	*275*	*275*	*324.5*	*324.5*
Total Volume (cubic meters)	*132,027*	*132,027*	*264,157*	*264,157*
Gross Tonnage	*39,927*	*39,927*	*81,476*	*81,476*

DWT, draft, breadth, length and total volume are calculated from the ship specification spreadsheet from the Danish Ship-owner' Association while Gross tonnage are based on own calculations.

Furuichi and Otsuka (2013, p. 5) list non-ice-reinforced container ship building prices in the year 2012 for container ships of several container capacities with a price of 47 million USD and 87.9 million USD for a 4,000 and 8,000 TEU containership respectively. Due to the larger size of the 4,300 TEU vessels used in this study, the price is increased to 50 million USD. Additionally a 20 percent increase in the initial price is expected for the production of an ice-reinforced vessel designed for shipping along the NSR (Kronbak & Liu, 2010, p. 441). The building price development of vessels are in this paper assumed to follow general inflation as well as not being affected by the volatility of shipping cycles.

Like macroeconomic business cycles, the shipping cycles describe the seasonal fluctuations of economy demand and supply. These fluctuations cause shipbuilding, ship chartering and freight rates to vary significantly over time resulting in fluctuations in the future cash flows (Stopford, 2009, pp. 93-134).

- ***Assumption 2:*** *Throughout this paper, demand and supply of ship building services are assumed constant and the prices encountered are therefore not subject to business fluctuations.*

The prices reported above are based on 2012 nominal USD for the acquisition of a vessel. Assuming a constant annual rate of inflation, denoted as π_t, the new building price of a vessel in year 2014 denoted by S_0 equals $S_{2012} \cdot (1+\pi_t)^2$, which can be rearranged to equation 3.3.2 presented with numerical values in table 2.

$$S_{t,j} = S_{0,j} \cdot (1+\pi_t)^t \qquad (3.3.2)$$

$S_{t,j} = Newbuilding\ price\ of\ vessel\ j\ in\ year\ t$

Table 2: Ship building prices

	4300 TEU Vessel (Suez)	*4300 TEU Vessel (NSR/SCR)*	*8000 TEU Vessel (SCR)*	*8000 TEU Vessel (NSR/SCR)*
Building Price in year t (nominal USD)	$52{,}020{,}000 \cdot (1+\pi_t)^t$	$62{,}424{,}000 \cdot (1+\pi_t)^t$	$91{,}451{,}160 \cdot (1+\pi_t)^t$	$109{,}741{,}392 \cdot (1+\pi_t)^t$

New building price in year t using own calculations based on the values of the 2012 purchase prices listed in Furuichi & Otsuka (2013) assuming an annual rate of inflation of two percent in 2013 and 2014 .

The acquisition of the container ships are assumed to be financed by 70 percent debt as in Kronbak & Liu (2010) leaving 30 percent of the capital cost to be covered by the investor's reserves. The debt is amortized over 15 years, with a 7 percent annual interest rate (Kon & Kitagawa, 2001, p. 96).

The yearly debt service when acquiring the ship is calculated using the formula:

$$C = B * \frac{r}{1-(1+r)^{-n}} \qquad (3.3.3)$$

$C = Yearly\ Capital\ Cost$

$B = Initial\ payment$

$r = Yearly\ interest\ rate$

$n = Number\ of\ years\ the\ debt\ is\ serviced$

According to Stopford (2009, p. 239) the average lifetime of a transport ship is 25 years. A building time of one year is assumed with an initial shipbuilding payment to be transferred at the end of the first year of the investment. Therefore an investment is assumed to run for a span of 26 years, with the first year being used building the vessel while the remaining 25 years are used operating the vessel before it is sold to scrap. The demolition of transport ships is usually carried out in India, Bangladesh or Pakistan with the scrap metal used in local markets (ibid., p. 212). With a negligible scrap-value of 425 USD per ton in 2012 (Bloomberg News, 2012), the total scrapping revenue is negligible, reaching about 40.000 USD for the largest vessel examined in this paper. Due to the multimillion costs and revenues associated with an investment in a containership, the income of the sale to a scrap yard is looked aside.

- ***Assumption 3****: The investment is assumed to have a duration of 26 years of which the first year is used for the acquisition of the containership, thus being operated for 25 years before demolition.*

Through the rest of this paper, variables with values that differ between containership sizes are denoted with the letter j, such that X_j is variable X given vessel of size j.

3.4: Navigation Days and Ice Cover

The continuous decline of ice cover in the Arctic Ocean is one of the deciding factors on whether it is economically possible to transport goods through the NSR. Even though several Arctic climate studies have been published with various results, the future extent of the ice cover along the different sections of the NSR are not possible to forecast in a precise manner. The exact amount of navigational days forecasted here are purely speculative, based on the recent and more sophisticated global climate forecasts mentioned earlier in this paper. The only projection in the hands of the author, which so far directly forecasts the number of days the NSR are navigable, is the ACIA (2004), criticized by several scholars for overshooting the ice cover extent by a significant margin (see section 1.4). Rodrigues (2008, p. 136) lists the annual amount of navigation days along the five Russian Arctic seas in year 2007 (see figure 14). From figure 14, it is clear that even though most of the Arctic Seas are ice-free for over a hundred days throughout the year, the ice cover in the Laptev Sea severely limits the amount of days on which the NSR is navigable without icebreaker transport.

Sea	L′ (1979)	L′ (2006)	ΔL′	L(2007)
Barents Sea	194	251	57	294
Kara Sea	41	77	36	110
Laptev Sea	22	51	29	75
East Siberian Sea	7	46	39	103
Chukchi Sea	52	109	57	153
Russian Arctic	84	129	45	171

Figure 14: Ice-free season in the Russian Arctic
Ice free season for the Russian Arctic in 1979, 2006 and 2007.
Source: Rodrigues (2008)

The amount of days navigation is allowed along the NSR are divided into three scenarios for each of the two routes analyzed. These include a low navigation time scenario based on the forecasts of the ACIA (2004), a medium scenario with a faster rate of melting and, finally, a high navigation time scenario projecting a rapid melting of the ice cover akin to the scenarios presented by Smith & Stephenson (2013) and Maslowski, et al. (2012). The navigational days of the three scenarios presented all contain a stochastic variable due to the general volatilities in the year-to-year ice cover extent. With the projections of an ice-free Arctic Ocean and the resulting collapse of the multi-year ice sheet in the Arctic Ocean within a near future, the standard NSR should be navigable throughout most of the year. Due to the severe winter storms in the Arctic Ocean along with the still significant winter ice-cover and the shallow straits, the author deems it unlikely that all-year navigation on the standard NSR is plausible in the timespan of the analysis. Even though some scholars argue that the pace of the melting of the Arctic Ocean's ice-cover is increasing, the amount of navigation days over time are here assumed to follow a linear trend.

Standard Northern Sea Route (SNSR): The low Arctic warming scenario, is based on the projections by the ACIA (2004) where a projected amount of navigation days was set to approximately 85 days in year 2014 with an increase to approximately 110 days by 2040. Figure 14 indicates that, with the assistance of Russian icebreakers, the present day navigation period is larger than 85 days and is therefore increased to 95 days in the low Arctic warming scenario.
In the ACIA forecast, the navigation time approximately increases by one day annually and is subsequently used to describe the future amount of navigation days along the NSR, from a current amount of 95 days. Due to the volatile nature of the ice-cover in the Arctic Ocean, a stochastic variable is added taking uniformly distributed values between -10 and 10. The low scenario amount of navigation days in year *t* is presented by equation (3.4.1).

$$\tau_{t,low,SNSR} = 95 + \theta_t + t \qquad (3.4.1)$$

$\tau_{t,low,SNSR} = Navigation\ days\ on\ the\ SNSR\ for\ the\ low\ scenario\ in\ year\ t$

$\theta_t = Uniformly\ distributed\ value \in [-10,10]\ in\ year\ t$

The medium Arctic warming scenario uses the same base value but increases more rapidly with a yearly average increase of three navigation days and an ice-free Arctic Ocean around 2040. This equals an amount of navigation days on the NSR in 2040 to be between 163 and 183 days, considering the stochastic variable. The amount of navigation days in year *t* in the medium scenario is presented by equation (3.4.2).

$$\tau_{t,med,SNSR} = 95 + \theta_t + 3 \cdot t \qquad (3.4.2)$$

$\tau_{t,med,SNSR} = Navigation\ days\ on\ the\ SNSR\ for\ the\ medium\ scenario\ in\ year\ t$

The high Arctic warming scenario is based on the assumption that a September Arctic ice-free ocean will occur already within the next decade and increases with an average rate of five days per year. Including the stochastic variable, this equals between 215 and 235 navigation days along the NSR in 2040. The amount of navigation days in year *t* in the high scenario is presented by equation (3.4.3)

$$\tau_{t,high,SNSR} = 95 + \theta_t + 5 \cdot t \qquad (3.4.3)$$

$\tau_{t,high,SNSR} = Navigation\ days\ on\ the\ SNSR\ for\ the\ high\ scenario\ in\ year\ t$

High Northern Sea Route (HNSR): The yearly days of navigation allowed on the HNSR is set to follow the same trend as for the Standard NSR in all three scenarios due to the receding Arctic ice-cover. The stochastic variable θ_t is also included but the present amount of navigation days is reduced to 40 days due to the higher latitude of the route. The amount of navigation days on the HNSR for the low, medium and high warming scenarios are presented by the equations 3.4.4, 3.4.5 and 3.4.6 respectively.

$$\tau_{t,low,HNSR} = 40 + \theta_t + 1 \cdot t \qquad (3.4.4)$$

$\tau_{t,low,HNSR} = Navigation\ days\ on\ the\ HNSR\ for\ the\ low\ scenario\ in\ year\ t$

$$\tau_{t,high,HNSR} = 40 + \theta_t + 3 \cdot t \qquad (3.4.5)$$

$$\tau_{t,med,HNSR} = Navigation\ days\ on\ the\ HNSR\ for\ the\ medium\ scenario\ in\ year\ t$$

$$\tau_{t,high,HNSR} = 40 + \theta_t + 5 \cdot t \qquad (3.4.6)$$

$$\tau_{t,high,HNSR} = Navigation\ days\ on\ the\ HNSR\ for\ the\ high\ scenario\ in\ year\ t$$

A crucial assumption of this analysis is that the yearly navigation time on the NSR covers a continuous time span each year, such that no sudden NSR closures affect the vessel transit time.

- ***Assumption 4:*** *The yearly navigation time along the NSR covers a continuous time span from the opening of the route in spring/summer to the closure in autumn.*

Even during the navigation period in the Arctic Ocean, certain stretches along the NSR may still experience ice conditions too severe for the ice-strengthened container ships. Therefore, the need for icebreaker assistance will arise: Especially around the late and early weeks of the yearly navigation period. For simplicity, the amount of nautical miles, on which icebreaker assistance is required throughout the year, is divided equally on each passage of the NSR. The amount of nautical miles requiring icebreaker assistance on each trip is assumed to follow a linear relationship with the distance of required assistance to decrease over time, being the same for both routes in all the three warming scenarios. Kronbak and Liu (2010) assume an average distance of 700 nm of ice water per trip when the NSR is navigable for 91 days and 100 nm average when navigable for 274 days. The amount of nautical miles of ice water is presently (2014) set to 700 nm but due to the various scenarios the annual decrease is set to be 15 nautical miles of ice water per year. The amount of ice water in year *t* is presented by equation 3.4.7.

$$\omega_t = 700 - 15 \cdot t \qquad (3.4.7)$$

$$\omega_t = Nautical\ miles\ of\ ice\ water\ in\ year\ t$$

Throughout the rest of this paper, variables with values that differ between types of Arctic warming scenarios are denoted with the letter *i*, such that X_i is the variable *X* given Arctic warming scenario of type *i*.

3.5: Fuel Consumption

The consumption of bunker fuel is one of the largest operating costs of transporting goods using container ships around the World's oceans. The consumption of bunker fuel depends on several factors including ship size, sailing speed water currents and wind conditions. Further, the navigation speed in the Arctic Ocean also depends on the severity of the ice conditions and the speed of the icebreaker escort. Due to the scope of this assignment, it is not possible to realistically simulate the above-mentioned conditions and, therefore, two sailing speed aggregates are used instead. Verny and Grigentin (2009) use an average operating speed of 17 knots along the SCR and 15 knots along the NSR while Furuichi and Otsuka (2013) use an average speed of 20 knots in open water and a speed of 12-15 knots in ice water. The voyage speeds from Furuichi and Otsuka (ibid.) are adopted in this paper with an average sailing speed in ice-covered water of 13.5 knots. The fuel consumption of the vessels used, given the operational speeds, are calculated from the ship characteristics spreadsheet of the Danish Ship-owners' Association. For the ice-reinforced containerships a 10 %, increase in fuel consumption is added due to the increased weight of the hull (ibid.). Table 3 lists the calculated fuel consumptions for the containerships used in the analysis section, given the two travel speeds used.

Table 3: Containership fuel consumption in ice and non-ice water

	4300 TEU (Suez)	*4300 TEU (SCR/NSR)*	*8000 TEU (Suez)*	*8000 TEU (Suez/NSR)*
Speed in open water (knots)	*20*	*20*	*20*	*20*
Speed in ice water (knots)	*Na*	*13.5*	*Na*	*13.5*
Fuel consumption in open water (ton/nm)	*0.19*	*0.209*	*0.251*	*0.276*
Fuel consumption in ice water (ton/nm)	*Na*	*0.107*	*Na*	*0.145*

The spreadsheet from the Danish Maritime Union calculates the fuel consumption of the vessels in kilo per nm. The fuel consumption is converted to ton per nautical mile by dividing by 1000 while an additional a 10 % increase in fuel consumption is added for the ice-reinforced vessels.
Source: Own calculations based on information from the Danish Maritime Union and Furuichi & Otsuka (2013)

3.6: Travel Time and Number of Trips

In the previous sections, the lengths of the routes, navigation speeds of the vessels as well as the number of nautical miles on the NSR on which icebreaker assistance is needed have been defined. Using this information, it is therefore possible to calculate the average amount of time needed for a trip between Rotterdam and Yokohama depending on the route used. A trip is set to be one transit between the two ports regardless of the direction. In addition to the voyage time between ports, berthing time while handling the cargo and waiting time on the SCR and NSR also needs to be included. Kronbak and Liu (2010) note that average waiting time for the SCR and the NSR route along with the cargo handling time of the port visits per trip are 4 days and 8 days respectively.

When transporting goods between two points, the amount of trips is realistically measured in whole numbers. When only considering trips aggregated in whole numbers, while using discrete time, a significant number of revenue generating days risks being excluded from the analysis. Since it is always possible to sail along the SCR, the amount of trips per year using the SCR are assumed to take the form of fractional values. In the Arctic Sea, however, the total number of trips each year is set to be a whole number since a sudden closure of the NSR while a ship is transiting is not considered plausible in this scenario.

With an average length of 11.400 nautical miles and an average speed of 20 knots, the travel time using the Suez Canal Route is calculated using equation 3.6.1, where the link $\frac{1}{24\frac{h}{day}}$ is used to change the unit of travel time from hours to days.

$$\phi^{SCR} = D_{SCR} \cdot \frac{1}{V_{OW}} \cdot \frac{1}{24\,\frac{h}{day}} + W_{SCR} \qquad (3.6.1)$$

$\phi^{SCR} = Travel\ time\ for\ the\ Suez\ Canal\ Route\ (days)$

$D_{SCR} = Distance\ of\ the\ Suez\ Canal\ Route\ (nm)$

$V_{OW} = Speed\ in\ open\ water\ (knots)$

$W_{SCR} = Average\ waiting\ time\ for\ the\ Suez\ Canal\ Route\ (days)$

The total amount of annual trips for all-year shipping, only using the SCR is calculated by dividing 365 days with equation 3.6.1.

$$Q^{SCR} = \frac{365}{\phi^{SCR}} \qquad (3.6.2)$$

$Q_{SCR} = Yearly\ trips\ when\ using\ only\ the\ SCR$

Inserting the numerical values into equation 3.6.1 results in a total travel time of 27.86 days for one trip between Rotterdam and Yokohama using the Suez Canal Route and from equation 3.6.2, this result in 13.09 annual trips.

The travel time between Rotterdam and Yokohama, using the NSR varies due to shifts in the ice cover of the Arctic Sea, is subject to periods of slow speed when icebreaker assistance is required. The length of a trip is calculated using the formula by modifying equation 3.6.1 to include the ice water distance along with the icebreaker speed.

$$\phi_{t,j}^{NSR} = \left(D_{NSR,j} - \omega_t\right) \cdot \frac{1}{V_{OW}} \cdot \frac{1}{24\frac{h}{day}} + \omega_t \cdot \frac{1}{V_{IW}} \cdot \frac{1}{24\frac{h}{day}} + W_{NSR} \qquad (3.6.3)$$

$\phi_{t,j}^{NSR} = Travel\ time\ using\ the\ NSR\ for\ a\ vessel\ of\ size\ j\ in\ year\ t\ (days)$

$D_{NSR,j} = Open\ Water\ NSR\ Distance\ using\ a\ vessel\ of\ size\ j\ (nm)$

$\omega_t = Ice\ Water\ distance\ in\ year\ t\ (nm)$

$V_{OW} = Speed\ in\ open\ water\ (knots)$

$V_{IW} = Speed\ in\ ice\ water\ (knots)$

$W_{NSR} = Average\ waiting\ time\ on\ the\ NSR\ (days)$

The NSR travel time in year 2015 is 24.07 days and 23.28 days for the Standard NSR and High NSR respectively. The reduction in the ice water along the NSR reduces the travel time to 23.53 and 22.74 days in year 2050 for the Standard and High NSR respectively.

In addition to the ice water distance variable, the yearly amount of trips that an ice-strengthened container ship can sail using the NSR also depends on the number of days the Arctic Sea is open to navigation. Denoting the total amount of trips using the NSR in year *t* as $Q_{t,j,i}^{NSR}$, given vessel size and warming scenario, the total number of trips using the NSR in year t is calculated by dividing the navigation period by average travel time per trip and rounded down to the lowest integer denoted by the equation 3.6.4.

$$Q_{t,j,i}^{NSR} = \left\lfloor \frac{\tau_{t,j,i}}{\phi_{t,j}^{NSR}} \right\rfloor \qquad (3.6.4)$$

$Q_{t,j,i}^{NSR} = Number\ of\ NSR\ trips\ for\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

$\tau_{t,j,i} = NSR\ navigation\ days\ for\ vessel\ j\ and\ arctic\ warming\ scenario\ i\ in\ year\ t$

When the NSR is not open for navigation, the ice-strengthened container ships will sail using the SCR for the rest of the year. The amount of SCR trips is calculated using equation 3.6.1, substituting 365 days with the amount of yearly number of days not used voyaging the NSR. The days where Arctic navigation is allowed, but not spent sailing on the NSR, is calculated using Euclidian division (finds the remainder of the whole number division). The annual amount of trips using the SCR conditional on the amount of NSR trips possible is calculated using equation 3.6.5.

$$Q_{t,j,i}^{SCR|NSR} = \frac{365 + \tau_{t,j,i} \,\%\, \phi_{t,j}^{NSR} - \tau_{t,j,i}}{\phi^{SCR}} \qquad (3.6.5)$$

$Q_{t,j,i}^{SCR|NSR} = Number\ of\ SCR\ trips\ for\ NSR\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

$\tau_{t,j,i} \,\%\, \phi_{t,j}^{NSR}$
$= Arctic\ navigation\ days\ not\ spent\ on\ the\ NSR\ for\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

Figure 15 and 16 show the annual amount of NSR and SCR trips of an ice-strengthened vessel with a container capacity of 4300 TEU and 8000 TEU respectively, clearly showing the inverse relation between the annual amount of NSR and SCR trips.

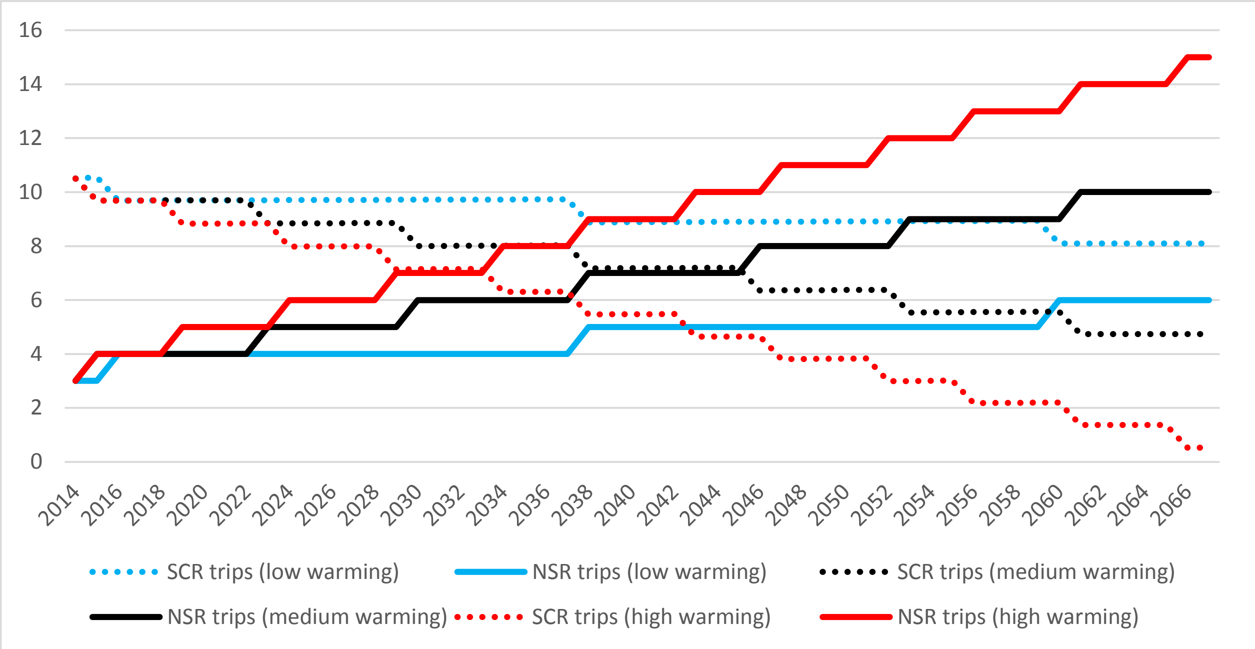

Figure 15: 4300 TEU ice-strengthened vessel NSR and SCR trips per year

The trips per year are calculated for a 4300 TEU ice-strengthened vessel using a constant navigation day uncertainty of $\theta_t = 0$ in all Arctic warming scenarios. The thick lines indicate the yearly amount of NSR trips while the dotted line shows the corresponding yearly amount of SCR trips.

