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Impact of the opening up of the Northern Sea Route on international maritime trade along the Southern Sea Route

by

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Acknowledgement

It has certainly been an arduous year for all of us at Maritime Economics and Logistics. To some, this academic year was a literal blood, sweat and tears; falling off the bike just to be in time for early morning lecture, the untimely demise of the air conditioner in Q building during mid-summer lectures and pent up frustration with assignments that sometimes ended with a tear or two. I am truly glad that the days of pressing deadlines and endless salvoes of assignments and exams have finally come to an end. Having said that, I would like to express my sincerest appreciations to the people that made this challenge achievable.

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Last but not least, I would like to thank all the friends in MEL for the fond memories you guys have made. I could not have asked for better colleagues. Good luck with your future endeavours.

Abstract

The deterioration rate of sea ice mass in the Arctic has been observed to be accelerating in the last decade. Numerous climatological studies conclude with mid-century projections of an ice-free summer. This would not only extend the length of shipping seasons in the Northern Sea Route (NSR), but also increase the voyage feasibility of non-ice classed vessels. Utilising the Arctic route could bring a 40% reduction in voyage distance compared to the Southern Sea Route (SSR), which translates into steep reductions in trade and transportation costs. The reduction in trade costs could potentially have global economic implications. Recently, a macro-economic study on the matter concluded that two-thirds of East – West global seaborne trade would be re-routed away from the SSR. However, the study grossly neglected the variability of sea ice conditions, vessel size limitations and limited navigation days.

That is why this thesis attempts to reassess the situation by incorporating the Arctic Transportation Accessibility Model of the mid-century projection with three scenarios. These are formed according to three radiative forcing levels: RCP 2.6, RCP 4.5 and RCP 8.5. The different liberalisation scenarios would consider the probability of successful independent voyage on PC6 vessels, the lengthening of navigable windows and vessel size restrictions.

The result shows that greater usage of the NSR is to be expected for the Western Europe – Far East pairing, which would chalk in a 39.7% increase under the RCP 8.5 scenario. However, this does not imply a substantial shift away from SSR. At RCP 8.5, the accessibility of NSR would only bring about a 16% decrease of maritime trade along the SSR. This is partly due to the fact that within the regions that are now more connected, trade decreases (e.g. within Western Europe or the Far East) and that ‘new’ trade is created that does not directly compete with trade currently transported along the SSR. NSR traffic linking the Baltic Region to South China Sea region also stands to gain, however to a lesser extent, suggesting the comparative advantage of SSR for the South China Sea region decreases but still remains. The Baltic Region would experience substantial increases in exports of up to 104% across all scenarios, while the Far East would see an increase in imports by 100%.

In terms of welfare, the lowering of transportation cost from accessible NSR benefits the Far East region the most, due to lower prices and thus large increases in benefits for consumers. While Western Europe would see the highest gains for producers, this comes as the expense of consumers, leading to negative overall welfare effects. Meanwhile, an overall positive change in output is observed for all regions assessed and the Rest of World. This suggests increases in GDP as implicated by the surpluses experienced by global producers.