Source: Own calculations

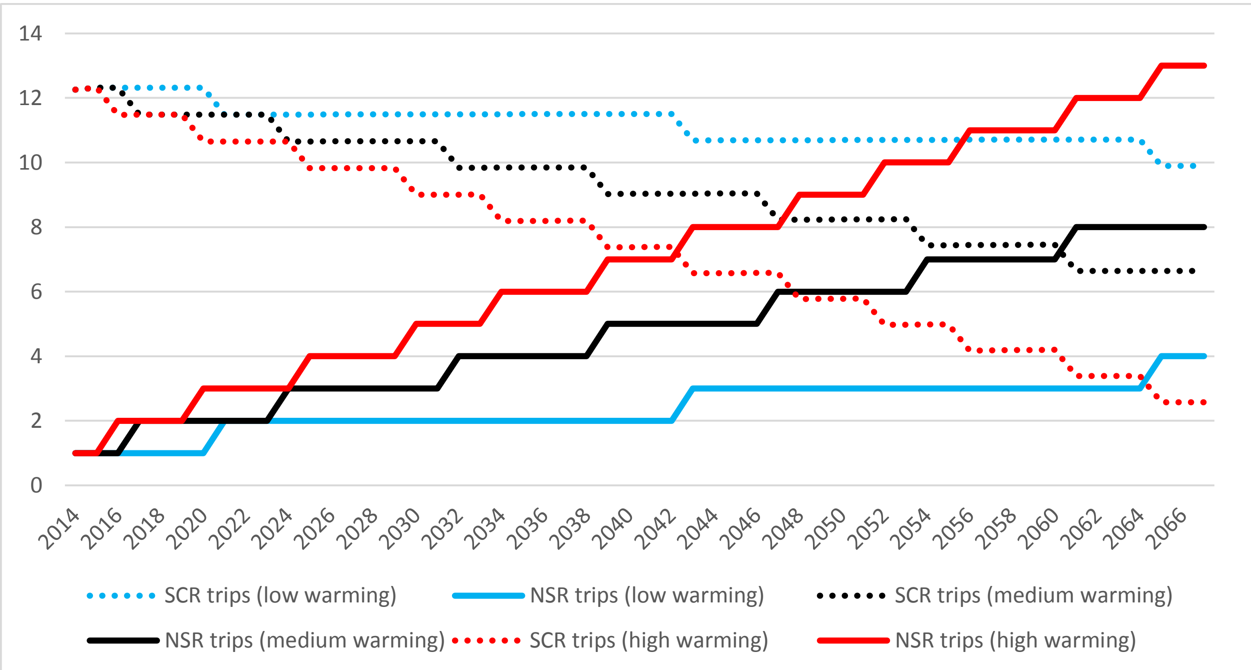

Figure 16: 8000 TEU ice-strengthened vessel NSR and SCR trips per year

The trips per year are calculated for an 8000 TEU ice-strengthened vessel using a constant navigation day uncertainty of $\theta_t = 0$ in all Arctic warming scenarios. The thick lines indicate the yearly amount of NSR trips while the dotted line shows the corresponding yearly amount of SCR trips.

Source: Own calculations

3.7: Fuel costs

The fuel cost for a trip between Rotterdam and Yokohama depends on the price of fuel, the sailing distance and the fuel consumption of the vessel. The fuel cost is calculated from the multiplication of the route distance with the fuel consumption of the vessel and the price of a ton of fuel.
The total fuel cost for a trip using the SCR is calculated for each vessel type using equation 3.7.1 and 3.7.2.

$$C^{F}_{t,j,SCR} = D_{SCR} \cdot \vartheta^{SCR}_{OW,j} \cdot P^{F}_{t} \qquad (3.7.1)$$

$C^{F}_{t,j,SCR} = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$\vartheta^{SCR}_{OW,j} = Open\ water\ fuel\ consumption\ for\ a\ SCR\ vessel$ of size j $(ton\ per\ nm)$

$P^{F}_{t} = Price\ for\ a\ ton\ of\ fuel\ in\ year\ t$

$$C^{F,NSR}_{t,j,SCR} = D_{SCR} \cdot \vartheta^{NSR}_{OW,j} \cdot P^{F}_{t} \qquad (3.7.2)$$

$C^{F,NSR}_{t,j,SCR} = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$\vartheta^{NSR}_{OW,j} = Open\ water\ fuel\ consumption\ for\ a\ NSR\ vessel$ of size j $(ton\ per\ nm)$

The Fuel costs for a trip using the NSR depend on the price of fuel, the fuel consumption of the ship in ice and open water along with the distance sailed. Equation 3.7.3 shows the total fuel costs for a trip using the NSR.

$$C^{F}_{t,j,NSR} = \omega_t \cdot \vartheta^{NSR}_{IW,j} \cdot P^{F}_{t} + \left(D_{NSR,j} - \omega_t\right) \cdot \vartheta^{NSR}_{OW,j} \cdot P^{F}_{t} \qquad (3.7.3)$$

$C^{F}_{t,j,NSR} = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$\omega_t = Ice\ water\ distance\ in\ year\ t$

$\vartheta^{NSR}_{IW,j} = Open\ water\ fuel\ consumption\ for\ a\ NSR\ vessel$ of size j $(ton\ per\ nm)$

$D_{NSR,j} = NSR\ distance\ for\ a\ vessel\ of\ size\ j\ measured\ in\ nm$

3.8: The Price of Fuel

The price of fuel is one of the largest components in determining the costs of seaborne transport. The price of crude oil has shown a significant volatility during the last decade (See figure 17) and future price movements have a large impact on the present value of an investment. Therefore, a future projection of the price of fuel oil is needed in order to conduct a NPV analysis on the prospect of shipping goods between Europe and East Asia.

Predicting the future price developments of fuel oil is an essential part of many economic investments. A multitude of political and scientific factors influence the price of oil, and proper econometric forecasts are made difficult by methodical problems as well as the lack of proper explanatory data (Kaufmann, et al., 2008). Various papers concerning the development of the world price of oil have been published, presenting different views on the future supply and price schemes on the price of oil.

Baumeister and Kilian (2013) calculate the forecast errors of six different forecasting models using a maximum forecast time of 24 months and combines the different forecasting models in order to improve the forecasting power of the price of oil. The conclusion of the paper is that no specific model is superior, and a weighted combination of the forecasting models therefore minimizes the forecast errors. In the 2013 report by the United States Department of Energy Administration (EIA), three scenarios on the future development of the real price of oil are projected; a reference case as well as a high and low price case up to the year 2040. They forecast under the critical assumption of no geopolitical shocks using OECD and non-OECD country data on Gross Domestic Growth rates as well as liquid fuels consumption per dollar of Gross Domestic Product. The price for a barrel of

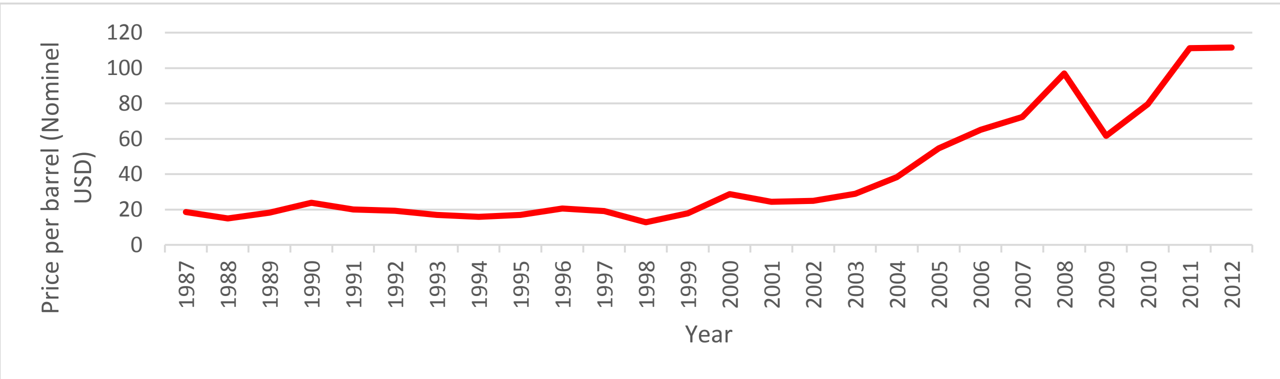

Figure 17: Brent Crude oil prices

Source: Own calculations based on EIA data on Brent Crude oil price oil in 2040 is projected to be 163 USD a barrel in the reference case, 75 USD in the low price case and 237 USD in the high price case (all prices are denoted in constant 2011 USD). Fournier and Wanner (2013) forecast the cost of a barrel of Brent Crude oil in 2020 to be 190 nominal USD with a range between 150 and 270 USD. The forecast is based on data on GDP per capita along with population size and oil intensity to create an oil demand model using two stage least squares (An extension of ordinary least squares method is presented later in this chapter). In addition, Fournier and Wanner (ibid., p. 30) mention that future development in the extraction of oil shale and tar sands might negatively affect the price of oil. Kaufmann, et al. (2008) use the model from the EIA and the International Energy Agency to forecast the future oil demand in the world. They criticize the models for overrating the amount of undiscovered conventional oil and conclude that world demand for oil will increase and therefore cause the price of oil to rise even further. Fournier and Wanner (2013) along with EIA (2013) and Kaufmann, et al. (2008) all highly emphasize that predictions on the future price of oil depends on the strategic behavior of the OPEC countries due to the significant world market share of oil production controlled by the cartel. Due to the scope of this paper, the replication or creation of an econometric time series model, incorporating large quantitiesof variables, as presented in the above-mentioned papers, are beyond the scope of this master thesis.

Figure 17 is plotted using Brent Crude oil spot price from EIA, normally used as benchmark oil price index (EIA, 2013, p. 30). Due to the lack of available time series data on the average market price of refined oil in the form of bunker fuel prices, data on Brent Crude raw oil is used to forecast the price of bunker fuel. From the observed values of the oil price, it is clear that the price for a barrel of oil is upwards trending, although subject to fluctuations resulting in a dramatic increase in the last few years. Selecting the appropriate univariate forecast method is important in achieving reliable estimation results.

The Holt-Winters double exponential smoothing method is an extension of the exponential smoothing model that uses two smoothing constants and is used to forecast time series variables that can be described by the linear relationship $y_t = \beta_0 + \beta_1 t + \varepsilon_t$. Contrary to a simple linear regression model, the Holt-Winters model allows for a changing mean and unstationarity in the data, by placing weight on the previous observations. Following the method in Bowerman and O'Connell (2007, pp. 855-857) the Holt-Winters Double exponential smoothing model is described by equation 3.8.1.

$$P_{t+1}^{F} = \ell_t + b_t \qquad (3.8.1)$$

$P_{t+1}^{F} = forecasted\ price\ of\ a\ barrel\ of\ oil\ in\ year\ t+1$

In equation 3.8.1, the variable ℓ_t is defined as the forecast level and calculated using equation 3.8.2.

$$\ell_t = \alpha P_t + (1-\alpha)[\ell_{t-1} + b_{t-1}] \qquad (3.8.2)$$

$\ell_t = Forecast\ level\ in\ year\ t$
$P_t = Observed\ price\ of\ a\ barrel\ of oil\ in\ year\ t$
$\alpha = Smoothing\ constant\ \in [0,1]$

The variable b_t from the previous two equations is the slope component of the forecasting model defined by equation 3.8.3.

$$b_t = \gamma[\ell_t - \ell_{t-1}] + (1-\gamma)b_{t-1} \qquad (3.8.3)$$

$b_t = Forecast\ slope\ in\ year\ t$
$\gamma = Smoothing\ constant\ \in [0,1]$

In order to calculate the forecasted values of the price of a barrel of Brent Crude, a base value of the level and the slope component needs to be found. This is done by calculating ℓ_0 and b_0 in the equation $\widehat{P_t} = \ell_0 + b_0 t + \varepsilon_t$ using an Ordinary Least Squares regression (Henceforth: OLS) on a segment of the Brent Crude data set. The OLS regression coefficients, with one independent variable, are calculated by the following two equations (Gujarati & Porter, 2010):

$$b_0 = \frac{\sum(t_i - \bar{t})(P_t - \bar{P})}{\sum(t_i - \bar{t})^2} \qquad (3.8.4)$$

$$\ell_0 = \bar{P} - b_0\bar{t} \qquad (3.8.4')$$

$P_t = Observed\ oil\ price\ in\ period\ t$
$\bar{P} = Mean\ of\ the\ dependent\ variable\ (oil\ price)$
$\bar{t} = Mean\ of\ the\ independent\ variable\ (time)$

The regression estimates are calculated using the first half of the observed data set (1987-1999), using the two equations 3.8.4 and 3.8.4' yielding $\ell_0 = 19.233$ and $b_0 = -0.164$.

From the values of ℓ_0 and b_0, it is possible to create the first forecasted value for the year 1987 using equation 3.8.1. This amounts to $P_{1987}^F = \ell_0 + b_0 = 19.233 - 0.164 = 19.069$ where the observed oil price for 1987 is 18.53 USD per barrel. More importantly, it is now possible to calculate the future values of the level and slope component expressed as a function of the two smoothing constants α and γ using equation 3.8.2 and 3.8.3 with results to $\ell_{1987} = \alpha \cdot 18.53 + (1-\alpha) \cdot 19.069$ and $b_{1987} = \gamma \cdot (\ell_{1987} - 19.233) + (1-\gamma) \cdot 0.164$ and so forth.

The values of the smoothing constants α and γ are chosen as to minimize the Mean Absolute Percentage Error (MAPE) (Bowerman & O´Connell, 2007, pp. 855-857). The MAPE is defined as the absolute average percentage deviation between the observed and estimated value of the variable and is presented in equation 3.8.5 (Vose, 1996, p. 244).

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{P_t - P_t^f}{P_t} \right|}{n} \qquad (3.8.5)$$

Inserting equation 3.8.2 and 3.8.3 into equation 3.8.1 and substituting into the above equation (3.8.5) yields:

$$MAPE = \frac{\sum_{t=1987}^{2012} \left| \frac{P_t - \alpha P_t + (1-\alpha)[\ell_{t-1} + b_{t-1}] + \gamma[\ell_t - \ell_{t-1}] + (1-\gamma) b_{t-1}}{P_t} \right|}{n}$$

Using the GRG non-linear solver in excel to minimize the MAPE with the calculated values of the level and slope components, and under the smoothing constant constraints, yields the following results:

$$arg \min_{\alpha \in \{0,1\}, \gamma \in \{0,1\}} \frac{\sum_{t=1987}^{2012} \left| \frac{P_t - \alpha P_t + (1-\alpha)[\ell_{t-1} + b_{t-1}] + \gamma[\ell_t - \ell_{t-1}] + (1-\gamma) b_{t-1}}{P_t} \right|}{n}$$

$$\rightarrow \quad \begin{aligned} \alpha &= 0.422 \\ \gamma &= 0.312 \\ MAPE &= 0.177 \end{aligned}$$

An estimated value of the MAPE of 0.177 explains that the average value of the forecasted oil price deviates from the observed price by close to 18 %.

Figure 18 plots the observed and estimated yearly spot prices of a barrel of Brent Crude and shows that the forecasted values adaptively follows the observed values. This is characteristic of the exponential smoothing model continuously revising the forecast estimates when new observations are added (Hanke & Wichern, 2005, p.114). The historical data only cover the period up to year 2012, and the forecasting equation $P_{t+1}^F = \ell_t + b_t$ therefore only direcly forecasts the price up to year 2013. Consequently, the model needs a slight restructure in order to forecast the price of oil in subsequent periods after 2013.

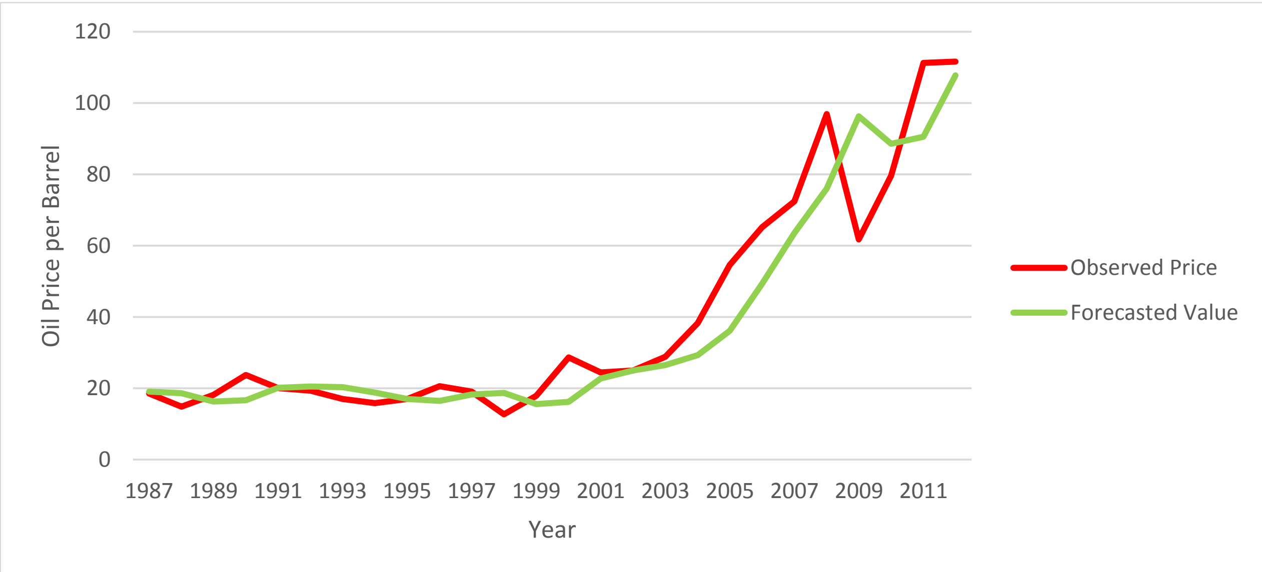

Figure 18: Observed and forecasted values of the spot price of a barrel of Brent Crude

The red line illustrates the observed prices while the green line denotes to forecasted values

Source: Own calculations based on EIA data on Brent Crude spot prices

Bowerman and O´Connell (2007, pp. 855-857) and Hanke and Wichern (2005, p. 124) use the intercept and slope levels of the last observed period to forecast the future price levels using the formula:

$$P^F_{2013+n} = \ell_{2012} + n \cdot b_{2012} \qquad (3.8.6)$$

The value of the slope component b_{2012} in equation 3.8.6 is the slope of the forecast of the price of oil. Due to the major oil price spike in recent years, the calculated slope component, b_{2012}, is 8.964, causing the price of a barrel of oil to increase annually by almost nine USD. This is a high annual price increase compared to the EIA forecast, which projects the real price to stabilize in the next few years before increasing again. Even though a nominal price increase of 8.964 is a significant increase in the yearly real price of oil, the costs of refining the raw oil to bunker fuel also needs to be taken into account. It is therefore assumed that the price projections of this chapter include the refinery costs and thus the price of bunker fuel encountered by the owner of the vessel when refueling.

In order to run Monte Carlo simulation on the forecasted values of the price of oil, an error distribution needs to be included in the forecasting model as a replacement for the observed oil price variable. As in Vose (1997, pp. 250-257), equation 3.8.2 can be rearranged to include the forecast error term from which the error term distribution is derived. Rearranging equation 3.8.2 from $\ell_t = \alpha P_t + (1-\alpha)[\ell_{t-1} + b_{t-1}]$ into $\ell_t = \alpha P_t - \alpha(\ell_{t-1} + b_{t-1}) + \ell_{t-1} + b_{t-1}$ and using the fact that $P^F_t = \ell_{t-1} + b_{t-1}$ from equation 3.8.1, yields:

$$\ell_t = \alpha(P_t - P^F_t) + \ell_{t-1} + b_{t-1} \qquad (3.8.7)$$

The term $P_t - P^F_t$ is the forecast error in year *t* and inserting $\varphi_t = P_t - P^F_t$ into equation 3.8.7 yields the equation used to generate the forecasted values after the observed periods:

$$\ell_t = \alpha \cdot \varphi_t + \ell_{t-1} + b_{t-1} \qquad (3.8.8)$$

The observed error term φ_t is derived from the forecasted error term, estimated from $P_t - P^F_t$ during the time of the historical data. If the forecasted model used fits the data, the observed error term should have a mean of zero and be normally distributed as $(0, \sigma)$ (Hanke & Wichern, 2005, pp. 121-122; Vose, 1996, p. 251-252). The descriptive statistics of the observed error term is presented in table 4.

Table 4: Descriptive statistics of the observed oil price forecast error term

Observations	*Mean*	*Standard deviation*	*Variance*	*MAPE*
26	*2.662*	*10.808*	*116.811*	*0.177*

Source: Own calculations based on EIA data on Brent Crude oil price

The mean of the observed error term is positive, meaning that the values of the price of oil generated by the forecasting model are slightly undershooting the real prices. Compared to the rather large values of the oil price, the mean is still close to zero, and a z-test can reveal if the mean statistically equals zero by testing the hypothesis $H_0: \mu = 0$ against $H_a: \mu \neq 0$ and then calculating the critical Z value using equation 3.8.9 (Bowerman & O´Connell, 2007, p. 322):

$$Z = \frac{\mu - \mu_0}{\frac{\sigma}{\sqrt{n}}} \qquad (3.8.9)$$

$\mu = Mean\ of\ the\ observed\ error\ term$ $\qquad n = Number\ of\ observation$

$\mu_0 = Hypothesis\ mean$ $\qquad \sigma = Standard\ deviation$

Inserting the values from table 4 into the above formula yields a Z-value of 1.256. The two-sided 95 % critical Z-value is $z_{0.025} = 1.96$ and since $|1.256| < |1.96|$, hypothesis $H_0: \mu = 0$ cannot be rejected. It is therefore concluded at a 95 % significance level that the actual mean of the observed error term is no different from zero. The error term used to forecast the price of oil after year 2013 is defined as $\varphi_t = N(0{,}10.808)$. Substituting the level component ℓ_{2012} in equation 3.8.6 with equation 3.8.8 yields the forecasting equation algebraically in 3.8.10.

$$P^F_{2013+n} = \alpha \cdot \varphi_t + \ell_{2011} + b_{2011} + n * b_{avg} \qquad (3.8.10)$$

Inserting the calculated values of the forecast into equation 3.8.10 yields the equation used to calculate the forecasted values of the fuel price in numerical form.

$$P^F_{2013+n} = 0.422 \cdot N(0{,}10.808) + 107.732 + n \cdot 8.964 \qquad (3.8.11)$$

Rearranging the time notation of equation 3.8.11 into the time notation used throughout the rest of this paper, such that $2014 \rightarrow t = 0, 2015 \rightarrow t = 1, \ldots 2014 + n \rightarrow t = n$ the equation for the forecasted price of a barrel of bunker fuel is presented by equation 3.8.12.

$$P_t^F = 0.422 \cdot \varphi_t + 116.7 + 8.964 \cdot t \qquad (3.8.12)$$

The upper and lower bound of the price of oil is the 95 % confidence interval of the forecasted price calculated from the observed error term component. The two-sided 95 % interval for the normal distribution is 1.96 meaning that 95 % of the time a value φ_t generated from the distribution lies in the interval $\bar{\varphi} - 1.96 \cdot \sigma \leq \varphi \leq \bar{\varphi} + 1.96 \cdot \sigma$, where $\bar{\varphi}$ is the mean of the normal distribution (Bowerman & O´Connell, 2007, p. 264). Translated into the forecasting equation for the price of oil, this means that 95 % of the time P_t^F is between $116.7 + t \cdot 8.964 \pm 0.422 \cdot 1.96 \cdot 10.808 = 116.7 + t \cdot 8.964 \pm 8.94$.

Using the forecast presented by equation 3.8.12, the forecasted value for a barrel P_{2020}^F is 179.4 ± 8.94 and $P_{2040}^F = 358.7 \pm 8.94$. The forecast for 2020 lies in the range of the values forecasted by Fournier and Wanner (2013), who forecasted values for a 2020 value of a barrel of Brent Crude to be 190 with a range between 150 and 270 nominal USD. The EIA (2013) projects the price of a barrel of oil to be 163 constant 2011 USD in the year 2040 in the reference case, 75 constant 2011 USD in the low price case and 270 constant 2011 USD in the high price scenario. In nominal terms, assuming a constant annual inflation of two percent and a price of 111.26 USD in 2011, this translates to $111.26 \cdot 1.02^{29} \cdot \left(\frac{163-111.26}{111.26} + 1\right) = 289.5\ USD$ in the reference case, $111.26 \cdot 1.02^{29} \cdot \left(\frac{75-111.26}{111.26} + 1\right) = 133.2\ USD$ in the low price case and $111.26 \cdot 1.02^{29} \cdot \left(\frac{270-111.26}{111.26} + 1\right) = 479{,}5\ USD$ in the high price case. The result of $P_{2040}^F = 358.7 \pm 8.94$ is between the reference case and the high price case and fits well with Kaufmann, et al., (2008), who criticize the EIA's forecast for being too optimistic.

The fuel consumption variable defined in part 3.6 is denoted in ton per nautical mile while the forecasted fuel price is measured in barrels. According to British Petroleum conversion rates, a ton of oil equals 7.33 barrels. Multiplying equation 3.8.12 with 7.33 yields the price equation for bunker fuel measured in ton, which is presented in equation 3.8.13 and the used fuel price equation throughout the rest of this paper.

$$P_t^F = 3.093 \cdot \varphi_t + 855.411 + 65.706 \cdot t \qquad (3.8.13)$$

Figure 19 shows the bunker fuel price development over time, from three random samples calculated using the @Risk Monte Carlo simulation program.

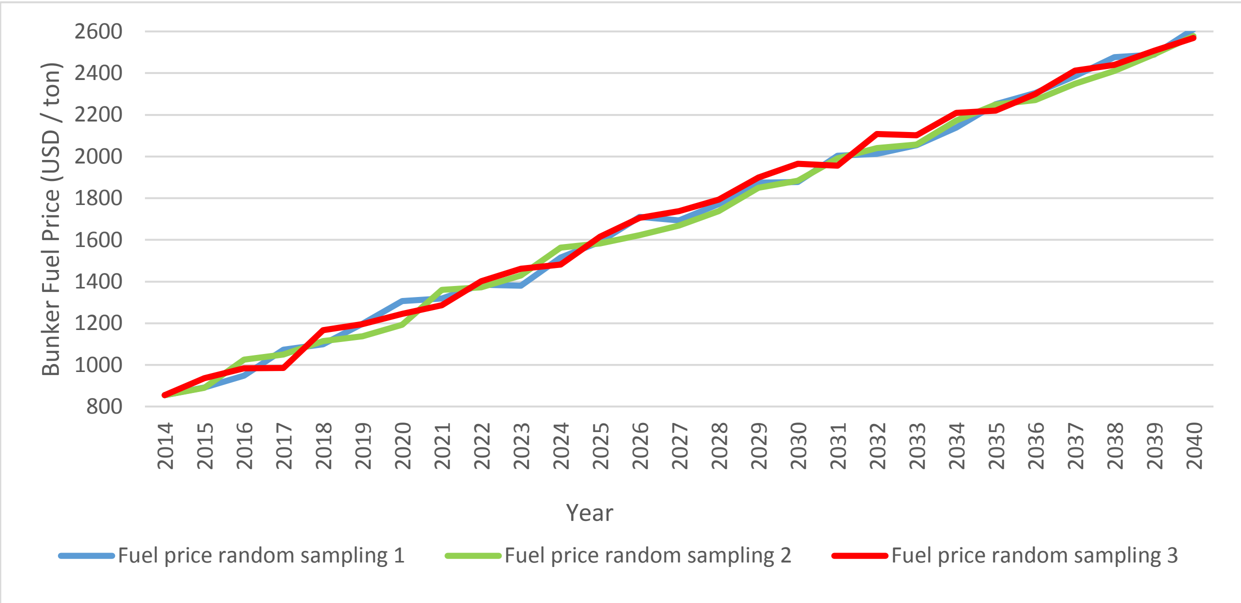

Figure 19: Bunker fuel price forecasts from 2014 to 2040

The fuel prices are calculated using three random Monte Carlo samplings of the fuel uncertainty variable φ_t.

Source: Own calculations using @Risk 6.0

3.9: Inflation

Inflation is defined as the sustained rise in the general price level, and the rate of inflation is the rate at which the price level increases, measured in percentages (Blanchard, et al., 2010, p. 25). The annual rate of inflation serves as a yearly mark of the price of costs and income components in order to calculate the future cash flows in the analysis section. In addition, the rate of inflation, together with the real discount rate, is used when calculating the NPV to discount future income streams. Due to the significance of the American economy, as well as the dollar being the international currency in maritime shipping, and thus used in this study, an annual rate of inflation, mirroring the one found in the Unites States, is selected. Figure 20 shows the annual US rate of inflation during the period 1983 to 2012 based on data from the World Bank.

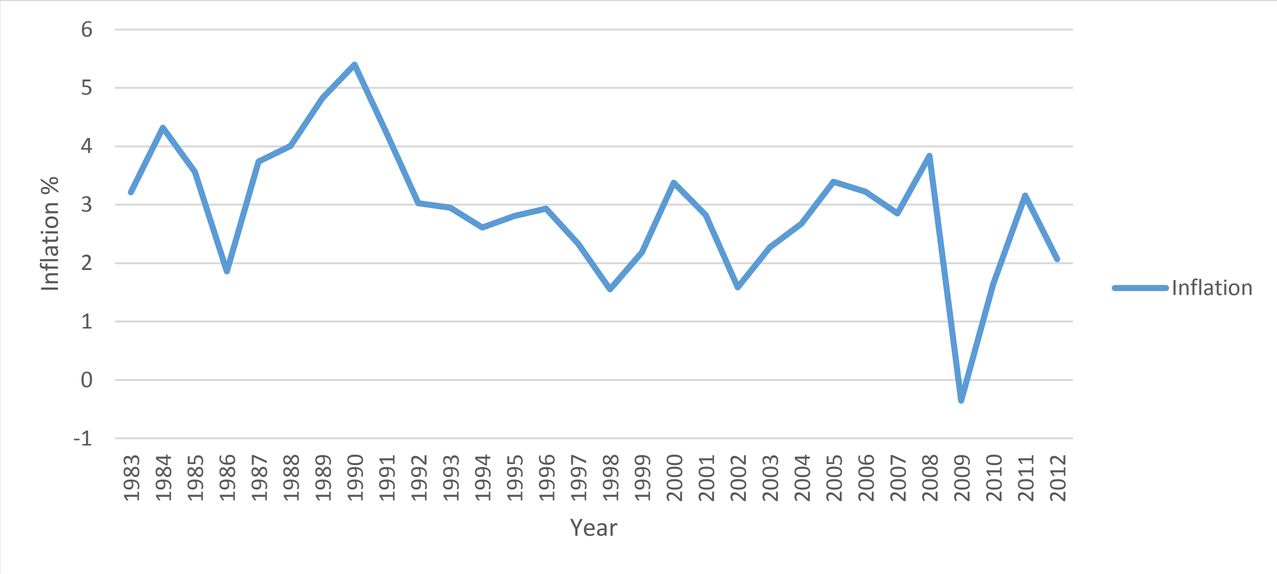

Figure 20: The Unites States annual rate of inflation from 1983 to 2012

Source: World Bank data on U.S Inflation

During the 30-year period from 1983 to 2012, the average yearly rate of inflation was 2.94 percent, while the American Central Bank has stated that one of its long-term goals is to keep the yearly rate of inflation below two percent (Federal Reserve, 2013). Since the Federal Reserve can affect American monetary policies and thereby affect the rate of inflation, while the previously observed annual rate of inflation has been above two percent, a constant annual rate of inflation of two percent is selected for transforming prices into nominal USD values throughout the rest of this paper.

All payments and incomes are assumed to be transacted at the end of each year and are thus subject to the rate of inflation during the same year. Variables subject to the annual rate of inflation are therefore multiplied by the rate of inflation in year *t* such that $P_t = P_{t-1} \cdot (1 + \pi_t)$, where P_t is the price of a good, subject to the annual rate of inflation in year *t*.

- ***Assumption 5:*** *All cash flows in year t are transferred ultimo year t such that prices in a given year are subject to the same annual rate of inflation.*

3.10: Port Dues

Depending on whether the route is eastbound or westbound the vessel enters Yokohama and Rotterdam respectively. This result in each trip including one port entry where the containers are discharged and subsequently new ones are loaded. Furuichi and Otsuka (2013) assume that the total cost of entering a port is 0.428 US dollars per gross ton for each port entry. This includes port entry and berthing as well as line-handling charges. In addition, they assume a cost of 100 US dollars in container handling per TEU, including both the discharge and loading of containers. Both the price developments of the berthing fee and container handling charges are assumed to follow the annual rate of inflation. The prices presented are in 2012 nominal US dollars and therefore need conversion into year *t* nominal US dollars.

Denoting the berthing fee in $C^{B}_{2012,j} = 0.428 \cdot G_j$ and using an annual inflation of two percent, then $C^{B}_{2014} = 0.445 \cdot G_j$. The Berthing costs per trip for vessel j in year t is denoted by equation 3.10.1.

$$C^{B}_{t,j} = 0.445 \cdot G_j \cdot (1+\pi)^t \qquad (3.10.1)$$

$C^{B}_{t} = Berting\ fee\ per\ trip\ in\ year\ t$

$G_j = Gross\ ton\ of\ the\ vessel\ j$

Inflating the container handling charge of 100 USD per TEU into 2014 prices yields 104.04 nominal USD. Multiplying the container handling charge with the amount of containers transported in year *t* yields the total container handling charges per trip presented in equation 3.10.2.

$$C^{CH}_{t} = \epsilon_t \cdot L_j \cdot 104.04 \cdot (1+\pi)^t \qquad (3.10.2)$$

$C^{CH}_{t} = Container\ handling\ costs\ per\ trip\ in\ year\ t$

$\epsilon_t = Load\ factor\ in\ year\ t$

$L_j = Container\ capacity\ of\ vessel\ j$

3.11: Suez Canal Costs

The Suez Canal is an artificial waterway separating the African continent from the Sinai Peninsula. As the historically shortest sea route between Europe and Asia, it is one of the most important waterways in the world and subsequently heavily trafficked (SCA, 2014).

The Suez Canal toll is based on the calculations of the Suez Canal net tonnage and the Special drawing rights, and it is not easily comparable to general cargo capacity measurements (Stopford, 2009, p. 236) but approximated by the gross ton of the vessel, according to Suez Canal Authorities. The Suez Canal toll is calculated from the Leth Agencies Suez Canal toll calculator for a laden containership with the gross ton of the vessel substituting the Suez Canal net tonnage input. The tolls are calculated at 267,623.01 and 453,614.41 USD for the 4300 and 8000 TEU vessels respectively. The Suez Canal toll is assumed to follow the general rate of inflation, and the transit costs for one trip through the Suez Canal route, depending on vessel size, is presented in equation 3.11.1 and 3.11.2.

$$C^S_{t,4300} = 267{,}623.01 \cdot (1+\pi)^t \qquad (3.11.1)$$

$C^S_{t,4300} = Suez\ Canal\ toll\ for\ a\ 4300\ TEU\ vessel\ in\ year\ t$

$$C^S_{t,8000} = 453{,}614.41 \cdot (1+\pi)^t \qquad (3.11.2)$$

$C^S_{t,8000} = Suez\ canal\ toll\ for\ a\ 8000\ TEU\ vesel\ in\ year\ t$

3.12: NSR Fee

Compared to the information on tariffs, encountered when crossing the Suez Canal, reliable information on the price of sailing along the NSR is much harder to come by. Icebreaker assistance is mandatory when the NSRA deems it necessary. The NSR authorities only set a maximum price of icebreaker assistance of 1048 Rubles per ton on their homepage but state that the rates varies and are negotiable. Kronbak and Liu (2010, p. 440) report that the Russian icebreaker fleet department measures one TEU to equal 24 ton resulting in an NSR transit fee of close to one thousand USD per TEU, which is extremely high compared to the Suez Canal fee. A scenario with lower NSR tariffs seems plausible since the Russian Authorities have recently announced plans to lower the icebreaker escort rates as well as streamlining the administrative requirements (Flake, 2013, p. 48). Verny and Grigantin (2009, p. 111) use an icebreaker fee of 4.36 to 23.82 US dollars per ton yielding a price of 104.64 to 571.68 USD per TEU. Furuichi and Otsuka (2013, pp. 5-6) use an icebreaker fee of 5 US dollars per Gross ton based on recent NSR transactions reported by Henrik Falck of Tschudi Shipping Company AS. A price of five US dollars per Gross ton per passage is only marginally higher than the Suez Canal fee while the maximum price set by the NSRA would effectively make sailing on the NSR impossible. Since Furuichi and Otsuka (ibid.) use data based on recent transactions, the price of five US dollars per gross ton measured in 2012 dollars is used as a guideline in this study. Due to the extreme price differences reported by the various scholars, the price for a passage using the NSR is increased to 15 US dollars per Gross Ton per passage in this study. The Price of 15 USD per gross ton is set to include the ice pilot fee and follow general inflation.

$$C_{t,j}^{N} = 15 \cdot (1+\pi_t)^t \cdot G_j \qquad (3.12)$$

$C_{t,j}^{N} = NSR\ fee\ for\ one\ passage\ using\ a\ vessel\ of\ size\ j\ in\ year\ t$

$G_j = Gross\ Tonnage\ of\ a\ vessel\ of\ size\ j$

3.13: Insurance

The insurance of the vessel consists of two forms of insurance required for operating the containership. The Hull and Machinery (H&M) insurance obtained from a marine insurance party protects the owner from the physical loss or damage to the vessel while damage to cargo, collision damage, pollution and general damage affecting third party liabilities are obtained from Protection and Indemnity (P&I) Clubs (Stopford, 2009, p. 230). Due to the risks involved in shipping on the NSR, Verny and Grigentin note that several insurance companies have previously denied insurance to vessels, sailing on the NSR, and conclude that the insurance costs are *"[…] among the least predictable cost headings*" (2009, p. 114). Despite these uncertainties, the scenarios investigated in this paper are assumed to be insurable although the vessels using the NSR are expected to be subject to a larger insurance risk premium. Kronbak and Liu (2010, p. 442) use a price of 700 US dollars per day for H&M and P&I for an open water vessel. Further, they use a 1400 and 875 US dollars price for H&M and P&I respectively, for a 4300 TEU container ship used for sailing on the NSR. These prices are also used in this study with an additional 50 percent added to the insurance cost of the 8000 TEU container ships due to the larger size and cargo value of those vessels. Inflating the prices to the nominal 2014-dollar level and multiplying by 365 yields the annual insurance costs given the vessel type in year t and presented in equation 3.13.1 through 3.13.4.

$$I_{t,4300}^{SCR} = 1534.763 \cdot 365 \cdot (1+\pi)^t \qquad (3.13.1)$$

$I_{t,4300}^{SCR} = Price\ of\ insurance\ for\ a\ 4300\ TEU\ SCR\ vessel\ in\ year\ t$

$$I_{t,8000}^{SCR} = 2302.105 \cdot 365 \cdot (1+\pi)^t \qquad (3.13.2)$$

$I_{t,8000}^{SCR} = Price\ of\ insurance\ for\ a\ 8000\ TEU\ SCR\ vessel\ in\ year\ t$

$$I_{t,4300}^{NSR} = 2493.947 \cdot 365 \cdot (1+\pi)^t \qquad (3.13.3)$$

$I_{t,4300}^{NSR} = Price\ of\ insurance\ for\ a\ 4300\ TEU\ NSR\ vessel\ in\ year\ t$

$$I_{t,8000}^{NSR} = 3740.92 \cdot 365 \cdot (1+\pi)^t \qquad (3.13.4)$$

$I_{t,8000}^{NSR} = Price\ of\ insurance\ for\ a\ 8000\ TEU\ NSR\ vessel\ in\ year\ t$

3.14: Repairs and Maintenance

When operating a ship at sea, the hull, engine and other machinery will suffer durability losses, which increases the risk of breakdowns if not maintained by the crew or third party contractors. In order to obtain insurance coverage of the vessel, the owner is also required to dry-dock the containership once a year with the purpose of repairing hull damage and insure that the vessel is sea worthy and follows the requirements set by the IMO and other authorities, relevant to the destinations of the vessel (Stopford, 2009, p. 231). Due to the scope of this paper the time component of the dry-docking requirements are excluded, although a cost component including yearly repairs and maintenance is included in the analysis. Furuichi and Otsuka (2013, p. 7) set maintenance costs to be 1.095 % of building costs while Kronbak and Liu (2010, p. 442) use an average daily repair and maintenance cost of 1200 USD for a Suez Canal designed vessel and 2400 USD for an NSR designed ice strengthened vessel. It is assumed that the amount of repairs and maintenance does not increase with the age of the vessel and that prices follow general inflation. Emulating the prices used by Kronbak and Liu (ibid.) and inflating them to 2014 nominal dollar prices multiplied by 365 days, in order to denote a yearly cost component, the annual price of maintenance dependent on the design specifications of the vessel is presented in equation 3.14.1 and 3.14.2.

$$M_t^{SCR} = 1315{,}488 \cdot 365 \cdot (1+\pi)^t \qquad (3.14.1)$$

$M_t^{SCR} = Total\ maintenance\ and\ repar\ costs\ for\ a\ SCR\ vessel\ in\ year\ t$

$$M_t^{NSR} = 2630{,}977 \cdot 365 \cdot (1+\pi)^t \qquad (3.14.2)$$

$M_t^{NSR} = Total\ maintenance\ and\ repar\ costs\ for\ a\ NSR\ vessel\ in\ year\ t$

3.15: Crew Costs

The crew costs consist of the salary of the crew working on the vessel. The size of the crew varies depending on the regulatory policies of the flag state and the vessel type (Stopford, 2009, p. 226). Verny and Grigantin (2009, p.115) use a cost of 1,200,000 USD a year for the entire crew while Kronbak and Liu (2010, p. 442) set crew costs to be 2500 USD and 2750 USD per day for ordinary vessels and ice-classed vessels respectively. AECOM (2012, p. 4) argue that modern container ships use the same crew size regardless of vessel size and set a yearly cost for a crew of 12 persons to be 1,314,000 in 2012 USD. Using the crew costs from AECOM (2012) and inflating the price to 2014 USD while assuming that the average salary follows general annual inflation, the crew cost in year *t* is presented by equation (3.15.1).

$$C_t^{Crew} = 1{,}367{,}086 \cdot (1+\pi)^2 \qquad (3.15.1)$$

$C_t^{Crew} = Crew\ Cost\ in\ year\ t$

3.16: Load Factor

The load factor is defined as the percentage of the container capacity of the vessel that is loaded. Major fluctuations in the load factor will seriously affect the cash flows of the investment and therefore the NPV. The demand for the freight of containers is highly volatile and depends on several world economic factors (Stopford, 2009, pp. 139-150). Additionally, the demand for transporting containers from Asia to Europe is higher causing the freight rate to differ between west and eastbound traffic (Kronbak & Liu, 2010, p. 442). Furuichi and Otsuka (2013, p. 11) use an average load factor of 70 percent while Kronbak and Liu (2010) define an average load factor of 60 percent. Because of the volatility of the amount of cargo transported on the vessel, the load factor in year t, defined as ϵ_t, is set to follow a uniform distribution between 60 and 70 percent.

Part IV: Combining the Costs

In this part, the various costs are combined while the freight rate is determined creating the framework for the financial cost-benefit analysis in the sixth part of the paper. Since most of the equations and variables defined in the previous part appear in this section, it is highly recommended to use the variable guide found in appendix D when reading the next sections.

4.1: Variable Costs

In this study, the variable costs are defined as the costs associated directly with transporting goods between Rotterdam and Yokohama. These costs include fuel costs, berthing and container handling costs as well as icebreaker fee and Suez Canal fee depending on the route used.