Table of Contents

List of Figures

List of Tables

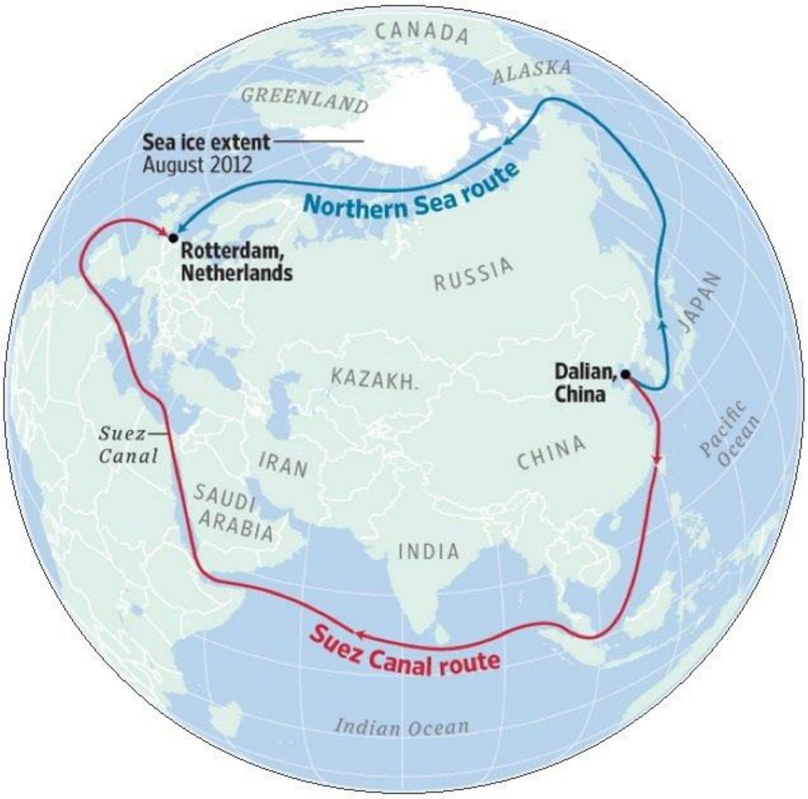
List of Abbreviations

ACCESS	Arctic Climate Change Economy and Society
ARI	Arctic Research Institute
ATAM	Arctic Transportation Accessibility Model
CGE	Computable General Equilibrium
CHNL	Centre for High North Logistics
DNV	Det Norske Veritas
DWT	Deadweight Ton
EEZ	Exclusive Economic Zone
GCM	General Circulation Models
GDP	Gross Domestic Product
GSIM	Global Simulation
GT	Gross Ton
IACS	International Association of Classification Societies
IFO	Intermediate Fuel Oil
IMO	International Maritime Organisation
INSROP	International Northern Sea Route Programme
IPCC	Intergovernmental Panel on Climate Change
ITF	International Transport Forum
LNG	Liquefied Natural Gas
NEP	North Eastern Passage
NSR	Northern Sea Route
NSRA	Northern Sea Route Administration
NTM	Non-Tariff Measure
OECD	Organisation for Economic Co-operation and Development
OW	Open Water
PC	Polar Class
RCP	Representative Concentration Pathways
ROW	Rest of World
SAR	Search and Rescue
SSR	Southern Sea Route
TCE	Trade Cost Equivalent
TEU	Twenty-foot Equivalent Unit
TRAINS	Trade Analysis Information System
TSR	Transpolar Sea Route
UNCTAD	United Nations Conference on Trade and Development
VLCC	Very Large Crude Carrier
VLCV	Very Large Container Vessel
VLOC	Very Large Ore Carrier
WTO	World Trade Organisation

1. Introduction

1.1 Research background

The loss of ice sheets and the declining sea ice mass in Northern Polar region has been well studied (Laxon et al., 2013; Rothrock, Yu, & Maykut, 1999; Shepherd et al., 2012). With it, an alternative east-west v.v. shipping route known as the Northern Sea Route (NSR), has been heralded as one of the disruptive developments in global seaborne transportation (Fang et al., 2013). Traversing through the NSR cuts down 40% of sailing distance as compared to de facto east-west trade route, the Suez Canal route - also known as the Southern Sea Route (SSR) (Liu & Kronbak, 2010). The shorter distance and sailing time directly translates to operational costs savings, while relatively slow sailing speed via the NSR could further lower bunker consumptions (Pruyn, 2016). The risk premiums associated with NSR navigation do not make it a costlier option as compared to the Suez Canal route, where piracy threats in the Gulf of Aden and off Somali coast have increased insurance cost (Bjørn, 2015). It is believed that the increasing accessibility of the Arctic region in the coming years could eventually lead to diversion of trade flow via the NSR (Baker, 2013).



Source: Vedomosti (2013)

Figure 1. The Northern Sea Route and the Southern Sea Route

It has been corroborated that ice free summers could occur as early as 2030 up to 2050 (Overland & Wang, 2013; Smith & Stephenson, 2013). Under this scenario, non-ice-classed vessels (Open Water, OW vessels) could sail through the NSR during summer months. Meanwhile, a light-ice-classed vessel (Polar Class 6, PC 6) can traverse NSR even in winter. With the aid of icebreaking ship, a PC 6 vessel would be able to navigate the Transpolar Sea Route (directly on the North Pole), bringing a further 20% reduction in distance as compared to the NSR (Baker, 2013). Based on these findings, the commercial viability of NSR passage has been studied according to different ship types, such as LNG carrier (Haeffelle, 2013), container vessels (Liu & Kronbak, 2010), dry bulk carrier (Schøyen & Bråthen, 2010), and oil tanker (T. Dimitrios, Stephen, Anthony, & Rodrigues, 2015). These consequently have been followed by studies on the macroeconomic impact of the phenomenon, within specific cargo type such as LNG (Broek, 2014) as well as the overall economic implication (Bekkers, Francois, & Rojas-romagosa, 2015).

Given the challenging navigation in NSR, ships that are currently able to ply the route are limited in their sizes. As such, very large container vessels (VLCV), very large crude carrier (VLCC) and very large ore carrier (VLOC) will not be able to traverse the route (D. Dimitrios, Baxevani, & Siousiouras, 2016). The variability of sea ice conditions also would cause schedule unreliability of liner service, such that regular east-west containerized seaborne trade via the NSR would likely to remain unfeasible, unless there is no ice left in the arctic (Pruyn, 2016). Therefore, NSR traffic will still likely be dominated by smaller vessel carrying valuable cargoes, or as an alternative trade route where the transportation demand is small. This observation highlights the limitation of the study conducted by Bekkers et al. (2015), where the Arctic sea is treated as open sea that is fully operational year-round, implying 1:1 accessibility and substitutability of NSR as compared to the SSR. Due to this assumption, it was concluded in the study that up to two-third of east-west maritime seaborne trade will be re-directed via the NSR. This is unlikely to be the case, as many aspect that would otherwise limit shipping activities in the Arctic were not taken into consideration.

Meanwhile, new proposals of China's Belt and Road Initiative have recently been concluded in June 2017, proposing the NSR as "blue economic passage" between Asia and Europe (The State Council - The People's Republic Of China, 2017). In the document, it is mentioned that the Arctic route will serve as a complementary trade lane to the other two routes, namely the China-Indian Ocean-Africa-Mediterranean Sea and China-Oceania-South Pacific blue economic passages. China's desire to employ the NSR has been preluded by the country's numerous Arctic expeditions in the last decade, eventually fruited in its admission as permanent observer in the Arctic Council in 2013. This was also followed by few other Asian countries with potential stakes in the Arctic, such as Korea, Japan and Singapore. To add in, large amount of Chinese funds is currently being invested on ramping up Arctic's passage infrastructures, especially in the Arctic ports, resources extraction facilities and building of icebreaking vessels. The potential for a geopolitical freeze in the Southern China Sea perhaps can explain China's motivation towards employment of the Arctic route. In the meantime, Russia's Arctic resource extraction projects are also expected to play a much bigger role in the supply of global energy, especially to East Asia. Perpetuation of Western sanctions has certainly made Russia leaning more to Asia. Therefore, the prospect of opening an Arctic economic corridor connecting East Asia to North-western Europe is now no longer an "if", but a "when".

These recent developments since the last economic studies on NSR call for a re-assessment of the economic implication of the route. At the same time, recent studies by Stephens (2016), Zhang, Meng, & Zhang (2016), Sungwong (2016) and Lasserre, Beveridge, Têtu, & Huang (2016), which were based on the actual NSR traffic, highlight the inherent limiting factors that restrict maritime activities via the NSR. These would 'sober up' the notion of NSR as a "polar highway" that Bekkers et al. (2015) has since theorised. Hence, the main motivation of this thesis is to investigate whether the renewed interests to employ NSR as Europe – Asia maritime trade lane would have any impact on the trade along the SSR, considering the inherently restrictive nature of the route. These will be carried out by the assessment and incorporation of the latest climatological findings, projections of navigability window and vessel size limitations.

1.2 Research questions and methodological approach

This research aims to assess how the accessible Northern Sea Route, fuelled by rapid climate, infrastructure and geopolitical developments, will implicate trade along the Southern Sea Route. This thesis would consider the vessel size limitation and duration of NSR accessibility. Assessment of the result will focus on deviations in trade routes, traded value and amount of cargo transported. In addition, it will also touch upon the welfare effects of the identified countries. The appropriate main research question is therefore:

What is the effect of a more accessible Northern Sea Route for global maritime trade, in particular on the Southern Sea Route?

To answer the main research question, the following sub research questions are presented:

1. What are the characteristics of the Northern Sea Route?
2. How is the NSR as compared to the SSR in terms of accessibility?
3. How can we account for the climatology projections and degree of navigability of the Northern Sea Route?
4. How would the shorter voyage distance and duration, with consideration of the route's restrictions, affect trade flows?

The first part of this thesis uses a qualitative literature review to answer the first three sub research questions, which then would be used to build up the argument whether the NSR will be a disruption in seaborne trade. The inputs from this part will then be used to build the scenarios. The second part of this thesis will involve the quantitative econometric model, the Global Simulation (GSIM) model. We will explain the choice for the GSIM model, answering research question four.

The inputs of GSIM model are the bilateral values of traded goods between (up to 35) countries, initial and final tariff values and initial and final trade cost equivalents (TCE) of the different global routes, and the elasticities of trade between the different countries specified. The way we construct these data follows three steps. First, the countries of which goods are loaded and unloaded will be identified, including the total value of all goods traded between them. Second, tariffs and non-tariff measures (NTM) will be specified as a baseline and then changed (NTMs, not tariffs) depending on the NSR scenarios formulated.

1.3 Structure of thesis

In order to answer the research questions presented, the structure of the thesis is as follows.

In chapter 2, assessment of literature backgrounds on the Northern Sea Route will be laid out, focusing on the historical background and recent developments, corroborated with climatological and future navigability projections of the route, supplemented by the technical aspects of the route. Further in the chapter, brief assessment of the Southern Sea Route will also be included, focusing on the historical background and recent trends of that route, while also includes assessment of the technical aspects of the route and current cargo volume. Chapter 3 then delves with the methodology, introducing the Global Simulation (GSIM) econometric model that will be used to assess the economic impact, presenting the different scenarios and calculations of the initial and final tariff equivalents of traversing the Northern Sea Route, according to days of navigability and vessel size restriction. Chapter 4 lays out the result of the analysis, emphasizing on the trade and cargo deviations effect, but also highlights the most important observations in terms of output and welfare effects. Chapter 5 concludes the thesis, reflecting on the research limitation and suggestion for future studies.