The costs of one trip between Rotterdam and Yokohama using the Suez Canal for an open water vessel size *j* are calculated by combining equation 3.7.1, 3.10.1, 3.10.2 and 3.11.1 or 3.11.2 yielding equation 4.1.1.

$$C_{t,j}^{SCR} = C_{t,j,SCR}^{F} + C_{t,j}^{S} + C_{t,j}^{B} + C_{t,j}^{CH} \qquad (4.1.1)$$

$C_{t,j}^{SCR} = Total\ costs\ for\ one\ SCR\ trip\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,SCR}^{F} = Fuel\ cost\ for\ one\ trip\ using\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{S} = Suez\ Canal\ fee\ using\ a\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{B} = Berthing\ costs\ per\ trip\ for\ a\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{CH} = Container\ handling\ costs\ for\ one\ trip\ for\ a\ vessel\ of\ size\ j\ in\ year\ t$

The costs for an SCR trip using an ice-strengthened vessel of size j is calculated by substituting the fuel consumption variable in equation 4.1.1 with equation 3.7.2.

$$C_{t,j}^{SCR|NSR} = C_{t,j,SCR}^{F,NSR} + C_{t,j}^{S} + C_{t,j}^{B} + C_{t,j}^{CH} \qquad (4.1.2)$$

$C_{t,j}^{SCR|NSR} = Total\ costs\ for\ one\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,SCR}^{F,NSR} = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

The costs of a trip using the NSR is calculated by substituting the Suez Canal fee and SCR fuel costs in equation 4.1.2 with the icebreaker fee from equation 3.12 and NSR fuel cost from equation 3.7.3.

$$C_{t,j}^{NSR} = C_{t,j,NSR}^{F} + C_{t,j}^{N} + C_{t,j}^{Berth} + C_{t,j}^{CH} \qquad (4.1.3)$$

$C_{t,j}^{NSR} = Total\ costs\ for\ one\ NSR\ trip\ for\ vessel\ j\ in\ year\ t$

$C_{t,j}^{N} = NSR\ icebreaker\ fee\ for\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,NSR}^{F} = Fuel\ cost\ for\ one\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

Figure 21 (next page) shows the cost component breakdown for the costs of one trip in 2015. From the costs for one trip between Rotterdam and Yokohama, it is clear that the reduced distance of the NSR compared to the SCR results in a major reduction of bunker fuel costs. The fuel costs using the NSR are dramatically reduced for both sizes of the ice-strengthened vessel on the NSR while the increased weight of the vessel causes a higher fuel cost on the SCR compared to the ordinary containerships. This fuel cost difference shows the importance of the reduction of the ice-cover in the Arctic Sea on the economic feasibility of using the NSR for the transport of goods. The other major cost component affecting the NSR is the icebreaker fee taking up a significant part of the route costs compared to the Suez Canal fee.

For a 4300 TEU vessel the costs of a trip using the NSR are, by a small margin, less than the costs of an ordinary 4300 TEU vessel using the SCR. In similarity to the smaller vessel, the total cost of a trip using the NSR with an 8000 TEU containership is less than using the SCR with both an ice-strengthened and an ordinary vessel of the same size. Some major differences in the cost component proportions between the two containership sizes clearly stand out. The fuel costs of the 8000 TEU containership using the SCR are only about 30 percent higher than the 4300 TEU vessel even though the container capacity of the 8000 TEU vessel almost doubles that of the smaller vessel. This clearly shows the positive economics of scale associated with vessels of increasing size.

Another major difference is the proportion of the total cost per trip using the NSR covered by the icebreaker fee of the NSRA. With an icebreaker fee of 610 thousand USD covering about 25 percent of the total costs of the 4300 TEU vessel using the NSR, the fee increases to 1.24 million

USD, or around 35 percent of the total costs for the 8000 TEU containership given 2015 nominal prices. The difference in the icebreaker fee proportion of the NSR between the two vessel sizes indicates that the current pricing scheme set by the NSRA, which bases the price on gross ton of the vessel, works contrary to the passage of large containerships. This diminishes the positive economics of scale normally encountered with using oversized transport ships. Finally, the cost per trip using the NSR almost equals the costs of the SCR using an ordinary vessel while the SCR cost for an NSR vessel is higher than for an ordinary vessel. This indicate that shipping along the NSR is only feasible when the amount of navigation days allows for a sufficiently large amount of NSR trips per year.

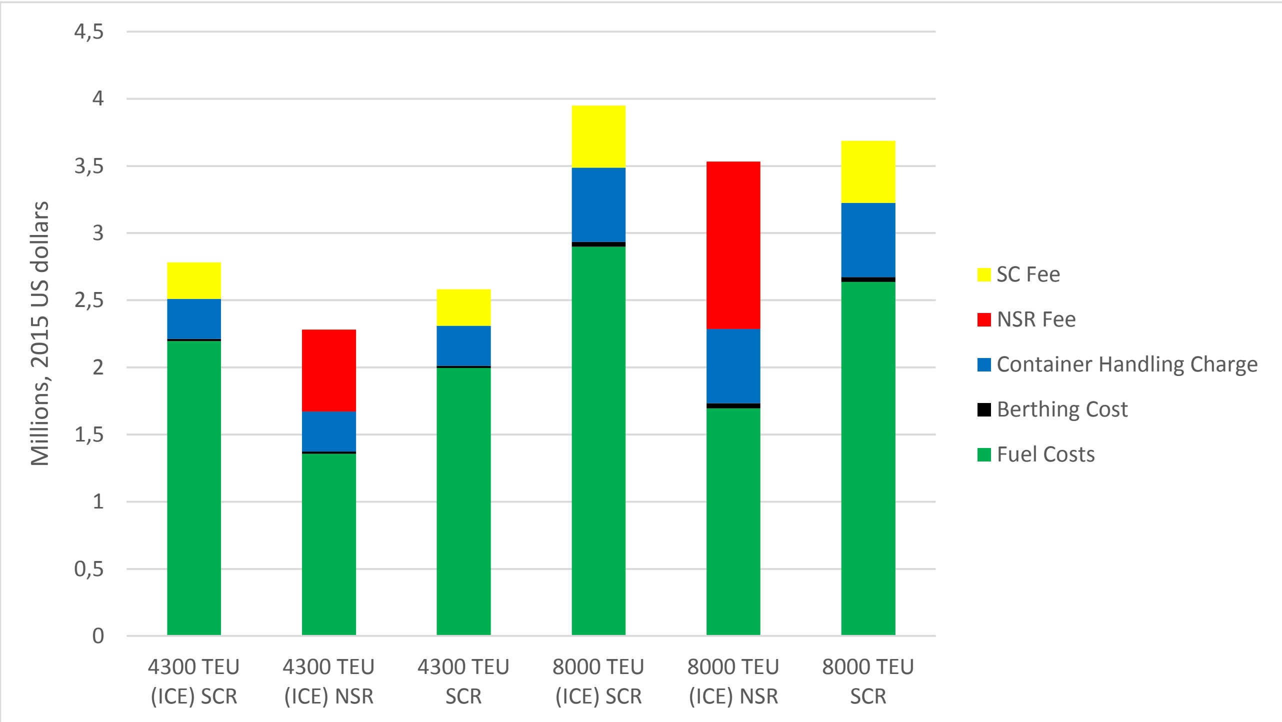

Figure 21: Cost component breakdown for one trip between Rotterdam and Yokohama

The costs are in year 2015 measured in 2015 US dollars with a load factor of $\epsilon_1 = 0.65$ *and a fuel cost uncertainty given by* $\varphi_1 = 0$*. The notation (ICE) means the vessel is designed for operation on the NSR while NSR / SCR denotes the route used.*

Source: Own calculations

The yearly variable operation costs are found by multiplying the costs per trip with the amount of trips completed each year. Thus, multiplying equation 4.1.1 and 4.1.2 with the amount of SCR and NSR trips respectively (see chapter 3.6) given ice-cover scenario $i = \{low, medium, high\}$ yields the variable costs in year *t* for an SCR and NSR vessel presented in equation 4.1.4 and 4.1.5.

$$VC_{t,j}^{SCR} = Q^{SCR} \cdot C_{t,j}^{SCR} \qquad (4.1.4)$$

$VC_{t,j}^{SCR} = Variable\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$Q^{SCR} = Yearly\ trips\ for\ a\ vessel\ using\ only\ the\ SCR$

$$VC_{t,j,i}^{NSR} = Q_{t,j,i}^{SCR|NSR} \cdot C_{t,j}^{SCR|NSR} + Q_{t,j,i}^{NSR} \cdot C_{t,j}^{NSR} \qquad (4.1.5)$$

$VC_{t,j,i}^{NSR} = Variable\ costs\ for\ NSR\ vessel\ of\ size\ j\ and\ ice\ scenario\ i\ in\ year\ t$

$Q_{t,j,i}^{SCR|NSR} = Number\ of\ SCR\ trips\ for\ NSR\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

$Q_{t,j,i}^{NSR} = Number\ of\ NSR\ trips\ for\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

4.2: Fixed Operation Costs

In this study the yearly fixed costs from maintaining a functional container ship consist of the annual payments of insurance (chapter 3.13), maintenance costs (chapter 3.14) and crew costs (chapter 3.15). Equation 4.2.1 and 4.2.2 show the yearly fixed costs of the container ship used for the SCR and NSR respectively.

$$FC_{t,j}^{SCR} = C_{t,j}^{I} + C_{t}^{crew} + M_{t}^{SCR} \qquad (4.2.1)$$

$FC_{t,j}^{SCR} = Fixed\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t}^{crew} = Crew\ costs\ in\ year\ t$

$P_{t,j}^{M} = General\ maintenance\ consts\ for\ vessel\ of\ size\ j\ in\ year\ t$

$I_{t,j}^{SCR} = Insurance\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$$FC_{t,j}^{NSR} = I_{t,j}^{NSR} + C_{t}^{crew} + M_{t}^{SCR} \qquad (4.2.2)$$

$FC_{t,j}^{NSR} = Fixed\ costs\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$I_{t,j}^{NSR} = Insurance\ costs\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

4.3: Total Costs

In addition to the variable and fixed operational costs, the yearly capital costs are added in order to calculate the total yearly costs. Denoting the capital costs in year *t* for vessel *j* conditional on the investment year *s* as $A_{t|s,j}$, the total costs for a vessel of size j given Arctic warming scenario *i* in year *t* are presented for an NSR and an SCR vessel in equation 4.3.1 and 4.3.2 respectively.

$$TC_{t,j}^{SCR} = Q_{t,j}^{SCR} \cdot C_{t,j}^{SCR} + FC_{t,j}^{SCR} + A_{t|s,j}^{SCR} \qquad (4.3.1)$$

$TC_{t,j}^{SCR} = Total\ costs\ of\ a\ SCR\ vessel\ of\ type\ j\ in\ year\ t$

$A_{t|s,j}^{SCR} = Capital\ cost\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t\ conditional\ on\ investment\ year\ s$

$$TC_{t,j,i}^{NSR} = Q_{t,j,i}^{SCR|NSR} \cdot C_{t,j}^{SCR} + Q_{t,j,i}^{NSR} \cdot C_{t,j}^{NSR} + FC_{t,j}^{NSR} + A_{t|s,j}^{NSR} \qquad (4.3.2)$$

$TC_{t,j,i}^{NSR} = Total\ costs\ for\ a\ NSR\ vessel\ of\ type\ j\ and\ warming\ scienario\ i\ in\ year\ t$

$A_{t|s,j}^{NSR} = Capital\ cost\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t\ conditional\ on\ investment\ year\ s$

Figure 22 and 23 show the yearly total cost component breakdown for the investment of an ordinary and ice-strengthened 4300 TEU vessel respectively in year 2014 for the medium Arctic warming scenario. As previously stated, the investment runs for 26 years where the first year is used for building the vessel and the subsequent twenty-five years used for the transport of goods.

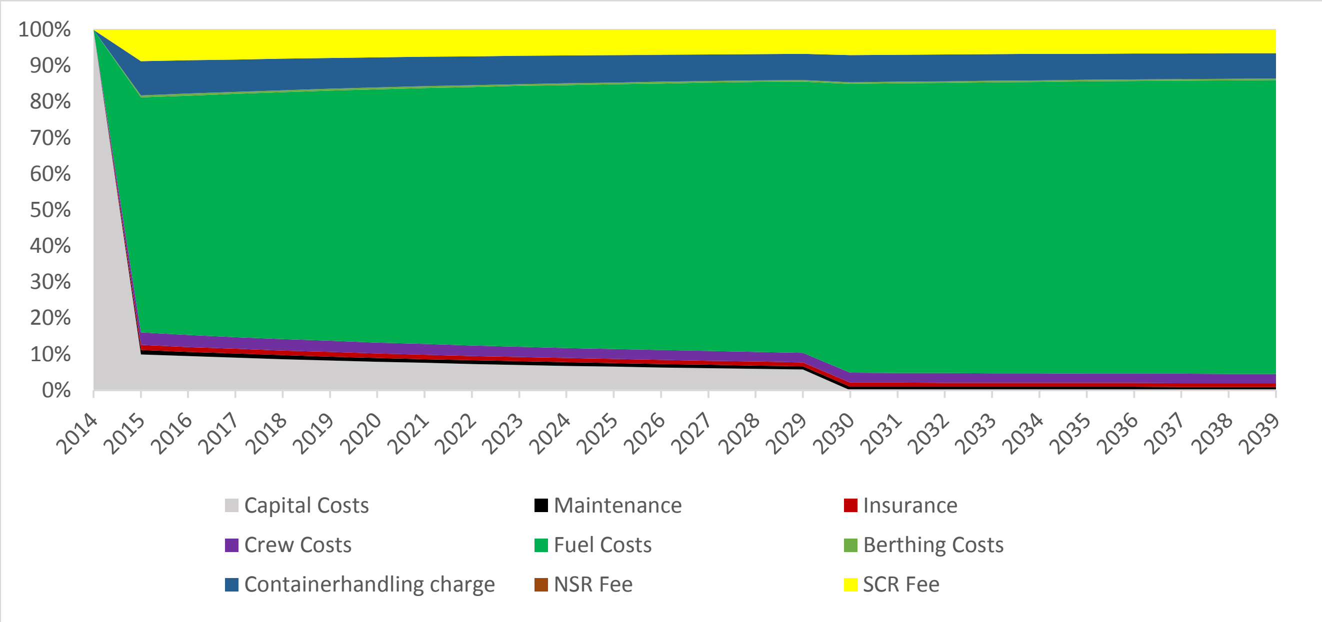

Figure 22: Total yearly cost for a 4300 TEU SCR vessel

The costs are listed for the investment of an 4300 TEU SCR vessel in year 2014 measured in nominal USD, with a constant load factor of $\epsilon_t = 0.65$*, a constant fuel cost uncertainty of* $\varphi_t = 0$.

Source: Own calculations

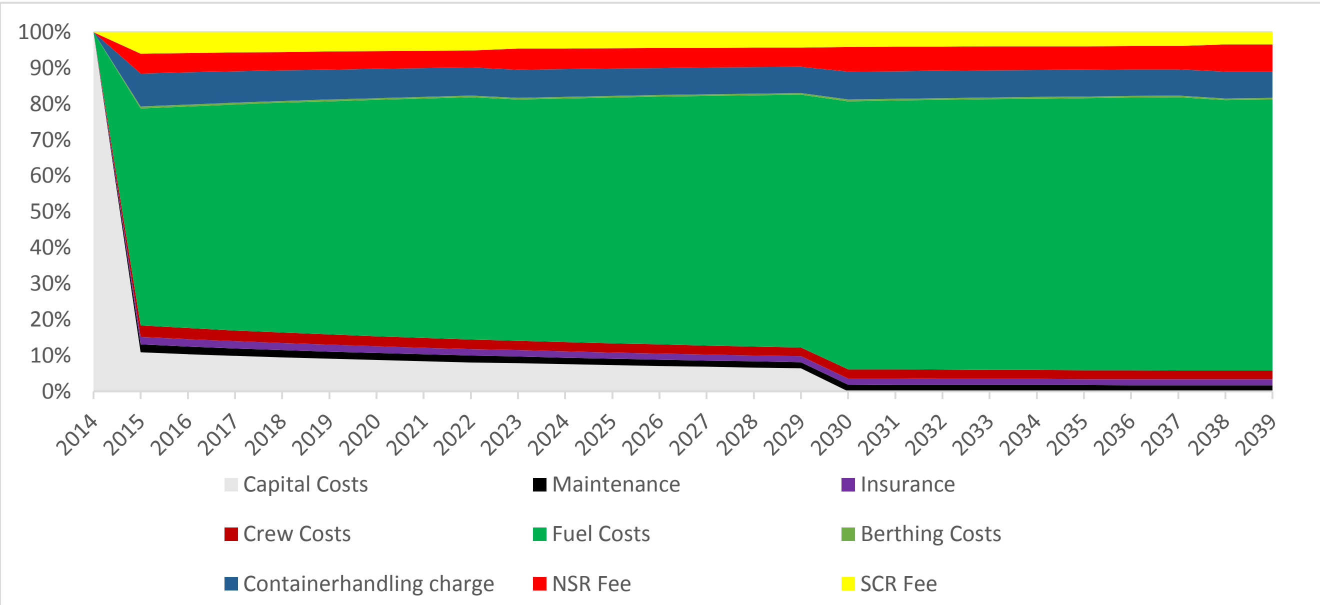

Figure 23: Total yearly cost for a 4300 TEU NSR vessel

The costs are listed for the investment of an ice-strengthened 4300 TEU vessel in year 2014 under the medium Arctic warming scenario measured in nominal USD, with a constant load factor of $\epsilon_t = 0.65$*, a constant fuel cost uncertainty of* $\varphi_t = 0$ *and a constant navigation uncertainty of* $\theta_t = 0$.

Source: Own calculations

From figure 22 and 23, it is clear that the fuel cost is by far the largest cost component ranging between sixty and eighty percent of the total yearly cost during the years operating the ship. For the ship solely operating the SCR the fuel cost accounts for a slightly larger percentage of the total costs explained by the high NSRA fee, encountered by the vessel operating along the NSR. As expected, the cost allocated by the Suez Canal toll relative to the NSRA fee, for the ice-strengthened vessel, is reduced over time explained by the increasing amount of days on which the NSR is navigable. For both vessels, the container handling charges and the capital costs account for close to ten percent of the yearly costs until the debt of the initial investment costs are fully paid. Lastly, the berthing fee and the yearly fixed costs contribute marginally to the overall costs of operating the vessel.

The cost proportions presented in this analysis differ from the results of Stopford (2009, p. 225) where a cost component breakdown of a ten-year-old bulk carrier is presented. According to Stopford (ibid.), a 42 percent of the total costs of operating the bulk carrier is attributed to the capital costs while fuel consumption accounts for only 30 percent of total costs. A reason for these significant differences can be the price of bunker fuel, which has soared in real terms in recent years (figure 17) and in this analysis, therefore, accounts for roughly twice the amount presented by Stopford (ibid.). Different vessel purchase prices can also explain the differences due to the volatility of ship building demand.

Common to this analysis and the one presented by Stopford (ibid.) is the approximately 25 percent of the total costs distributed amongst the rest of the cost components of the vessel, indicating that the bunker fuel price development could explain the total cost differences between the two analyses. The cost component breakdowns for the investments of the two 8000 TEU vessels are presented in appendix A.

Part V: Revenue

The Revenue received in period *t* consists of the income from the transportation of containers between Rotterdam and Yokohama. The amount of containers transported depends on the load factor and the container capacity of the ship as well as the total number of NSR and SCR trips in the given year. Equation 5.1 shows the revenue from the amount of containers transported for one trip in year *t*.

$$R_{t,j} = L_j \cdot \epsilon_t \cdot F_t \qquad (5.1)$$

$R_{t,j} = Revenue\ for\ one\ trip\ for\ a\ vessel\ of\ size\ j\ in\ year\ t$

$L_j = Container\ capasity\ of\ a\ vessel\ of\ size\ j$

$\epsilon_t = Load\ Factor\ in\ year\ t$

$F_t = Freight\ rate\ for\ one\ TEU\ in\ period\ t$

Multiplying the Revenue per trip with the amount of trips completed in year *t* yields the total revenue for a vessel of size *j* given warming scenario *i*, as presented in equation 5.2 and 5.3 for an NSR and SCR vessel.

$$TR_{t,j}^{SCR} = L_j \cdot \epsilon_t \cdot F_t \cdot Q^{SCR} \qquad (5.2)$$

$TR_{t,j}^{SCR} = Total\ revenue\ of\ an\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$$TR_{t,j,i}^{NSR} = L_j \cdot \epsilon_t \cdot F_t \cdot \left(Q_{t,j,i}^{NSR} + Q_{t,j,i}^{SCR|NSR}\right) \qquad (5.3)$$

$TR_{t,j,i}^{NSR} = Total\ revenue\ of\ an\ NSR\ vessel\ of\ size\ j\ and\ warming\ scenario\ i\ in\ year\ t$

The freight rate is defined as the price a costumer faces for the transport of a certain unit of cargo. In this study, the freight rate is denoted as a fixed rate per TEU transported between the ports of Rotterdam and Yokohama. The freight rate is generally characterized by high price fluctuations depending on the container transport supply and demand, which in turn is affected by business cycle fluctuations. In addition, freight rates are higher for eastbound cargo than westbound cargo (Kronbak & Liu, 2010, p. 442) and can be negotiated by large firms regularly needing transport of goods, which results in a lack of freight rate transparency (Stopford, 2009, p. 555). Comprehensive time series data on the freight rate of containerized goods is offered by several maritime consulting firms but is due to financial considerations not readily available to the author. The freight rates used in this analysis are spot prices calculated using the freight rate service World Freight Rates for a 40 feet container (73 percent of world containerized cargo is transported in 40 feet containers equivalent to two TEU (Stopford, 2009, p. 511)) with an estimated cargo value of 30.000 USD of goods per TEU. The eastbound freight rate is calculated to lie between 1,808.77 and 1,999.16 USD while the significantly higher westbound freight rate is calculated to lie between 2,637.62 and 2,915.27. The mean value of the east- and westbound freight rates then calculates to ≈ 1904 USD and ≈ 2776 USD, respectively. Since the average amount of east and westbound trips in the long run is equal and the load factor is the same for both directions in this scenario, an average of the two mean prices is used. This calculates to 2340 USD for a 40 ft. container, which translates to 1170 USD per TEU and is therefore used in this study. According to the Maersk Line Shipping Service a freight rate consists of several variable factors. These are the basic freight rate (BAS), terminal handling charges (THC), documentation charges and the bunker adjustment factor (BAF). The price development of the basic freight rate is set to follow the annual rate of inflation. The THC and the documentation charges are set to be included in the annual inflationary price increase, captured by the price development of the container handling charges and the berthing fee. Additionally, the Aden Bay pirate security charge is also assumed to be included in the basic price leaving only the BAF to be calculated separately. The freight rate in year t is presented in equation 5.4.

$$F_t = 1170 \cdot (1+\pi)^t + \gamma_t \qquad (5.4)$$

$F_t = Freight\ rate\ in\ year\ t\ (USD)$
$\gamma_t = Bunker\ adjustment\ fee\ in\ year\ t$

The annual freight rate increase is assumed to be determined by the 4300 TEU vessel solely operating along the SCR such that the revenue of the NSR vessels depends on the exogenously given SCR freight rate. As long as the NSR is in the container shipping entry game, the freight rates are set exclusively by the ordinary SCR vessels due to the use of the major transport route as well as being the incumbent and dominating container transport supplier.