2. Literature background

2.1 The Northern Sea Route

2.1.1 Definition of the term

The Northern Sea Route is formally defined in USSR legislation of 1932 as a separate part of the North-Eastern Passage (NEP). According to The Northern Sea Route Administration (NSRA), it stretches from the tip of Novaya Zemlya (68° 35` E) to Dezhneva Cape (168° 58` 37`W), bordering Barents Sea and Bering Sea, respectively. The NSR typically stretches about 2,200 to 2,900 nautical miles. However, voyage distance highly varies with the sea ice condition (PAME, 2009). As such, there are alternative routes within the NSR (see figure 2). Nevertheless, it features four marginal seas: Kara Sea, Laptev Sea, East Siberian Sea and Chukchi Sea. These marginal seas are connected by 5 main straits between the four biggest islands: Novaya Zemlya, Severnaya Zemlya, New Siberian Islands and Wrangel Island. However, the functional definition of NSR is the same as that of the NEP, which is the maritime route connecting the White Sea in the west to Bering Sea in the east (Østreng, 2010). For the purpose of this thesis, the terms NSR and NEP may be used interchangeably, and they refer to the sea route parallel to the northern coasts of Russia, connecting the Atlantic Ocean in the west and Pacific Ocean in the east. Most importantly, this thesis will regard the Northern Sea Route as an alternative sea passage connecting Far East Asia with North and North-western Europe, which would rival the Suez Canal Route.

Source: Claes Lykke Ragner (2010)

Figure 2. Formal boundaries of the Northern Sea Route

2.1.2 Historical background

The first NSR voyages from the 19th century up to the 1930s were expeditionary and sporadic in nature. Swedish scientist A.E. Nordenskjöld, on board the ship *Vega,* became the first person who successfully sailed the entire span of NSR (Klyuchevskiy, n.d.). Departing from Gothenburg in July 4th1878, the team sailed along the coastal lines, initially under favourable ice condition off the coast of Taymyr but later on encountered heavy ice condition in East Siberian Sea. It was so heavy that the voyage had to be put on hold for 264 days until the summer next year. On July 18h 1879 the team commenced their voyage the for the second time, and then managed to sail pass the Bering Strait 2 days later. They then sailed on and reached Yokohama on September 2nd1879. Nordenskjöld later lamented on the NSR that “This route…will hardly ever have any actual importance to trade”.

Meanwhile, the ending of the Russo-Japanese war in 1905 brought renewed interest of Russian government in Arctic exploration and realization of the strategic importance of Russian Arctic regions (Pastusiak, 2016). The exploration carried out by Russia’s Academy of Science had contributed to the detailed survey and mapping of the coasts along the NSR, including significant input into ice research, geology and meteorology. However, no international commercial voyages took place in the period 1901-1911, owing to the lack of customs facilities and the high insurance premiums imposed on traversing this route. During the 1910-1915 hydrographic expedition, Severnaya Zemlya Archipelago was discovered, which then followed by the annexation of the chain of islands into Russia’s territory in 1916. It was also discovered that the Arctic seas are not entirely covered in sea ice and that the condition and location of sea ice fluctuates yearly, signifying the possibility of safe passage in the Arctic during summer months. The increasing need for domestic maritime transportation in Kara Sea region, to support the remotely populated areas in the Arctic, had spurred the increasing number of icebreaking vessels to support the activity, which contributed to the increase of navigability days (Drent, 1993). This period also saw the growth of traffic at both ends of the NSR, but not yet the entirety of the route.

The period 1930s up to 1950s saw the era of administrated and organised sailings, and construction of Arctic infrastructures. The Main Administrator of the Northern Sea Route (MANSR) was formed in December 1932, tasked to lay out the sea route between White Sea to Bering Strait, to control the icebreaking services and equip and maintain the route to ensure safe navigation of NSR. In addition, MANSR was also responsible for the operation of hydrographic and communication equipment and monitoring of ice condition through air reconnaissance, as it was also appointed the control over Arctic Research Institute (ARI). With this new development, NSR traffic soared. However, the growth was once again slowed down by overwintering of several cargo vessels and their icebreaker escorts. Poor organization of the MANSR was blamed for the lack of integration between the air reconnaissance and the supporting vessels, leading to the delays (Klyuchevskiy, n.d.). Nonetheless, the system that MANSR put in place had resulted in the increase of navigability days of NSR. Between 1935 to 1940, western Arctic was navigable on average 107 days annually, while the eastern part was navigable for 79 days. This was a substantial improvement compared to period between 1925 to 1930, where the navigable days were 45 and 30 days for the western and eastern parts of the Arctic respectively.