Since the forecasted values of the price of bunker fuel are subject to a real price increase (because the annual fuel price increase exceeds two percent), the BAF is determined such that the annual real freight rate increase equals the annual real costs increase, excluding the vessel building price. If no BAF is included in this scenario, the profits of the SCR transport companies will eventually turn negative as all income only increases in nominal terms while the total costs are increasing in real terms due to the fuel price development. Because the voyage time along the SCR is constant, the annual amount of trips is also constant, causing a constant revenue to cost ratio given the assumptions of this analysis. The constant $\bar{k}$ is set to be the revenue to cost ratio for the 4300 SCR vessel (SCR4) in year 2014 (*t=0*). This means that the ratio of revenue is constant for all periods shown mathematically by equation 5.5.

$$\frac{TR_{t,4300}^{SCR}}{VC_{t,4300}^{SCR} + FC_{t,4300}^{SCR}} = \bar{k}_{0,4300} \qquad (5.5)$$

$\bar{k}_{0,4300} = Revenue\ to\ cost\ ratio\ for\ a\ 4300\ TEU\ SCR\ vessel\ in\ year\ 2014\ (t = 0)$

Expanding the total revenue (equation 5.2) transforms equation 5.5 into 5.6.

$$\frac{Q^{SCR} \cdot L_{4300} \cdot \epsilon_t \cdot [F_0 \cdot (1+\pi)^t + \gamma_t]}{VC_{t,4300}^{SCR} + FC_{t,4300}^{SCR}} = \bar{k}_{0,4300} \qquad (5.6)$$

Isolating γ_t in equation 5.6, yields the equation used to calculate the BAF in year *t* (equation 5.7).

$$\gamma_t = \bar{k}_{0,4300} \cdot \frac{VC_{t,4300}^{SCR} + FC_{t,4300}^{SCR}}{L_{4300} \cdot \epsilon_t \cdot Q^{SCR}} - F_0 \cdot (1+\pi)^t \qquad (5.7)$$

It is important to note that the BAF is set to vary with price fluctuations in the price of bunker fuel but is independent of the load factor, such that actual demand fluctuations do not affect the BAF, resulting in the need for a constant average load factor in the calculations.

Inserting the numerical values while defining constant value of the load factor of $(\epsilon) = 0.65$ and a revenue to cost ratio of in year 2014 of $\bar{k}_{0,SCR4} = 1.247$ yields the equation used to calculate the BAF per TEU for each year *t*. The BAF in numerical terms and expressed as a function of time (*t*), the annual rate of inflation (π) and the fuel price stochastic variable φ_t are presented in equation 5.8.

$$\gamma_t = 829.92 + 63.75 \cdot t + 3 \cdot \varphi_t - 829.92 \cdot (1+\pi)^t \qquad (5.8)$$

Inserting equation 5.8 into the freight rate equation 5.4, yields the freight rate equation in numerical terms.

$$F_t = 829.92 + 63.75 \cdot t + 3 \cdot \varphi_t + 340.08 \cdot (1+\pi)^t \qquad (5.8)$$

Throughout the analysis, the stochastic load factor is assumed the only variable describing world freight demand fluctuations and the freight rate therefore does not affect demand as long as the freight rates are described by the equations of this chapter.

- ***Assumption 6***: *The freight rate pricing schemes described in this paper do not affect world demand for transport of containerized goods.*

Part VI: Financial Cost-Benefit Analysis

The Financial cost-benefit analysis is performed by calculating the NPV of the investment in a vessel for transporting goods between Rotterdam and Yokohama, depending on the year the investment is initiated. The theory behind the calculation of the NPV of an investment is presented in chapter 2.1, earlier in this paper. The discount factor is defined as the rate of return on an alternative investment. Depending on the risk averseness of the ship owner an alternative investment can take the form of risk free or high risk stocks, but will most likely be the investment in an alternative ship. Stopford (2009, p. 261) notes that many shipping companies use a real yearly discount factor of 15 percent, which is therefore used for the NPV analysis of this paper.

The purpose of this analysis is to determine the year where the NPV of an investment in a vessel designed for the transport on the NSR exceeds the NPV of an investment in a normal SCR vessel initiated in the same year. Equation 6.1 shows the equation used for calculating the NPV with an investment start in year s, with a duration of *25* years.

$$NPV_{s,j,i} = \sum_{t=s}^{s+25} \frac{TR_{t,j,i} - TC_{t,j,i}}{(1+\pi+\delta)^t} \qquad (6.1)$$

$R_{t,j,i} = Revenue\ for\ vessel\ of\ size\ j\ and\ ice\ scenario\ i\ in\ year\ t$

$TC_{t,j,i} = Total\ costs\ for\ a\ vessel\ of\ size\ j\ and\ ice\ scenario\ i\ in\ year\ t$

$\delta = Real\ rate\ of\ depreciation$

$s = Year\ in\ which\ investment\ is\ initiated$

Expanding the total revenue and total costs components in equation 6.1, for the NSR and SCR vessels, yields equations 6.2 and 6.3.

$$NPV_{s,j,i}^{NSR} = \sum_{t=s}^{s+25} \frac{Q_{t,j,i}^{SCR|NSR} \cdot (R_{t,j} - C_{t,j}^{SCR}) + Q_{t,j,i}^{NSR} \cdot (R_{t,j} - C_{t,j}^{NSR}) - FC_{t,j}^{NSR} - A_{t|s,j}^{NSR}}{(1+\pi+\delta)^t} \qquad (6.2)$$

$NPV_{s,j,i}^{NSR} = NPV\ of\ a\ year\ s\ investment\ in\ an\ NSR\ vessel\ of\ size\ j\ and\ warming\ scenario\ i$

$$NPV_{s,j}^{SCR} = \sum_{t=s}^{s+25} \frac{Q^{SCR} \cdot (R_{t,j} - C_{t,j}^{SCR}) - FC_{t,j}^{SCR} - A_{t|s,j}^{SCR}}{(1+\pi+\delta)^t} \qquad (6.3)$$

$NPV_{s,j}^{SCR} = NPV\ of\ a\ year\ s\ investment\ in\ an\ SCR\ vessel\ of\ size\ j$

Dividing the NPV of the investment in an NSR vessel with the NPV of the investment in an SCR vessel, for containerships of the same carrying capacity with an investment start in the same year, yields the investment NPV ratio. If the ratio takes a value of above one, the investment of an NSR vessel take a higher NPV than the investment in an ordinary SCR vessel, while a value between zero and one results in the opposite. It is important to note, that when calculating the year when the NPV of an investment in an NSR vessel exceeds the investment in an SCR vessel, both investments in a containership must be initiated in the same year. For a comparison between the two investment types the cash flows also need to be discounted to the same year (all cash flows in this analysis are discounted to 2014 USD).

An alternative way of comparing the two transport route investments is to use the annual rate of return from the investment in a Suez Canal vessel as a discount factor in the NPV investment analysis of an NSR containership. Doing so would result in the NPV of the investment in an NSR vessel to be preferable to an investment in an SCR vessel, for investment values of above zero, while also presenting the results in numerical terms. As this thesis provides a comparative analysis between the two transport routes, the investment ratio is deemed to be more in line with the research question.

The NPV investment ratio for vessels of size j and Arctic warming scenario i, given an investment start in year s, is calculated using equation 6.3.

$$Ratio_{s,j,i} = \frac{NPV_{s,j,i}^{NSR}}{NPV_{s,j}^{SCR}} \qquad (6.3)$$

$Ratio_{s,j,i} = Ratio\ of\ the\ NPV\ for\ vessel\ type\ j\ in\ global\ warming$
$scenario\ i\ for\ investment\ start\ in\ year\ s$

The NPV ratio conditional on the investment year is calculated using Monte Carlo simulation with 500 iterations by use of the program @Risk. The simulations of the investment ratio include all the stochastic variables: The load factor ϵ_t, the navigation day uncertainty θ_t and the fuel price uncertainty φ_t. The graphs of the simulations for the 4300 and 8000 TEU vessels in medium and high Arctic warming scenarios are presented in the figures 24 through 27, while the ones for the low Arctic warming scenarios are listed in appendix B (In the low Arctic warming scenarios none of the investment years reach a value of one).

Note: Due to financial considerations, a trial version of @Risk 6.0 is used to perform Monte Carlo simulations throughout this analysis section, and the graphs and distribution outputs therefore come with a trial version label.

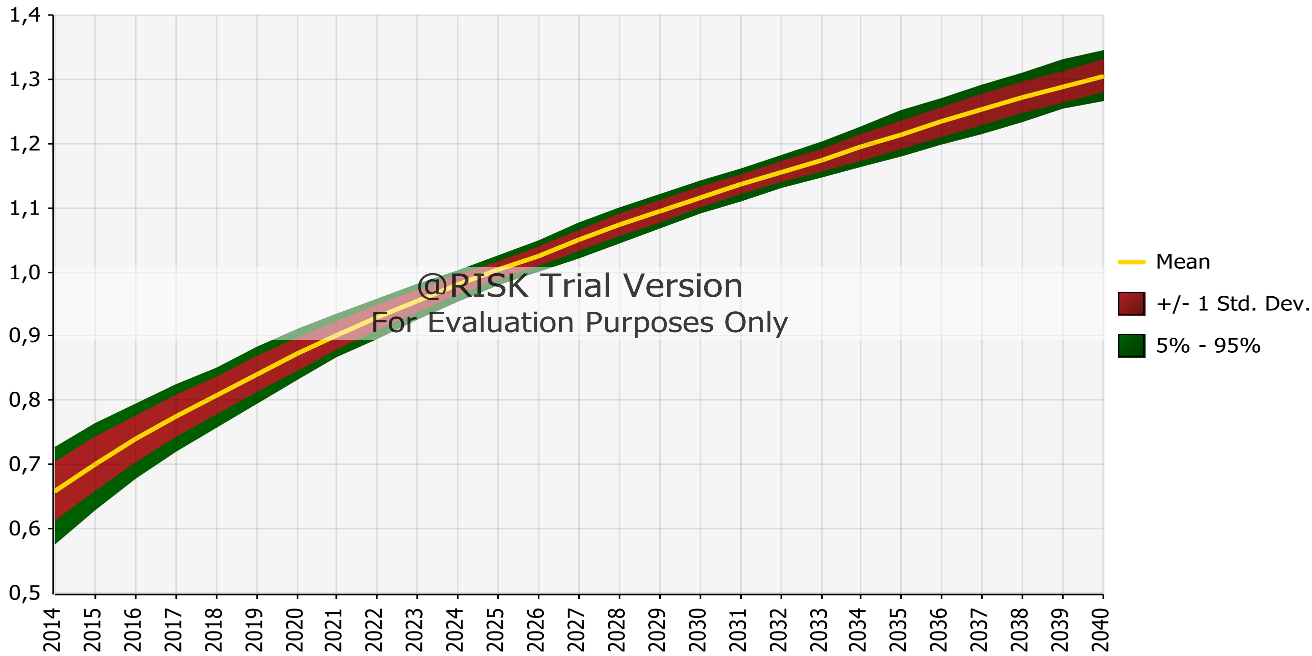

Figure 24: Investment Ratios of 4300 TEU vessels in medium Arctic warming scenario
The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 4300 TEU containership in the Arctic medium warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

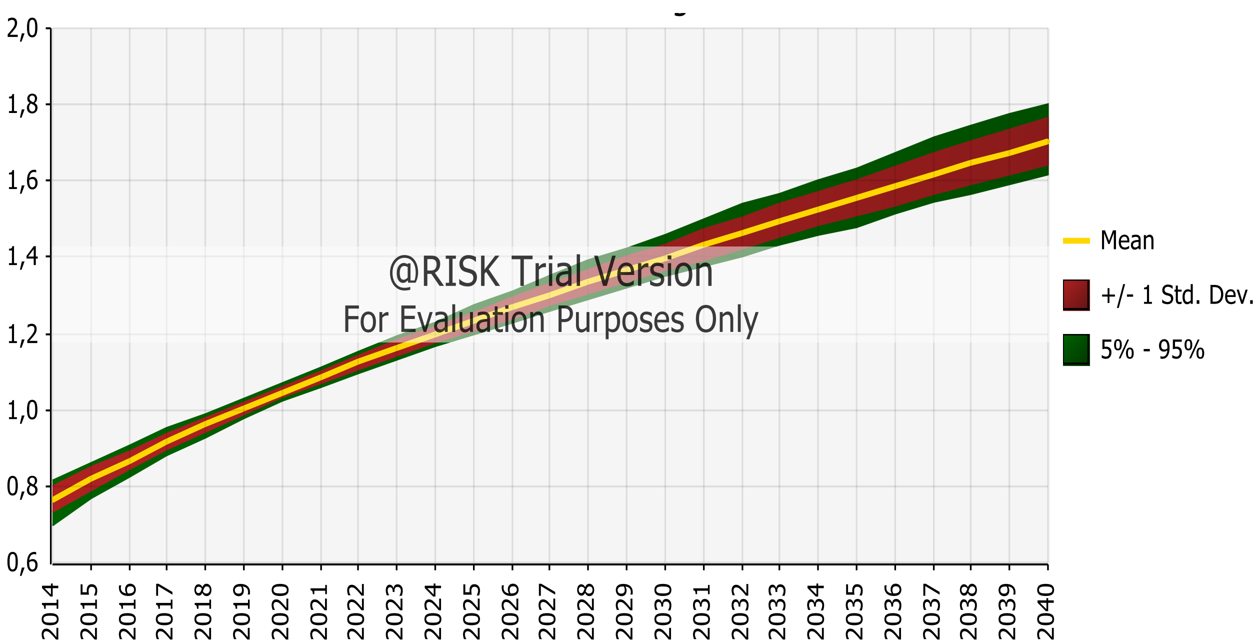

Figure 25: Investment *Ratios of 4300 TEU vessels in the high Arctic warming scenario*
The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 4300 TEU containership in the Arctic high warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

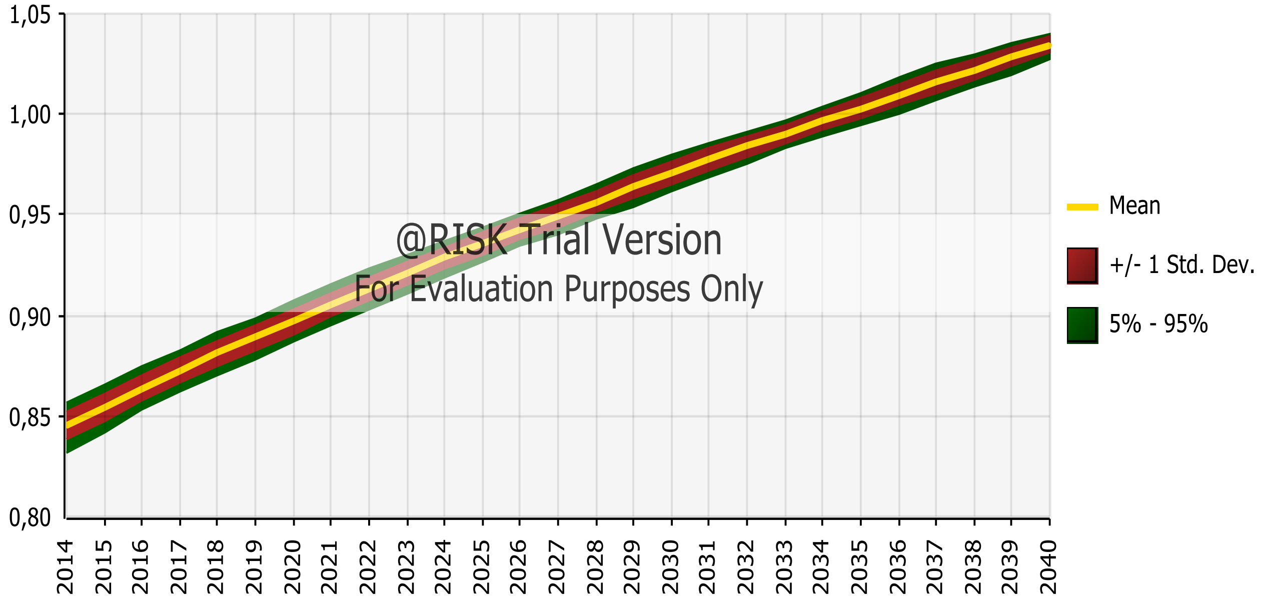

Figure 26: Investment Ratios of 8000 TEU vessels in the medium Arctic warming scenario

The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 8000 TEU containership in the Arctic medium warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

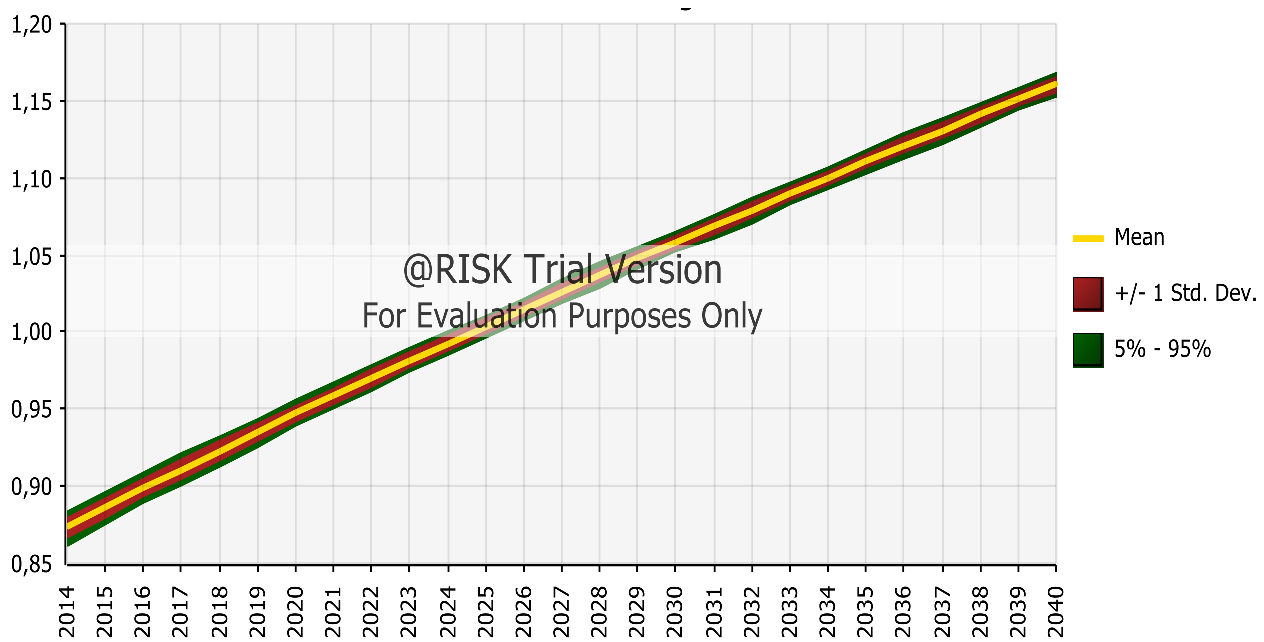

Figure 27: Investment Ratios of 8000 TEU vessels in the high Arctic warming scenario
The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 8000 TEU containership in the Arctic high warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

The figures 24 through 27 all show an increasing trend in the investment ratio as a function of time explained by the increase in the investment return of a NSR vessel as the Arctic is warming. This trend clearly illustrates the effect an increasing number of navigation days have on the economic feasibility of using the NSR compared to the SCR. The standard deviations are all small ranging between 0.005 and 0.03 causing an easy interpretation of the investment break even points. Table 5 shows the earliest point where the NPV of an investment in an NSR vessel equals or exceeds the NPV of the investment in an SCR vessel on a 95 percent significance level. The significance levels are calculated from the individual Monte Carlo simulation probability density functions listed in appendix B.

Table 5: Earliest years with significance levels of above 95 percent

	Earliest 95 % Significance level of investment ratio ≥ 1 (year)	*Significance level (percent)*
4300 TEU – medium Arctic warming	*2026*	*96*
4300 TEU – high Arctic warming	*2020*	*100*
8000 TEU – medium arctic warming	*2036*	*95.6*
8000 TEU – high Arctic warming	*2026*	*100*

Source: Own calculations using @Risk 6.0

In the high Arctic warming scenario, the investment in a 4300 TEU ice-strengthened containership becomes favorable to an investment in an ordinary SCR vessel already in 2020, while this increases to 2026 for the medium warming scenario – both on a 95 significance level. This means that if the amount of annual navigation days increases by just three, the NSR becomes economically feasible compared to the SCR within a little more than a decade. This changes to within a little less than a decade if the ice cover allows for an average increase of five navigation days.

Not surprisingly, the higher latitudes of the NSR, allowing for the transit of the 8000 TEU vessels, causes the time, at which the investment is favorable, to lie further in the future. In the medium Arctic warming scenario, the ratio is significantly greater than one at a 95 percent significance level from 2036. Given a high Arctic warming scenario, the investment in an 8000 TEU NSR vessel is favorable to an SCR vessel built in the same year in 2026 on a 100 percent significance level, which is only six years later than the smaller 4300 TEU vessel. This implies that the transit of goods using large containerships along the NSR is possible within 12 years if Arctic warming is sufficiently high, creating the potential to turn the high NSR into a major world transport lane.

Part VII: Breakeven NSR Fee

In the previous part it was concluded that as early as 2020 the investment in an ice-strengthened containership using the NSR when navigation is allowed, and the SCR when not, is favorable to the investment in an open water SCR vessel of the same size. A lowering of the icebreaker fee set by the NSRA would most certainly cause the breakeven point between the NSR and the SCR designed vessels to move closer to the present time.

Isolating the base icebreaker fee P_{2014}^{IB} in the NPV ratio of the previous section allows for the finding of the critical value of the icebreaker fee that yields an investment breakeven point.

$$\frac{NPV_{2014,j,i}^{NSR}(P_{2014}^{IB})}{NPV_{2014,j}^{SCR}} > 1 \qquad (7.1)$$

Equation 7.1 shows the point where an investment in an ice-reinforced vessel of container capacity *j* given Arctic warming scenario *i,* initiated in year 2014 is higher compared to an investment in an ordinary vessel of same capacity and same investment year, as a function of the icebreaker fee.

The equation is not possible to solve algebraically due to the number of NSR trips only taking whole number values, and it therefore needs to be solved using the @Risk goal seek program. The goal seek function of @Risk works by finding the value of the variable cell that approximates the values of the restrictive cell to form a user set value and standard deviation. Solving equation 7.1, means finding the critical value of the icebreaker fee P_{2014}^{IB} (under the assumption of $P_t^{IB} = (1+\pi)^t$), that causes the simulated value of the investment ratio to be significantly above one.