Thanks to previous studies and data collected on sea ice pattern, ARI scientist started to produce long-term ice forecasts in 1940s. But most importantly, the ARI was also given the managerial decision-making role on the employment of the route, linking the research aspect of the Arctic with its operational (Klyuchevskiy, n.d.). This contributed to the increase in cargo throughput via the NSR from 1940-1960. The ending of World War II saw rapid economic progress in Siberia, which prompted the building of new, more powerful icebreaking ships to serve the entire route (Pastusiak, 2016). In 1959, delivery of the first nuclear-powered icebreaking vessel *Lenin* marked the modernization of Soviet's ageing icebreaking fleet, followed by the delivery of seven other nuclear-powered icebreakers in the next decade. This was followed by the introduction of ice-classed multipurpose cargo vessels destined to transport timber, ores and coal to serve the proliferation of mining and industrial complex in the region. Up to this point however, the route was still exclusively used by Soviet fleet serving domestic seaborne transportation needs. This was due to the absence of the legal provisions for international passage owing to the impenetrable iron curtain and the deep freeze of relationship between USSR and the international community.

The thawing of the Cold War signalled new potential for the route. As part of his *glasnost* or 'openness' policy, Mikhail Gorbachev suggested in 1987 that the passage should be opened for foreign vessels. The vision was only formally realized in 1 July 1991, coincided with the imminent downfall of the Soviet Union. Vessel traffic in the NSR dwindled as the fallout of USSR's collapse resulted in economic turbulence that wiped out industries, infrastructures and settlements in Russia's arctic regions, and therefore the demand for transportation (Arbakhan Magomedov, 2013). The dilapidated state of the supporting infrastructures for safe Arctic navigation were also responsible for the decline of seaborne trades along the NSR. This situation would later last for the next two decades. Nonetheless, Russia, together with Japan and Norway, pioneered a comprehensive study on the commercial feasibility of Northern Sea Route as international seaborne trade lane. The study especially focuses on the technical and insurance requirements for vessels navigating the hazardous Arctic environment. Called the International Northern Sea Route Programme (INSROP), the study commenced in 1993 and ended in 1999. It involved 50 international research institutions and transportation companies. In 1995, an experimental voyage from Yokohama to Kirkenes was carried out as part of the joint study. The *Kandalaksha,* an ice-classed general cargo ship, accomplished the journey in 28 days. It is 15-days shorter than if the voyage would be carried out via the SSR. The transportation cost savings from the reduction in sailing time achieved by this voyage spurred the arguments supporting the commercial feasibility of NSR as alternative to the SSR. By the ending of INSROP programme, the route was given the status of Europe – Asia transport corridor at the First International Euro-Asian Conference on Transport (Østreng, 2006).

In conclusion, historical assessment reveals that accessibility of the NSR is largely driven by resource extraction and economic progress in Arctic regions. At the same time, legal provisions and structured administration of the route is essential for safe passage of the route, which is also contributing factor for the growth of traffic in the NSR.

2.1.3 Recent developments

The beginning of 21st century signifies the internationalisation of the NSR. In 2007, a symbolic planting of Russian flag on the seabed beneath North Pole marked the rekindling of Russia's interest in the Arctic. The country's determination to exert its sovereignty in the Arctic was dominated by the desire to extract the newly-discovered large reserves of oil and gas in the region. This intention was cemented in a 2008 official document approved by then-president Medvedev, titled "Fundamentals of State Policy of the Russian Federation in the Arctic for the Period Until 2020 and Beyond". The essence of the policies is focused towards resource extraction in the arctic and national security. However, it also emphasises the modernization of NSR infrastructures and fostering of peace through bilateral cooperation as facilitator for Arctic resource developments (Kefferpütz, 2010). As a follow-up to this strategic plan, during Arctic Forum held in Murmansk in 2011, president Putin expressed his vision for the NSR to "rival traditional lanes in service fees, security, and quality" (Bryanski, 2011). Meanwhile, to facilitate safe passage of vessels and protection of Arctic environment, the Northern Sea Route Administration (NSRA) was founded in 2013. The organization is tasked to issue permissions for NSR transit, consolidate hydrographic surveys, to assist Search and Rescue (SAR) operations and to prevent pollution in Arctic environment. This marks the rebirth of organized and administrated NSR, which, together with the increasing shipping demand, was responsible for the boom in throughput during period 1930-1960 period. In 2015, Prime Minister Medvedev reiterated the desire to boost traffic in NSR through the "Integrated Development Plan for the NSR 2015-2030", aiming for 80 million tons of cargo by 2030 (Gunnarsson, 2015). This building momentum was then followed by the order of three new, most powerful nuclear-powered icebreaking vessels ever built, the *Arktika, Sibir* and *Ural*. These vessels, which would see active service with the state-owned Rosatomflot starting from 2017-2021, are capable to crush up to 3 m of ice (RT, 2016). The main purpose of these is to support the annual transportation of gas and gas condensates from Yamal Peninsula to Asian market (Arbakhan Magomedov, 2013). Clearly, this action shows the commitment of Russia in reviving the NSR for international seaborne trade and towards facilitation of resource extraction.

September 2012 saw the lowest summer sea-ice extent ever recorded in the Arctic (Smith & Stephenson, 2013). Not coincidentally, it was followed by the admission of Japan, South Korea and China as permanent observers in the Arctic Council in 2013. This could be interpreted as intentions of these countries to obtain a piece of the "Arctic pie". It hardly came as a surprise as these high-latitude Asian countries are lacking in natural resources, while at the same time are major exporters to Europe. As such, they are to be benefitted most from the distance savings associated with NSR navigation and Arctic resource extraction (Buixadé Farré et al., 2014a). For instance, Japan's interest in the Arctic is closely tied with the country's reliance on LNG imports for domestic energy production. The opening of Yamal LNG facilities and the time-sensitive nature of the commodity makes the interlinkage of Arctic LNG projects and NSR particularly beneficial to Japan. For that, Japan have recently strengthened diplomatic ties and economic cooperation with Russia. Meanwhile, South Korea's interest in the Arctic is tied with the desire by its shipping industry to employ the NSR, which in turn is driven by the country's increasing trade with Europe (Ha & Seo, 2014). South Korea's import of gas condensates and clean petroleum products from North-western Europe made up the bulk of cargo transported through NSR in recent years (Sungwong, 2016). The country is also a large exporter of large machineries and vehicles to Europe, high-value commodities that would benefit most from the shorter sailing time. To add on, imbalances of empty containers coming from Europe is also seen as a potential driver for the route's future usage by Korean shipping companies (Ha & Seo, 2014).

However, China's ambition and commitment in the Arctic have so far dwarfed that of other Asian countries. Not long after Russia's flag planting ceremony in 2007, China's strategic interest in the Arctic took off. The government has since then been gradually investigating and acting on three main issues: the effect of climate change on extreme weather and food production, securing access to Arctic resources, and the use of Arctic shipping routes (Jakobson & Peng, 2012). China's foray into Arctic resource extraction projects is especially important to ensure long-term energy availability to support the continuation of China's economic growth. The country's hefty investments and stakes in Yamal LNG projects have fruited in not only the safeguarding of long-term LNG supply, but also the building of the plants' equipment (Sørensen & Klimenko, 2017). State-owned Poly Group Corporation has agreed in 2015 for the construction and operation of Belkomur Railway, which connects the Trans-Siberian Railway with the new deep-water port in Arkhangelsk, which is also to be constructed by them. The objective is to connect the resource-rich Siberia and Ural regions. This project is expected to be completed in 2022 to the tune of USD 6.7 billion (Belkomur, 2012). Developments in Sino-Russian cooperation in Arctic resource extraction has been linked with the consequence of the souring Russian – EU relationship in the aftermath of Russia's annexation of Crimea and conflict in Ukraine (Sørensen & Klimenko, 2017).

Meanwhile, the utilisation of NSR as an economic corridor between Asia – Europe has so far garnered the most publicity (Weidacher Hsiung, 2016). In 2012, scientific exploration on-board the Chinese icebreaker *Xue Long* successfully traverse the route for the first time. The year after, general cargo vessel *Yong Sheng*, owned by Chinese-government COSCO Shipping, became the first Chinese vessel carrying containerized cargo along the NSR, followed by a roundtrip journey soon after in 2015. The company has since then actively suggesting future possibility towards regular shipping service along the NSR during summer months (American Bureau of Shipping, 2017). Formal incorporation of NSR into China's Belt and Road Initiative on 20 June 2017 further supports the intention, where it was indicated that Chinese enterprises are encouraged to contribute towards the commercial employment of the route (The State Council - The People's Republic Of China, 2017). The country's interest to employ the route makes a lot of sense since it would benefit the export-driven economy to a large extent (Masters, 2013). However, ongoing disputes with the country's Southern China Sea neighbours perhaps could also explain the desire towards the push. Especially since up to 80% of China's energy imports pass through Malacca Strait (Chen, 2010). The country's ambition to utilise the NSR can therefore be interpreted as a mission to diversify its lifeline route in the event of a geopolitical freeze in the seas of South East Asia.

To conclude, the melting of sea ice in the Arctic has been shadowed by the warming of relationships between Russia and East Asia counterparts. Increasingly East-leaning policies of Russia and the souring of relationships between China and its South China Sea neighbours, catalysed by the common goal towards Arctic resources extraction all point out to the possibility of the NSR being used as the East – West trade corridor that many have envisioned.

2.1.4 Technical aspects and distance reduction

Navigating the NSR is inherently difficult and restrictive. This is so since Russian Arctic continental shelf forms shallow water along the narrow channels that connect the marginal seas. On top of that, challenging sea ice conditions add on to the risk factor. These consequently would impact vessel sizes and ice class requirements.