The critical icebreaker fee values are presented in table 6. The negative values indicate that the NSRA should pay the ship operators a fee for the icebreaker assistance along the NSR, which is obviously unrealistic. If the icebreaker fee is set to 3.3 USD per gross ton in the current year an investment in a 4300 TEU containership is presently favorable to investment in an open water SCR containership in both the medium and high Warming scenarios.

Table 6: Critical NSRA icebreaker fees for a 2014 breakeven investment ratio

	Critical NSRA icebreaker fee (USD/GT)
4.300 TEU low Arctic warming	*-2.54*
4.300 TEU medium Arctic warming	*3.318*
4.300 TEU high Arctic warming	*7.825*
8.000 TEU low Arctic warming	*-41.23*
8.000 TEU medium Arctic warming	*-17.773*
8.000 TEU high Arctic warming	*-5.81*

The critical icebreaker fees are calculated for the investment ratio to be significantly above one. The investment ratio is the NPV for an ice-reinforced vessel divided by the NPV of an open water vessel initiated in the same year. Values are calculated using the @Risk goal seek with 100 iterations using all stochastic variables ϵ_t, φ_t *and* θ_t.
Source: Own calculations using @Risk 6.0

While such a low icebreaker fee also seems unrealistic, the critical value in the high scenario of 7.8 USD per gross ton is comparable to the actual icebreaker fee used as reported by Falck (2012). If the NSRA is persistent in keeping the icebreaker fee on such a level and global warming causes the ice-cover to recede in accordance with the high warming scenario of this analysis, a current year investment in a 4300 TEU NSR vessel is favorable to an investment in an SCR vessel of the same size.

Part VIII: Possible Route Extensions

With a total amount of TEU of 48 and 17 million handled in 2012, the Shanghai/Ningbo area and the Port of Busan dwarf the Tokyo ad Yokohama bay area with 7.6 million TEU handled in the same year (Containerisation International, 2013). Other major ports in the vicinity include the Chinese cities of Qingdao and Tianjin with a yearly container handling of 14.5 million and 12.3 million TEU. From part six, the conclusion was that the return of an investment in an ice strengthened vessel for the use on the NSR exceeds the return of an investment in a SCR vessel as soon as the year 2020. With an ever-decreasing ice-cover in the Arctic Ocean the annual revenue of transporting goods using the NSR will only increase compared to the SCR. This means that reaching a breakeven point between the two routes will result in the maximum NSR distance moving further south towards the major port cities in South Korea and China. The fastest way to reach Busan, Qingdao, Tianjin or Shanghai using the NSR is to use a route west of Japan through the Sea of Japan towards the Korean peninsula. Figure 28 shows the NSR extensions to the cities of Busan, Shanghai, Qingdao and Tianjin.

In regards to using the above mentioned port cities, the determination of a yearly cash flow breakeven point must be found in order to explore the competitiveness of using the NSR, when open to navigation, and the SCR when not, as opposed to an all-year use of the SCR.

Since the NSR extensions potentially allow for a continuous increase, the yearly profit, excluding the capital costs, is compared for the NSR and SCR vessel types, respectively. Leaving out the capital costs may cause the results to be slightly positive-biased towards the ice-strengthened containerships. Table 7 shows the different route distances from Rotterdam to the East Asian port cities of Busan, Shanghai, Qingdao and Tianjin.

Table 7: Route distances from Rotterdam to destination cities

	Busan	*Shanghai*	*Qingdao*	*Tianjin*
4.300 TEU SNSR distance (nm)	*7661*	*8105*	*8145*	*8360*
8.000 TEU HNSR distance (nm)	*7281*	*7725*	*7765*	*7980*
SCR distance (nm)	*10994*	*10764*	*11024*	*11309*

Source: Own calculations using Google Earth

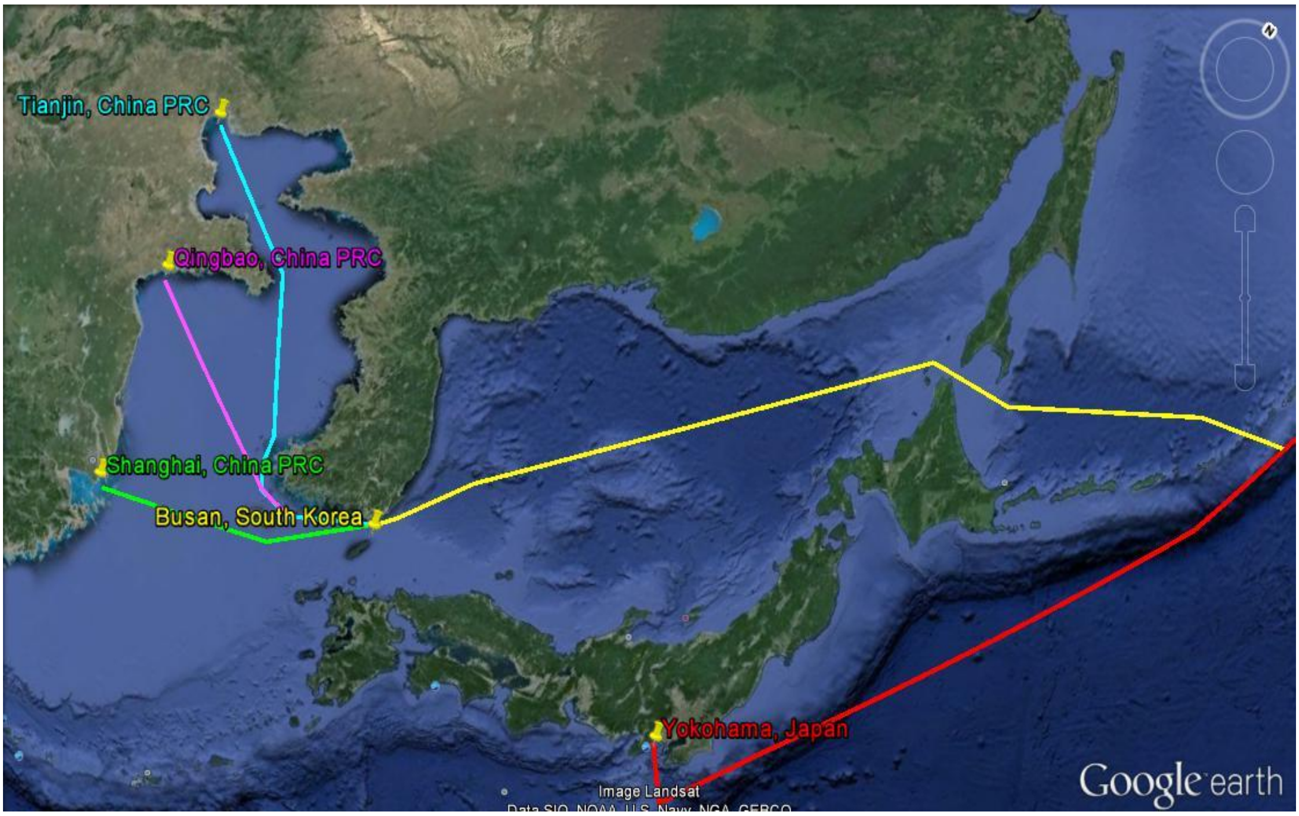

Figure 28: The Northern Sea Route alterations to destination ports.

The yellow line shows the point where the route diverges from the Yokohama route while the green, pink, and teal lines show the fastest route between Busan and Shanghai and Qingdao and Tianjin, respectively.

Source: Own calculations and Google Earth

Using the same method as in part six, the ratio between the yearly profits of an NSR vessel to an SCR vessel of the same size are calculated, using equation 8.1.

$$\Psi_{t,j,i} = \frac{TR_{t,j,i}^{NSR} - VC_{t,j,i}^{NSR} - FC_{t,j}^{NSR}}{TR_{t,j}^{SCR} - VC_{t,j}^{SCR} - FC_{t,j}^{SCR}} \qquad (8.1)$$

$\Psi_{t,j,i} = Profit\ ratio\ for\ a\ NSR\ vessel\ to\ a\ SCR\ vessel\ of\ size\ j$

$with\ Arctic\ warming\ scenario\ i\ in\ yaer\ t$

Changing equation 8.1 into a function of the modified route distances transforms it into equation 8.2.

$$\Psi_{t,j,i}(D_{SCR}, D_{NSR}, j) = \frac{TR_{t,j,i}^{NSR}(D_{SCR}, D_{NSR,j}) - VC_{t,j,i}^{NSR}(D_{SCR}, D_{NSR,j}) - FC_{t,j}^{NSR}}{TR_{t,j}^{SCR}(D_{SCR}) - VC_{t,j}^{SCR}(D_{SCR}) - FC_{t,j}^{SCR}} \quad (8.2)$$

$\Psi_{t,j,i}(D_{SCR}, D_{NSR}, j) = Profit\ ratio\ for\ a\ NSR\ vessel\ to\ a\ SCR\ vessel\ of\ size\ j$

$with\ Arctic\ warming\ scenario\ i\ in\ yaer\ t\ dependent\ on\ port\ city\ route\ distance$

$D_{SCRx} = SCR\ distance\ depending\ on\ port\ city$

$D_{NSR}, j = NSR\ distance\ for\ a\ vessel\ of\ size\ j\ depending\ on\ port\ city$

Due to the high Arctic warming scenario being the most interesting with respect to extending the NSR, the calculations are limited to this scenario. Inserting the new route distances into equation 8.2 for each route destination and vessel size, the yearly profit ratio is calculated using Monte Carlo simulation including all stochastic variables.

The following two figures show the yearly profit ratio calculations for the two vessel sizes using the route between Rotterdam and Shanghai. The figures showing the operation cost ratios for Busan, Qingdao and Tianjin are listed in appendix C.

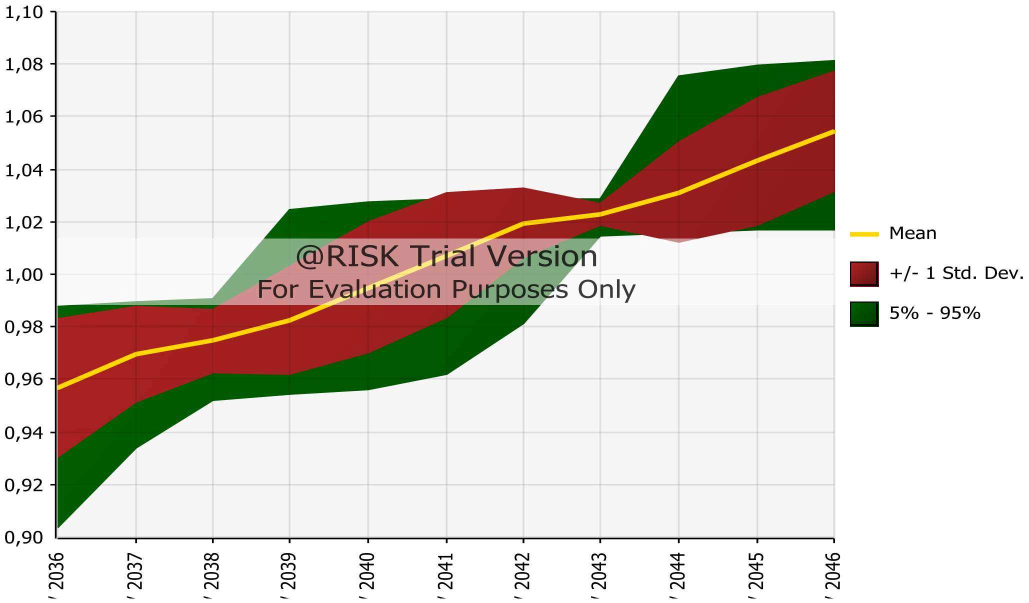

Figure 29: 4300 TEU vessel Rotterdam to Shanghai profit ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for a 4300 TEU containership between Rotterdam and Shanghai. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value, while the red band shows one standard deviation, and the green area shows the 95 percent interval.

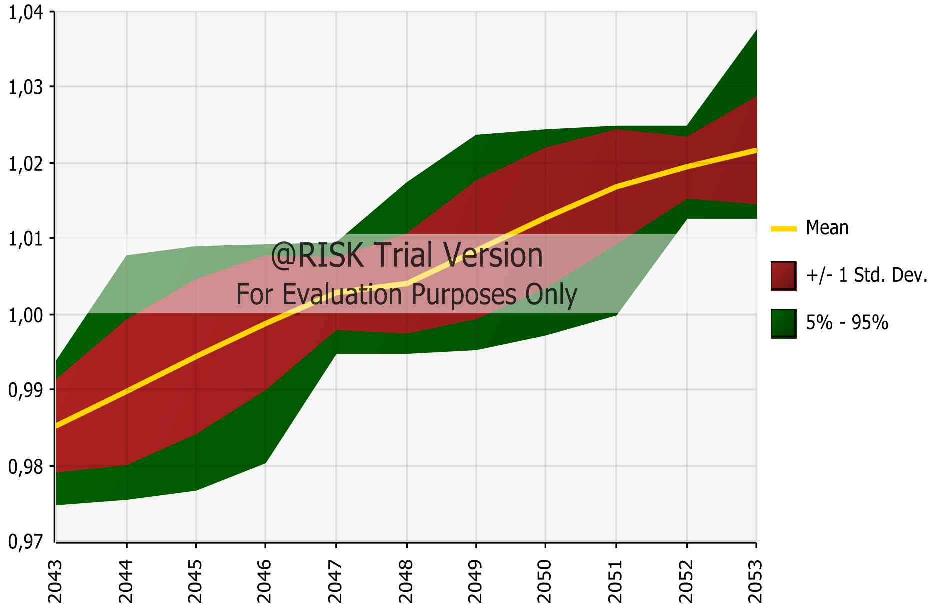

Figure 30: 8000 TEU vessel Rotterdam to Shanghai profit ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for an 8000 TEU containership between Rotterdam and Shanghai. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value, while the red band shows one standard deviation, and the green area shows the 95 percent interval.

Source: Own calculations using

From figure 29 and 30, it is clear that the increased NSR distance, along with the reduced SCR distance, causes the yearly profit breakeven point; $\Psi_{t,j,i}(D_{SCR}, D_{NSR}) = 0$, to move further into the future compared to the Yokohama route. For the 4300 TEU vessel using the Standard NSR the mean of the profit ratio reaches above one by 2041 while the ratio is not significantly above one before 2043 due to the large values of the standard deviation. The mean of the profit ratio of the 8000 TEU vessels, using the shorter high NSR, reaches above one by 2047 while the profit ratio is significantly above one in year 2051. For both ice-strengthened vessel sizes using the NSR to transport goods between Rotterdam and Shanghai, the yearly profit will not be competitive to an ordinary vessel within the next two to three decades, even given the high Arctic warming scenario.

The earliest year where the profit of an ice-strengthened vessel exceeds that of an ordinary vessel on a 95 percent significance level, depending the Asian port destination and vessel size, is presented in Table 8.

Table 8: NSR competitiveness depending on Asian destination ports

	Busan	*Shanghai*	*Qingdao*	*Tianjin*
Year with 95 % significance > 1 SNSR	*2031*	*2043*	*2038*	*2039*
Year with 95 % significance > 1 HNSR	*2036*	*2051*	*2045*	*2043*

Source: Own calculations using @Risk 6.0

The results presented in Table 8 are interpreted using @Risk simulation outputs listed in appendix C. Using an ice-strengthened NSR vessel to transport goods from Rotterdam to Busan is favorable to an ordinary SCR vessel already by 2031 and 2036 for the 4300 TEU and 8000 TEU vessel, respectively. For the 4300 TEU vessel, this increases to 2038 for Qingdao and 2039 for reaching Tianjin. This increases to 2045 and 2043 for the 8000 TEU vessel. The fairly large standard deviations of the 8000 TEU vessel profit ratios actually cause the ratio for Tianjin to be significantly above one, two years before Qingdao (note figure 43 and 44 in appendix C). All the profit-ratio simulation outputs are subject to periodically large standard deviation fluctuations causing the ratio mean to be above one, several years before the 95 percent confidence intervals. These standard deviation fluctuations are caused by the stochastic navigation day values reaching the critical levels that result in an additional NSR trip to be possible in the given year.

The prospect of the NSR being favorable to the SCR for transporting goods to several of the large East Asian ports within three decades creates the possibility of using the NSR for multiport visits. Visiting several ports during the voyage the ship operator hedges against local freight demand fluctuations and therefore reduces the overall load factor variance.

Conclusion and Discussion

The Arctic Sea ice-cover is continuously disappearing, creating the opportunities of using the NSR as an alternative maritime shipping lane to the SCR. Transporting goods via the NSR reduces the travel distance by up to 35 percent, resulting in significant reductions in voyage time and fuel costs. Due to the magnitude of the climate changes in the Arctic Sea, the need for research on the problems and economic possibilities of such an alteration has arisen. In this master thesis, a financial cost-benefit analysis was performed on the feasibility of transporting containerized goods between Rotterdam and Yokohama using the NSR as an alternative to the SCR. Throughout the paper two vessel sizes, each using a different NSR, were investigated for three different sea-ice projections. The two routes were divided into a southern NSR used by a 4300 TEU containership and a northern open water NSR used by an 8000 TEU containership.

By performing an NPV analysis using Monte Carlo simulation this paper finds that as soon as 2020 the investment in 4300 TEU containership using the NSR is preferable to an investment in an ordinary Suez Canal vessel, given a yearly navigation day increase of 5 on in the Arctic Sea. With such a reduction in the ice-cover, the investment in an 8000 TEU ice-strengthened containership becomes favorable to the investment in a Suez Canal vessel of the same size by 2026, creating the possibility of using super large transport ships on the NSR. In addition to the investment analysis, this paper finds that, given a reasonable icebreaker fee of seven US dollars per gross ton, an investment in a 4300 TEU ice-strengthened containership may already be favorable presently. From the assumption of a continuous and rapid decline of ice-cover in the Arctic Sea, this paper also finds that by the 2040s the NSR may compete with the SCR in several East Asian ports as far south as Shanghai.

The prospect of investing in an ice-strengthened vessel for transporting goods between Rotterdam and Yokohama, using the NSR as soon as 2020 rests upon several crucial assumptions and is subject to serious uncertainties. These uncertainties include the topics of icebreaker availability, uncertain variables, entry deterrence, future fuel prices and multiple port visits. The Arctic Ocean spans a vast area and is subject to extreme weather. The analysis assumed that the yearly navigation period was continuous and that icebreaker assistance was always available. In a real scenario however, a sudden change in the weather pattern may cause the NSR to close, severely increasing the voyage time, causing delays and loss of revenue. Icebreaker assistance might not always be readily available, causing the average waiting time of eight days on an NSR trip to further increase.

As mentioned in the previous section, multiple port visits along the voyage hedges the ship operator against local demand slumps while also having the potential to increase the amount of goods transported per trip. One of the assumptions throughout this paper was that a voyage only included one port visit, which is a realistic assumption for a vessel operating along the NSR given the sparsely populated Russian Arctic. In contrast to the NSR, numerous major port cities are situated along the SCR, creating the potential for a revenue much larger than calculated in this paper, and consequently overestimating competitiveness of the NSR.

Whether the results found in the analysis are over- or underestimating the competiveness of the NSR is a question only the future can reveal. In this paper, the price developments of bunker fuel are projected using a univariate forecasting model under the critical assumption of no major geopolitical events. Looking forty years into the past, it becomes clear that such dramatic events occurs frequently. Even during the months used writing this master thesis, shale gas and oil extraction in the Dakotas are changing the geopolitical landscape of the world (The Economist, 2014). The assumption of no such global events occurring is in itself contrary to the background of this master thesis. The ever-changing Arctic has the potential to change the transport infrastructure of the world and thereby deprive the Suez Canal of its choke point location as the fastest shipping lane between Europe and East Asia. With a sharp decline in the number of pirate attacks in the bay of Aden (Stavridis, 2013), the Suez Canal is still one of the world's most important transport routes. Unlike the Russian Federation, Egypt does not need to maintain a ready icebreaker fleet nor create a maritime infrastructure in a remote and sparsely populated part of the world. As the incumbent provider of one of the worlds most trafficked shipping lanes, the Suez Canal authority has the potential to use policies of entry deterrence in order to postpone the prospect of Arctic Shipping. By lowering the Suez Canal transit fee, the NPV and profit-ratios calculated in this paper are lowered and thereby reduce the ship-owners' incentives to use the NSR. Even the announcement by the Egyptian authorities of a lowering of the future Suez Canal tariff may increase the projected opportunity costs of investing in a vessel designed for the NSR and thereby maintain its role as the most important route between Europe and Asia. Even though the Suez Canal presently maintains its importance, a change of the pricing policies set by the canal authorities will still not be able to prevent the melting of the Arctic Sea ice-cover along the NSR, resulting in an increased inclination towards using the NSR in the future. Transporting goods through the Artic, as an alternative to the SCR, results in a dramatic reduction in the travel distances, which is still a major determining factor in the cost of maritime shipping. As the ice-cover along the NSR diminishes, the icebreaker fee, as well as the eight days of average waiting time encountered when navigating the NSR, will most certainly see a reduction in the future, adding to the already significant cost and voyage time advantages of the NSR.

Incorporating more advanced oil price forecasts, shipping cycles and multiple port visits per route will certainly enhance the predicting power of this paper and create a better economic foundation for investing in transport ships designed to operate in the high Arctic.

Literature List

ACIA. (2004). *Impacts of a Warming Arctic: Arctic Climate Impact Assessment.* Cambridge: Cambridge University Press. Retrieved from http://www.acia.uaf.edu

AECOM. (2012). *Vessel Size vs. Cost.* North Caroline Maritime Strategy.

Arctic Council. (2009). *Arctic Marine Shipping Assesment 2009 Report.* Arctic Council.

Arctic Econ. (2012). The Northern Sea Route as a Viable Development - Russia's Fleet of Atomic Icebreakers. Retrieved from http://Arcticecon.wordpress.com

Baumeister, C., & Kilian, L. (2013). Forecasting the Real Price of Oil in a Changing World: A Forecast Combination Approach. *Bank of Canada Working Paper*(28).

BBC News. (2013). Russia 'Seizes' Greenpeace ship after Arctic rig protest. BBC. Retrieved from http://www.bbc.co.uk/news/world-europe-24170129

Blanchard, O., Amighini, A., & Giavazzi, F. (2010). *Macroeconomics - A European Persective* (1 ed.). Essex: Pearson Education Limited.