While the depths of open water in the Arctic ranges from 20 to 200 m, it is, as will be discussed later, not yet feasible at least until the mid-century. Shipping along the coastal routes is the most traditional regime of traversing the NSR and currently the most feasible. However, it involves navigation through the many shallow straits that connects the four marginal seas. The shallowest amongst all is the Dmitriya Lapteva, with depths of only 8 to 10 m (The Arctic Institute). While Sannikova strait is an alternative, its depth at 15 m still makes it prohibitive to most of big vessels, especially when fully laden (ABS, 2008).

Source: American Bureau of Shipping (2008)

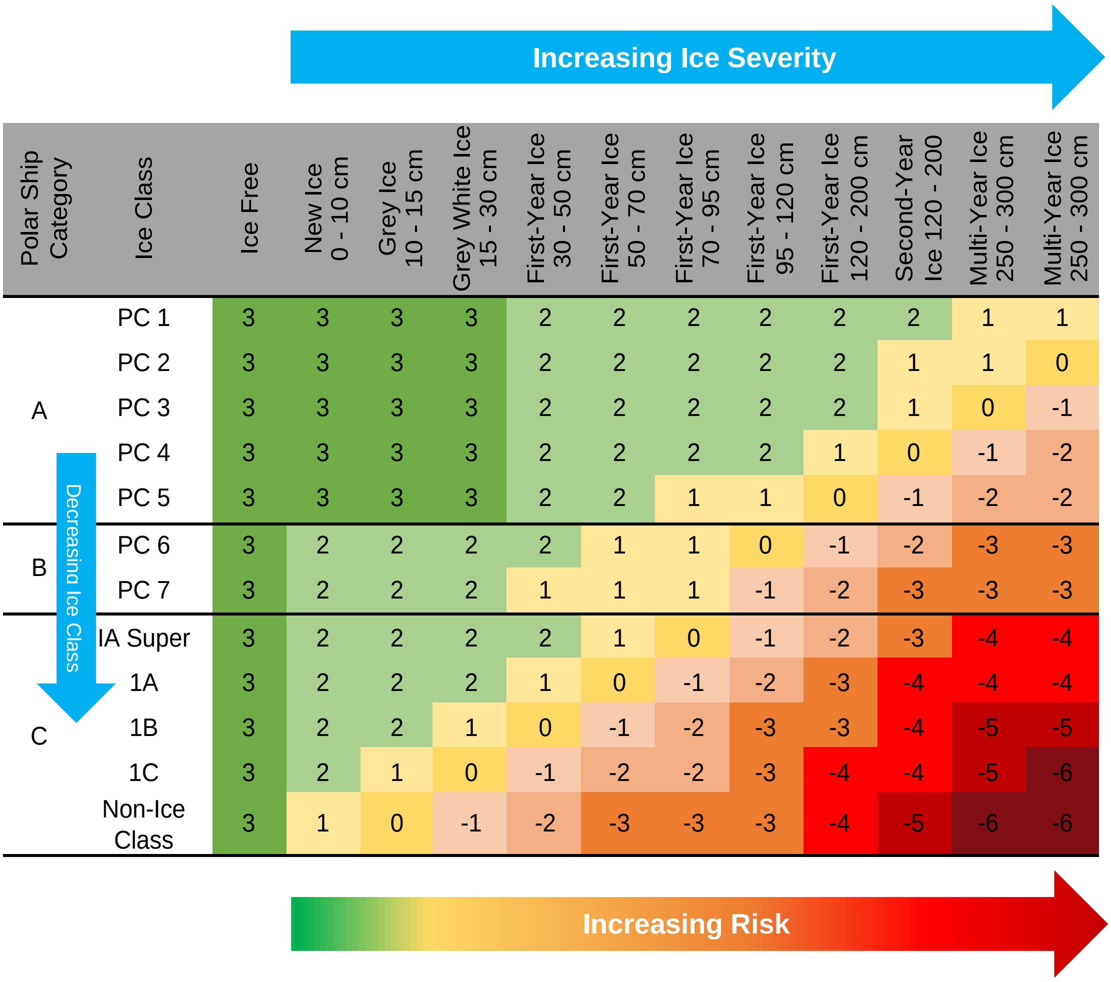
Figure 3. Potential choke points on the NSR

Vessels requiring ice-breaking assistance would be imposed with further size restriction. Icebreaking escort creates ~30 m-wide channel through the sea ice (Pruyn, 2016). The latest *Arktika* icebreaking vessel is only marginally better at 34 m wide. Together with the draft limitations, this constraint results in maximum vessel capacity of 4,500 TEU for container vessel, and 80,000 DWT for liquid and dry bulk carriers (The Arctic Institute). However, the use of ice-reinforced vessels would greatly negate these limitations as it opens up possibility to employ alternative routes with less restrictions. In August 2011, PC 6-classed Suezmax tanker (160,000 DWT) *Vladimir Tikhonov* became the first large vessel to successfully traverse the NSR. This voyage demonstrated the potential for larger vessels to eventually make use of the NSR. Nonetheless, such successful voyage still depends largely on the sea ice condition.