Bloomberg News. (2012). Ship-Scrapping Prices Plunge in Buyer's Market: Freight. Bloomberg. Retrieved from http://www.bloomberg.com/news/2012-07-11/ship-scrapping-prices-plunge-in-buyer-s-market-freight.html

Bowerman, B. L., & O´Connell, R. T. (2007). *Business Statistics in Practice* (Fourth Edition ed.). McGraw-Hill.

British Petrolium. (2014). *British Petrolium conversion rates*. Retrieved from http://www.bp.com/conversionfactors.jsp

Bryanski, G. (2013, September 22). Russia's Putin says Arctic trade route to rival Suez. Reuters Canada. Retrieved from http://ca.reuters.com/article/topNews/idCATRE78L5TC20110922?pageNumber=1&virtualBrandChannel=0

Canal, S. (2013). *The Suez Canal Authority*. Retrieved from http://www.suezcanal.gov.eg/

Christensen, P. O., & Sørensen, B. G. (2005). *Investment Theory (Danish).* Odense: University of Southern Denmark.

Containerisation International. (2013). *Top 100 Ports in 2013.* Lloyd´s List. Retrieved from http://europe.nxtbook.com/nxteu/informa/ci_top100ports2013

EIA. (2013). *Annual Energy Outlook 2013 - with Projections to 2040.* U.S Energy Information

Administration. Retrieved from www.eia.gov/forecasts/aeo

EIA. (2013). *U.S Energi Information Administation Data*. Retrieved from http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=A

Falck, H. (2012). *Shipping in Arctic Waters.* Tschudi Shipping Company AS. Retrieved from http://www.sjofart.ax/files/henrik_falck_shipping_in_arctic_waters.pdf

Federal Reserve. (2013). *Statement on Longer-Run Goals and Monetary Policy Strategy.* Federal Reserve Bank of America. Retrieved from http://www.federalreserve.gov/monetarypolicy/files/FOMC_LongerRunGoals.pdf

Flake, L. E. (2013). Navigating and Ice Free Arctic. *The RUSI Journal, 3*(158), pp. 44-52.

Fournier, J.-M., & Wanner, I. (2013). The Price of Oil - Will it Start Rising Again? *OECD Department Working Papers*(1031). Retrieved from http://dx.doi.org/10.1787/5k49q186vxnp-en

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

Gujarati, D. N., & Porter, D. (2010). *Essentials of Econometrics* (4 ed.). McGraw-Hill - International Edition.

Gupta, A. (2009). Geopolitical Implications of Arctic Meltdown. *Strategic Analysis, 33*(2), pp. 174-177.

Hanke, J. E., & Wichern, D. (2005). *Business Forecasting* (8 ed.). Upper Saddle River: TBS International Edition.

Ho, J. (2010). The implications of Arctic sea ice decline on shipping. *Marine Policy*(34), pp. 713-715.

Hoshmand, A. R. (2010). *Business Forecasting - A practical approach* (Second Edition ed.). Routledge - Tayler & Francis Group.

IMO. (1982). *International Conference on tonnage measurement of ships, 1969.* International Maritime Organisation. Retrieved from http://www.uscg.mil/hq/msc/tonnage/docs/TM_Convention_Draft_Text_Version_With_Figures.pdf

IMO. (2010). Guidelines for Ships Operating in Polar Waters. (Elektronic Edition). International Maritime Organisation. Retrieved from http://www.imo.org/Publications/Documents/Attachments/Pages%20from%20E190E.pdf

Kaufmann, R., Karadeloglou, P., & di Mauro, F. (2008). Will Oil Prices Decline over the Long Run? *Occasional Paper Series*(98).

Khanna, P. (2008). *The Second World - Empires and Influence in The New Global Order.* Penguin Books.

Kitagawa, H., & Kon, Y. (2001). *The Northern Sea Route - The shortest sea route linking East Asia and Europe.* Ship & Ocean Foundation.

Kon, Y., & Kitagawa, H. (2001). *The Northern Sea Route - The shortest sea route linking East Asia and Europe.* Ship & Ocean Foundation. Retrieved from http://www.sof.or.jp

Kristensen, H. O. (2013). *Danmarks Rederiforening - The Danish Shipowners' Association*. Retrieved from http://www.shipowners.dk/

Kronbak, J., & Liu, M. (2010). The Potential Economic Viability of Using the Northern Sea Route (NSR) as an Alternative Route between Asia and Europe. *Journal of Transport Geography*(18), pp. 434-444.

Kullerod, L., Beaudoin, Y., Poussart, J.-N., Prokosch, P., & Sund, H. (2013). The Arctic Ocean and UNCLOS Articly 76: Are There Any Commons. *NATO Science for Peace and Security Series C: Environmental Security*, pp. 185-194.

Laulajainen, R. (2009). The Arctic Sea Route. *International Journal of Shipping and Transport Logistics*(1,1).

Leth Agencies. (2014). *Leth Agencies Toll Calculator*. Retrieved from http://lethagencies.com/calculator-guidelines

Maersk Line. (2014). *Maersk Line Shipping Service*. Retrieved from http://www.maerskline.com/da-dk/shipping-services/rates-and-pricing

Maslowski, W., Kinney, J. C., Higgins, M., & Roberts, A. (2012). The Future of Arctic Sea Ice. *Annual Review of Earth and Planetary Sciences, 40*, pp. 625-654.

Mulherin, N., Sodhi, D., & Smallidge, E. (1994). *Northern Sea Route and Icebreaking Technology - An Overview of Current Conditions.* Hanover: US Army Corps of Engineers.

NBC News. (2013). Greenpeace activists seized by Russian authorities. NBC. Retrieved from http://www.nbcnews.com/news/world/greenpeace-activists-seized-russian-authorities-v20600751

Ragner, C. L. (2000). *Northern Sea Route Cargo Flows and Infrastructure - Present State and Future Potential.* The Fridtjof Nansens Institute.

Rodrigues, J. (2008). The Rapid decline of the Sea Ice in the Russian Arctic. *Cold Regions Science and Technology, 54*, pp. 124-142.

SCA. (2014). *Suez Canal Authority*. Retrieved from www.suezcanal.gov.eg

Smith, L., & Stephenson, S. (2013). *New Trans-Arctic shipping routes Navigable by midcentury.*

Los Angeles: Department of Geography, University of California.

Solomon, S., Manning, M., Qin, D., Chen, Z., Marquis, M., Averyt, K. B., . . . Miller, H. L. (2007). *Contribution of Working Group I to the Fourth Assesment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Somanathan, S., Flynn, P., & Szymanski, J. (2008). The Northwest Passage: A simulation. *Transportation Research Part A*. doi:10.1016/j.tra.2008.08.001

Stavridis, A. J. (2013). Pirate Droves. Foreign Policy. Retrieved from http://www.foreignpolicy.com/articles/2013/11/07/pirate_droves_stavridis

Stopford, M. (2009). *Maritime Economics* (3. ed.). Abingdon, Oxon: Routledge - Taylor & Francis Group.

Staalesen, A. (2013). First container ship on the Northern Sea Route. Barents Observer. Retrieved from http://barentsobserver.com/en/arctic/2013/08/first-container-ship-northern-sea-route-21-08

The Arctic Institute. (2011). *The Arctic Institute - Center for Circompolar Security Studies*. Retrieved from http://www.thearcticinstitute.org/2011/08/arctic-shipping-expected-to-double-in.html

The Arctic Instritute. (2014). *The Arctic Institute - Center for Circumpolar Security Studies*. Retrieved from http://www.thearcticinstitute.org/

The Economist. (2014). The Economics of Shale oil - Saudi America. The Economist. Retrieved from http://www.economist.com/news/united-states/21596553-benefits-shale-oil-are-bigger-many-americans-realise-policy-has-yet-catch

The Northern Sea Route Administration. (2013). Rules of navigation on the water area of the Northern Sea Route. Ministry of Transport of Russia. Retrieved from http://www.nsra.ru/files/fileslist/20130725190332en-Rules_Perevod_CNIIMF-25-04.pdf

The Suez Canal Authority. (2014). *Suez Canal Rules of Navigation*. Retrieved from http://www.suezcanal.gov.eg/

U.S Military. (2007). *The Commander's Handbook on The Law of Naval Operations.* Department of the Navy. Retrieved from http://www.usnwc.edu/getattachment/a9b8e92d-2c8d-4779-9925-0defea93325c/1-14M_(Jul_2007)_(NWP)

University of Illinois. (2014). *The Cryosphere Today*. Retrieved from http://arctic.atmos.uiuc.edu/cryosphere

Verny, J., & Grigentin, C. (2009). Container Shipping on the Northern Sea Route. *International*

Journal of Production Economics(122), pp. 107-117.

Vidal, J. (2014). Russian Artic city hopes to cash in as melting ice opens sea route to China. The Guardian. Retrieved from http://www.theguardian.com/world/2014/feb/01/arctic-city-new-route-china

Vose, D. (1996). *Quantitative Risk Analysis - A guide to Monte Carlo Simulation.* West Sussex: John Wiley & Sons.

Walsh, J. E. (2013). Melting Ice - What is Happening to Arctic Sea Ice and What Does It Mean for Us? *Oceanography, 26*(2), pp. 171-181. doi:http://dx.doi.org/10.5670/oceanog.2013.19.

Wang, M., & Overland, J. (2009). A sea ice free summer Arctic within 30 years? *Geophysical Research Letters, 36*.

Wang, M., & Overland, J. (2013). When will the summer Arctic be nearly ice free? *Geophysical research letters, 40*, pp. 2097-2101.

Weisstein, E. (2014). *Wolfram Math World*. Retrieved from http://mathworld.wolfram.com/

Wooldridge, J. M. (2009). *Introductory Econometrics - A Modern Approach* (fourth edition ed.). Mason, Ohio: South-Western Cengage Learning.

World Bank. (2013). *World Bank Data*. Retrieved from http://data.worldbank.org/country/united-states

World Freight Rates. (2014). *World Freight Rates*. Retrieved from www.worldfreightrates.com

Appendix A

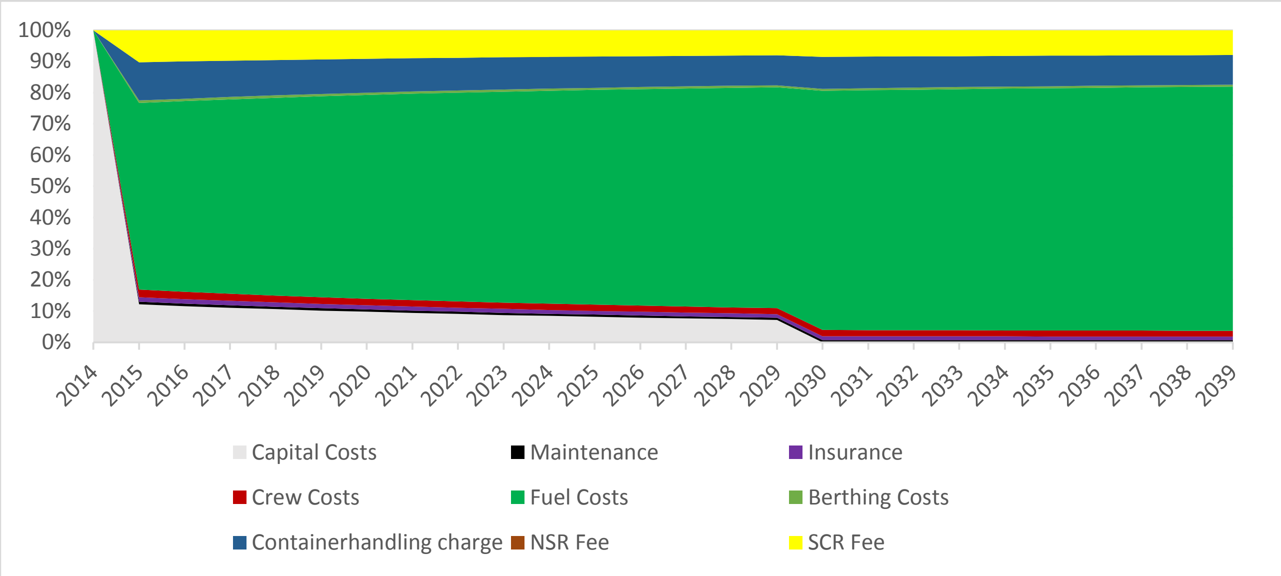

Figure 321: Total the yearly cost for an 8000 TEU SCR vessel

The costs are listed for the investment of an open water 8000 TEU vessel in year 2014 under the medium Arctic warming scenario measured in nominal USD, with a constant load factor of $\epsilon_t = 0.65$*, a constant fuel cost uncertainty of* $\varphi_t = 0$.

Source: Own calculations

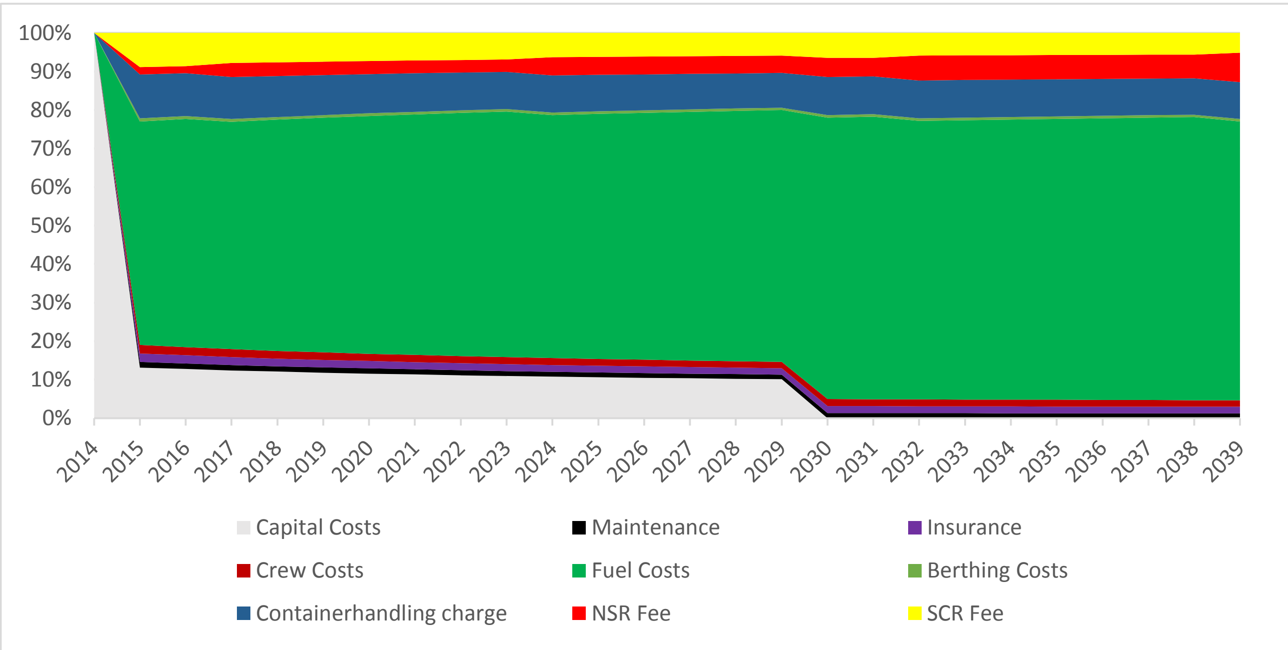

Figure 312: Total the yearly cost for an 8000 TEU NSR vessel

The costs are listed for the investment of an ice-strengthened 8000 TEU vessel in year 2014 under the medium Arctic warming scenario measured in nominal USD, with a constant load factor of $\epsilon_t = 0.65$*, a constant fuel cost uncertainty of* $\varphi_t = 0$ *and a constant navigation uncertainty of* $\theta_t = 0$.

Source: Own calculations

Appendix B

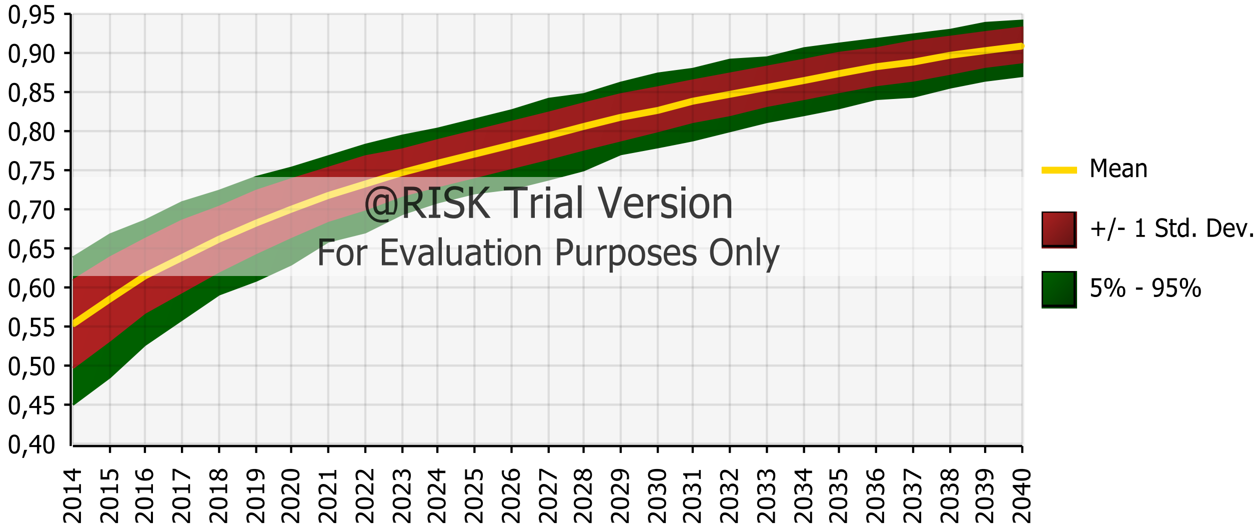

Figure 333: Investment Ratios of 4300 TEU vessels in the low Arctic warming scenario

The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 4300 TEU containership in the Arctic low warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

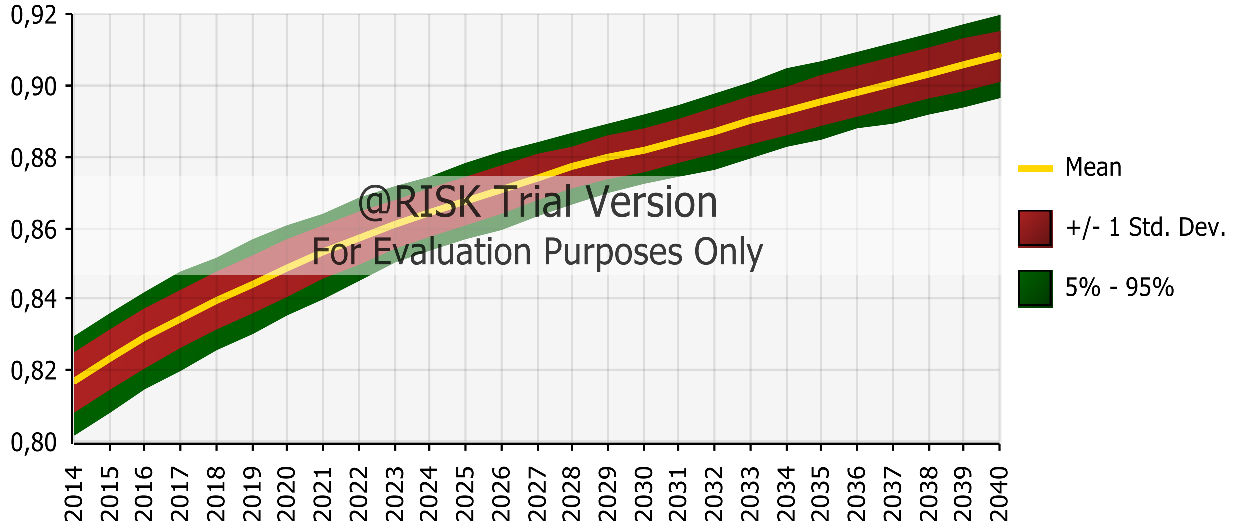

Figure 344: Investment Ratios of 8000 TEU vessels in the low Arctic warming scenario

The ratio of the NPV of the investment of an NSR vessel to SCR vessel, as a function of the investment year for a 8000 TEU containership in the Arctic low warming scenario, calculated using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red band shows one standard deviation and the green band shows the 95 percent interval.
Source: Own calculations using excel 2013 and @Risk 6.0

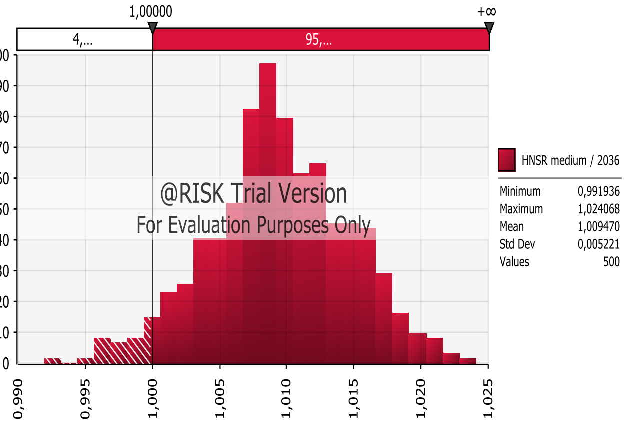

Figure 355: Investment ratio distribution

Distribution of the ratios of the net present value of a 2036 investment in an 8000 TEU NSR vessel to a SCR vessel in the Arctic medium warming scenario calculated using Monte Carlo Simulation with 500 iterations Source: Own calculations using excel 2013 and @Risk 6.0

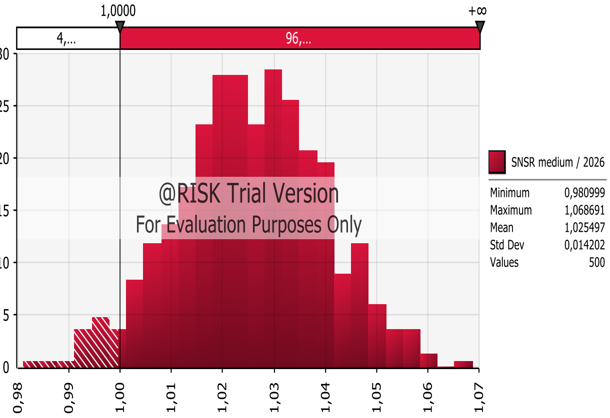

Figure 366: Investment ratio distribution

Distribution of the ratios of the net present value of a 2026 investment in a 4300 TEU NSR vessel to a SCR vessel in the Arctic medium warming scenario calculated using Monte Carlo Simulation with 500 iterations Source: Own calculations using excel 2013 and @Risk 6.0

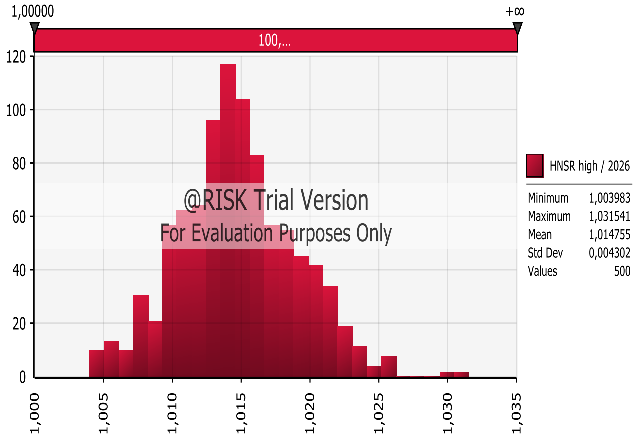

Figure 387 Investment ratio distribution

Distribution of the ratios of the net present value of a 2026 investment in an 8000 TEU NSR vessel to a SCR vessel in the Arctic high warming scenario calculated using Monte Carlo Simulation with 500 iterations Source: Own calculations using excel 2013 and @Risk 6.0

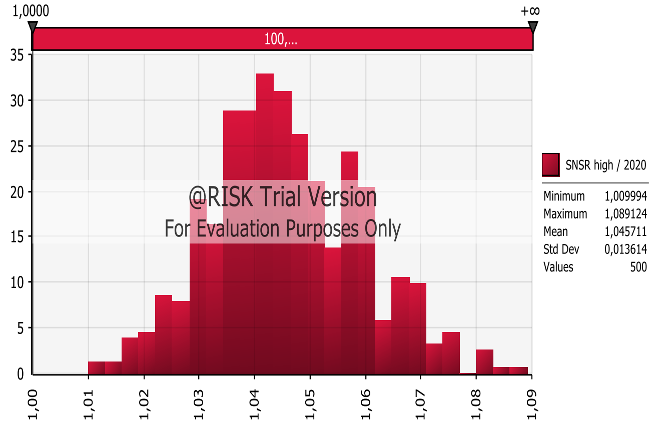

Figure 378: Investment ratio distribution

Distribution of the ratios of the net present value of a 2020 investment in a 4300 TEU NSR vessel to a SCR vessel in the Arctic high warming scenario calculated using Monte Carlo Simulation with 500 iterations Source: Own calculations using excel 2013 and @Risk 6.0

Appendix C:

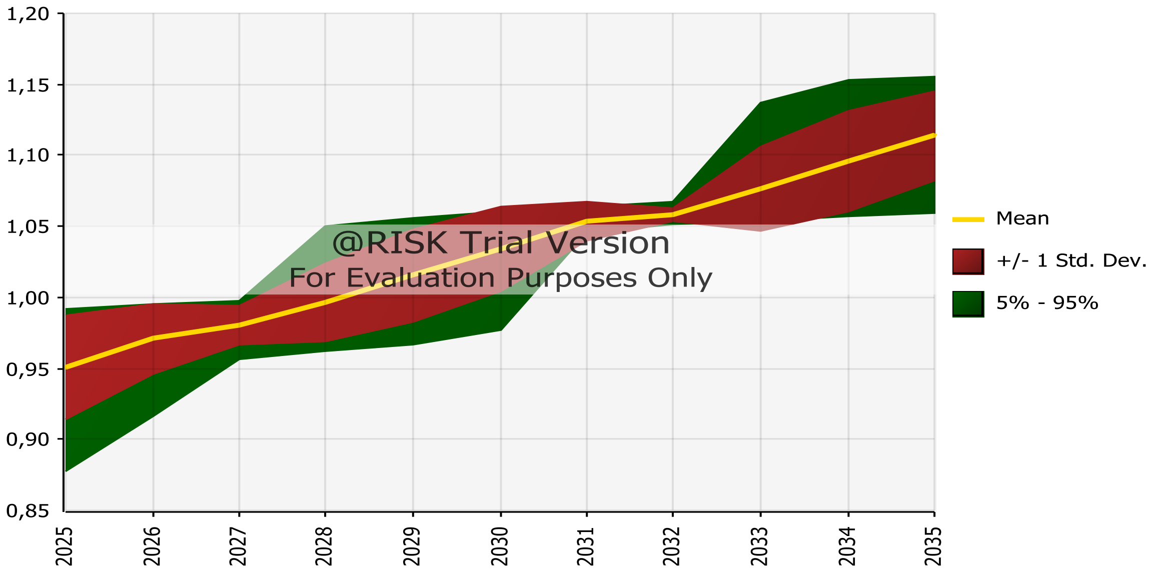

Figure 39: 4300 TEU vessel Rotterdam to Busan profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for a 4300 TEU containership between Rotterdam and Busan. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

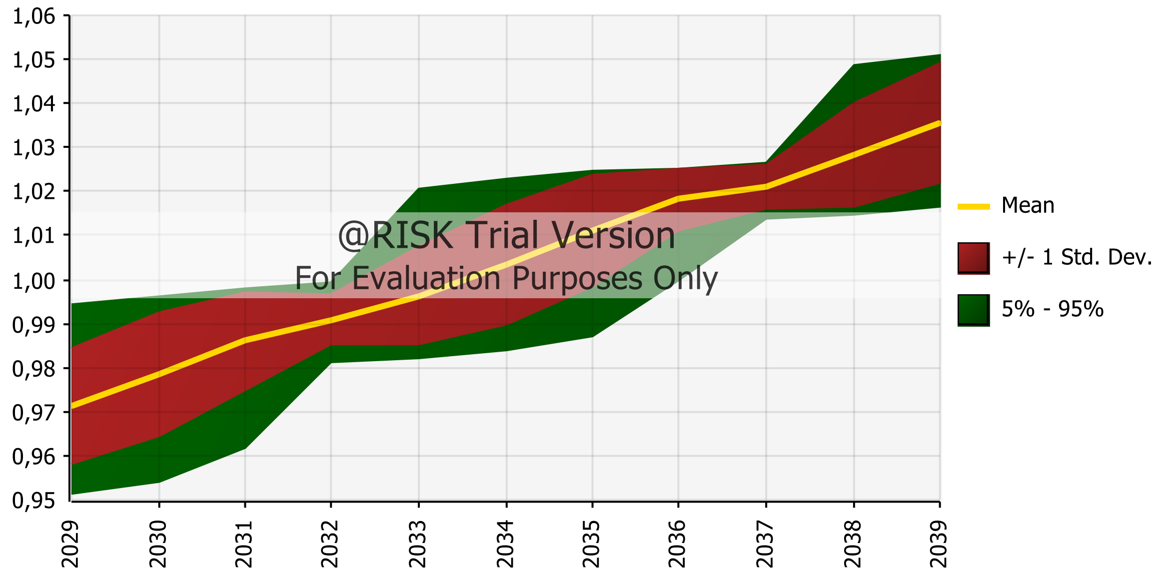

Figure 40: 8000 TEU vessel Rotterdam to Busan profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for an 8000 TEU containership between Rotterdam and Busan. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

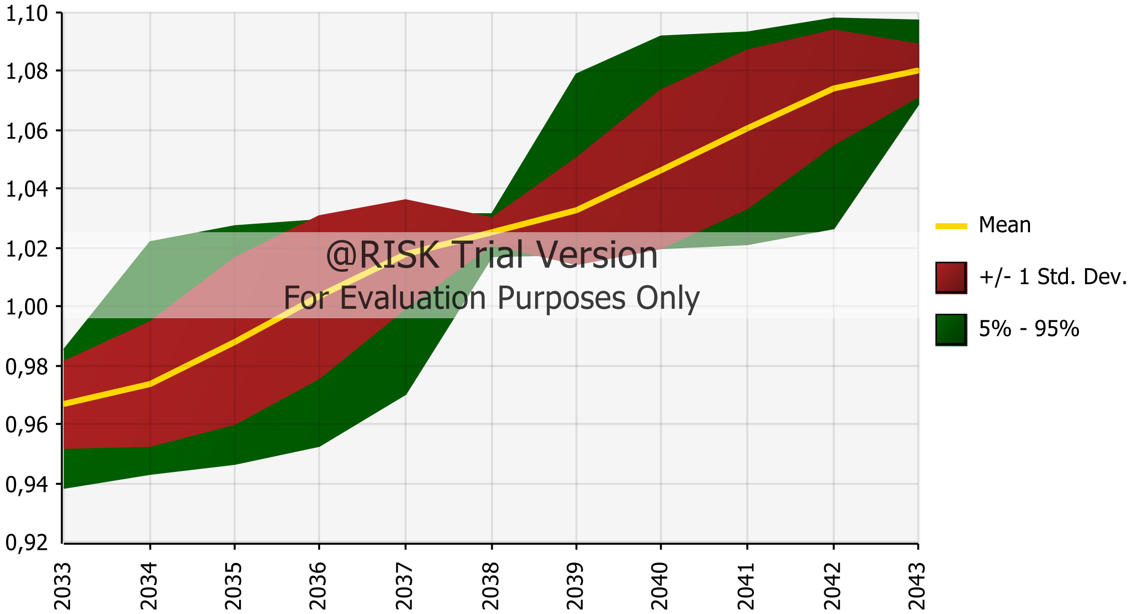

Figure 41: 4300 TEU vessel Rotterdam to Qingdao profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for a 4300 TEU containership between Rotterdam and Qingdao. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

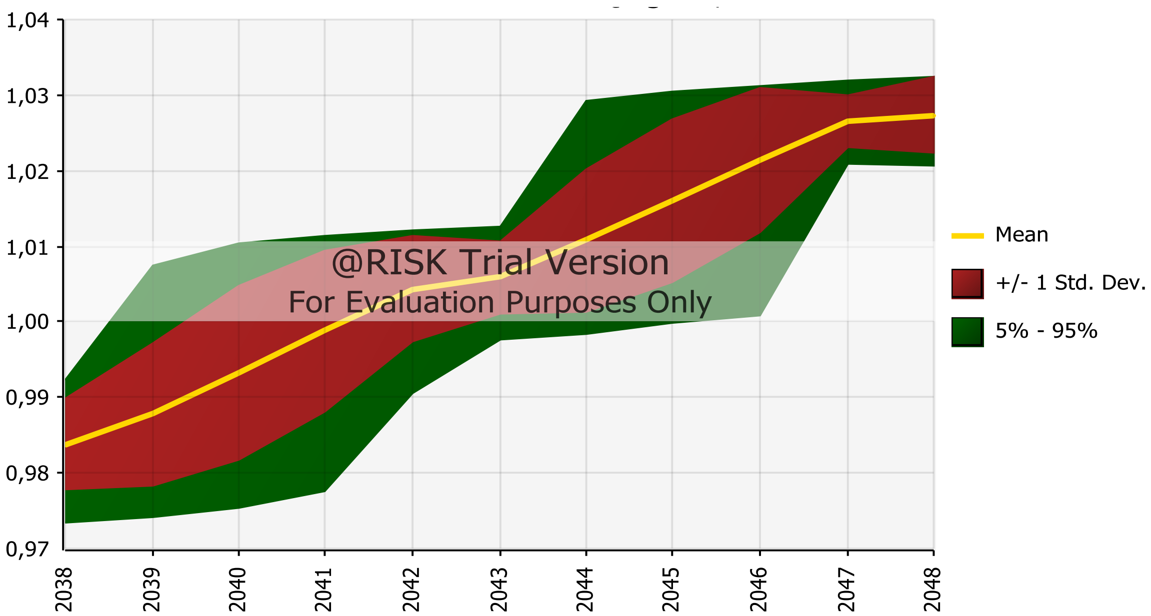

Figure 42: 8000 TEU vessel Rotterdam to Qingdao profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for an 8000 TEU containership between Rotterdam and Qingdao. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

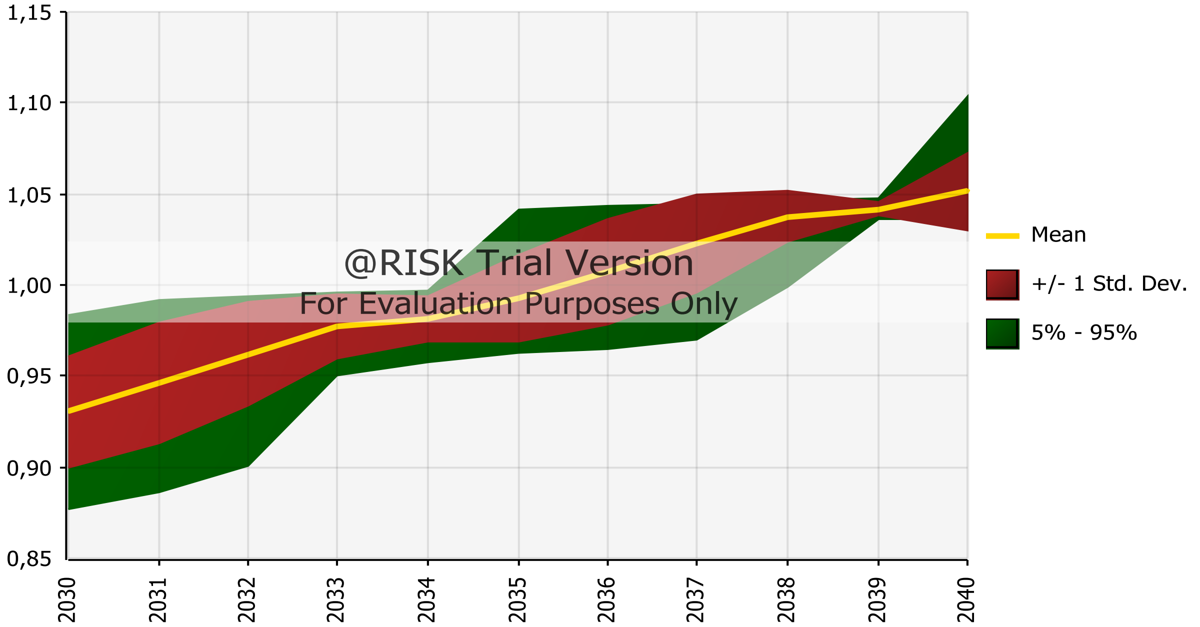

Figure 393: 8000 TEU vessel Rotterdam to Tianjin profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for a 8000 TEU containership between Rotterdam and Tianjin. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

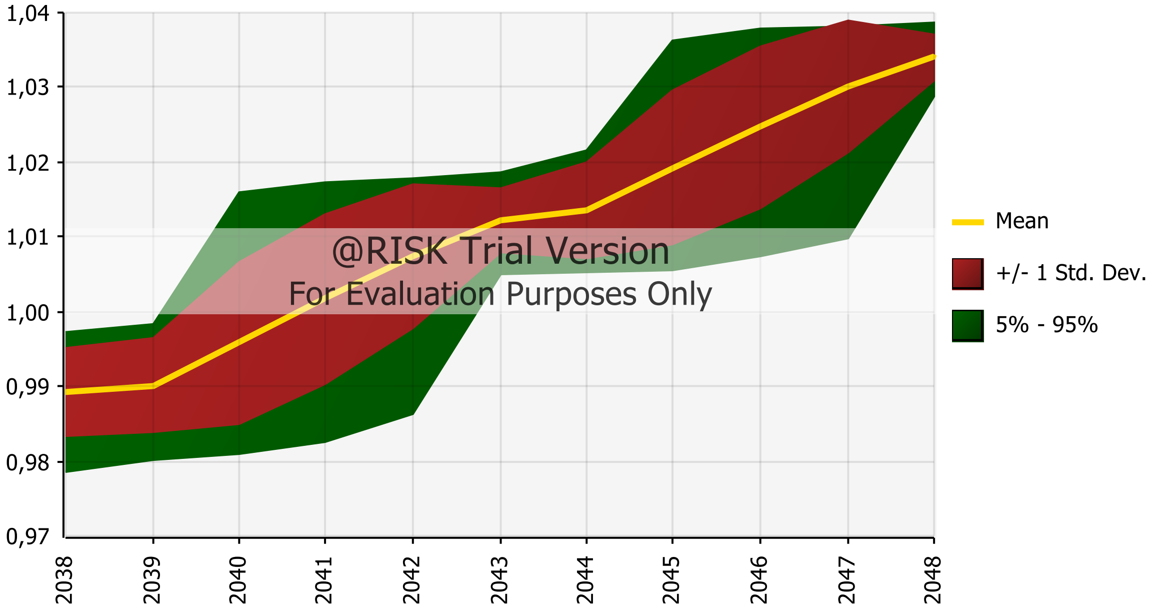

Figure 404: 4300 TEU vessel Rotterdam to Tianjin profit Ratios

The ratio of the yearly profit of an NSR vessel to SCR vessel as a function of time for a 4300 TEU containership between Rotterdam and Tianjin. The ratios are calculated for the high Arctic warming scenario using Monte Carlo Simulation with 500 iterations. The yellow line shows the mean value while the red shows one standard deviation and green area shows the 95 percent interval respectively.
Source: Own calculations using @Risk 6.0

Appendix D (Readers Guide)

Abbreviations:

NSR: Northern Sea Route

SCR: Suez Canal Route

NSRA: Northern Sea Route Administration

TEU: Twenty-Foot Equivalent Unit (twenty-foot container)

BAF: Bunker Fuel Adjustment Factor

NPV: Net Present Value

Denotations:

$t = time\ period\ (years)$

$j = vessel\ of\ a\ given\ hull\ and\ capacity$

$i = Arctic\ warming\ scenario$

Voyage Variables:

$D_{SCR} = Suez\ Canal\ Route\ distance$

$D_{NSR,j} = Northern\ Sea\ Route\ distance\ for\ vessel\ j$

$\omega_t = Ice\ water\ distance\ in\ year\ t$

$\tau_{t,j,i} = NSR\ navigation\ days\ for\ vessel\ j\ with\ Arctic\ warming\ scenario\ i\ in\ year\ t$

$\theta_t = Navigation\ days\ uncertainnity\ in\ year\ t$

$V_{OW} = Open\ water\ vessel\ speed\ (knots)$

$V_{IW} = Ice\ water\ vessel\ speed\ (knots)$

$\phi_{t,j,NSR} = NSR\ traveltime\ for\ vessel\ j\ in\ year\ t\ (days)$

$Q^{SCR} = Yearly\ trips\ for\ a\ vessel\ using\ only\ the\ SCR$

$Q_{t,j,i}^{SCR|NSR} = Number\ of\ SCR\ trips\ for\ NSR\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

$Q_{t,j,i}^{NSR} = Number\ of\ NSR\ trips\ for\ vessel\ j\ and\ warming\ scenario\ i\ in\ year\ t$

Cost variables:

$P_t^F = Bunker\ fuel\ price\ in\ year\ t$

$\varphi_t = Fuel\ cost\ uncertainity\ in\ year\ t$

$\vartheta_j^{SCR} = Fuel\ consumption\ for\ a\ SCR\ vessel\ of\ size\ j$

$\vartheta_j^{NSR} = Fuel\ consumption\ for\ a\ NSR\ vessel\ of\ size\ j$

$\pi_t = Annual\ rate\ of\ inflation\ in\ year\ t$

$C_{t,j}^S = Suez\ Canal\ fee\ for\ vessel\ of\ size\ j\ in\ year\ t$

$G_t = Gross\ ton\ for\ vessel\ of\ size\ j$

$C_{t,j}^N = Icebreaker\ fee\ for\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{CH} = Container\ handling\ charges\ per\ trip\ for\ a\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^B = Berthing\ costs\ per\ trip\ for\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,SCR}^F = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,SCR}^{F,NSR} = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j,NSR}^F = Fuel\ costs\ for\ a\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$I_{t,j}^{SCR} = Insurance\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$I_{t,j}^{NSR} = Insurance\ costs\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$C_t^{crew} = Crew\ costs\ in\ year\ t$

$M_t^{SCR} = Maintenance\ costs\ for\ a\ SCR\ vessel\ in\ year\ t$

$M_t^{NSR} = Maintenance\ costs\ for\ a\ NSR\ vessel\ in\ year\ t$

$C_{t,j}^{SCR|NSR} = Total\ costs\ for\ one\ SCR\ trip\ using\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{SCR} = Total\ costs\ for\ one\ SCR\ trip\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$C_{t,j}^{NSR} = Total\ costs\ for\ one\ NSR\ trip\ for\ vessel\ j\ in\ year\ t$

$VC_{t,j}^{SCR} = Variable\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$VC_{t,j,i}^{NSR} = Variable\ costs\ for\ NSR\ vessel\ of\ size\ j\ and\ ice\ scenario\ i\ in\ year\ t$

$FC_{t,j}^{SCR} = Fixed\ costs\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$FC_{t,j}^{NSR} = Fixed\ costs\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t$

$TC_{t,j,i}^{NSR} = Total\ costs\ for\ a\ NSR\ vessel\ of\ size\ j\ and\ warming\ scienario\ i\ in\ year\ t$

$TC_{t,j}^{SCR} = Total\ costs\ of\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$A_{t|s,j}^{SCR} = Capital\ cost\ for\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t\ conditional\ on\ investment\ year\ s$

$A_{t|s,j}^{NSR} = Capital\ cost\ for\ a\ NSR\ vessel\ of\ size\ j\ in\ year\ t\ conditional\ on\ investment\ year\ s$

Income variables:

$\epsilon_t = Containership\ load\ factor\ in\ year\ t$

$\gamma_t = Bunker\ adjustment\ factor\ in\ year\ t$

$F_t = Freight\ rate\ in\ year\ t$

$L_j = Container\ capasity\ of\ vessel\ of\ size\ j$

$R_{t,j} = Revenue\ for\ one\ trip\ for\ a\ vessel\ of\ size\ j\ in\ year\ t$

$TR_{t,j}^{SCR} = Total\ revenue\ of\ a\ SCR\ vessel\ of\ size\ j\ in\ year\ t$

$TR_{t,j,i}^{NSR} = Total\ revenue\ of\ a\ NSR\ vessel\ of\ size\ j\ and\ warming\ scenario\ i\ in\ year\ t$

$NPV_{s,j,i}^{NSR} = NPV\ of\ a\ year\ s\ investment\ in\ an\ NSR\ vessel\ of\ size\ j\ and\ warming\ scenario\ i$

$NPV_{s,j}^{SCR} = NPV\ of\ a\ year\ s\ investment\ in\ an\ SCR\ vessel\ of\ size\ j$