Sea ice is characterised according to its age and thickness. It can be divided into new ice, young ice, first-year ice and old ice. Ice extent in May usually goes up from 140 - 210 cm (ABS, 2008) and the thickest of all is the 2 to 3 m thick multi-year ice. The reduced salt content in multi-year ice and high content of air makes them especially tough and hence it is challenging even for icebreaker ships. The thawing of sea ice cover would usually begin around mid-June, and it would remain so until mid to late September. While average thickness of sea ice by the end of October is between 25 - 30 cm, it eventually reaches 70 - 90 cm by December. That is why shipping season usually commences from July to mid-November (The Northern Sea Route Administration, n.d.).

Accordingly, the many qualities of sea ice dictate the classes of vessel that can navigate through it. Pertinent to this thesis, we are using the IMO ice class notations (the ‘A’, ‘B’ and ‘C’ polar ship categories) and the International Association of Classification Societies (IACS) ice class nomenclatures (indicated by PC designations). According to IMO Polar Code, polar ship category A is certified for year-round operation in the Arctic, while category B is restricted to operation in summer and/or autumn. To fully grasp on how sea ice types would affect the minimum requirement of vessels, table 1 below summarizes characteristics of sea ice matched with the corresponding ice class requirement:

Table 1. POLARIS. Navigation capability of various ice-classed vessels.



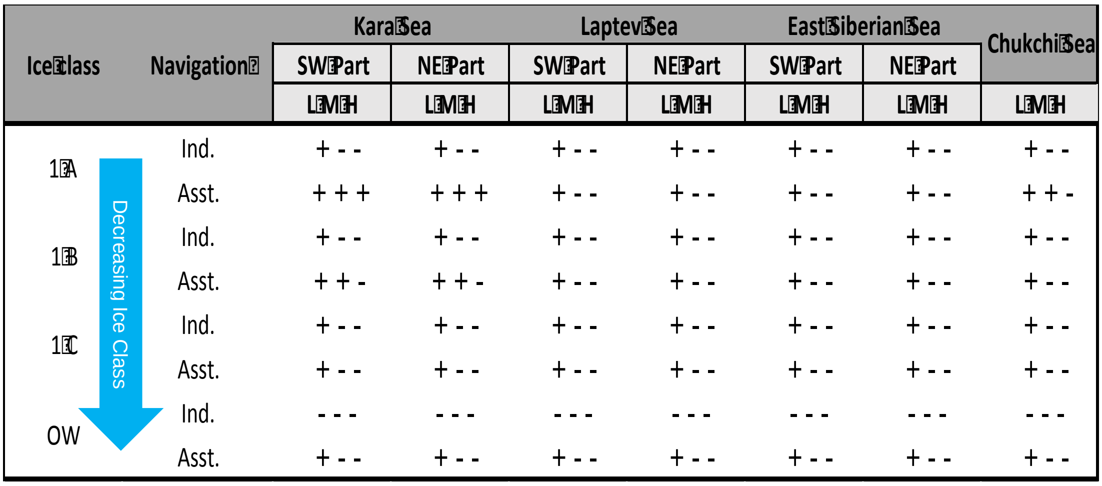
Polar Ship Category	Ice Class	Ice Free	New Ice 0 - 10 cm	Grey Ice 10 - 15 cm	Grey White Ice 15 - 30 cm	First-Year Ice 30 - 50 cm	First-Year Ice 50 - 70 cm	First-Year Ice 70 - 95 cm	First-Year Ice 95 - 120 cm	First-Year Ice 120 - 200 cm	Second-Year Ice 120 - 200	Multi-Year Ice 250 - 300 cm	Multi-Year Ice 250 - 300 cm
A	PC 1	3	3	3	3	2	2	2	2	2	2	1	1
	PC 2	3	3	3	3	2	2	2	2	2	1	1	0
	PC 3	3	3	3	3	2	2	2	2	2	1	0	-1
	PC 4	3	3	3	3	2	2	2	2	1	0	-1	-2
	PC 5	3	3	3	3	2	2	1	1	0	-1	-2	-2
B	PC 6	3	2	2	2	2	1	1	0	-1	-2	-3	-3
	PC 7	3	2	2	2	1	1	1	-1	-2	-3	-3	-3
C	IA Super	3	2	2	2	2	1	0	-1	-2	-3	-4	-4
	1A	3	2	2	2	1	0	-1	-2	-3	-4	-4	-4
	1B	3	2	2	1	0	-1	-2	-3	-3	-4	-5	-5
	1C	3	2	1	0	-1	-2	-2	-3	-4	-4	-5	-6
	Non-Ice Class	3	1	0	-1	-2	-3	-3	-3	-4	-5	-6	-6

Source: Own elaboration, based on American Bureau of Shipping (2016)

The Northern Sea Route Administration, as the governing body that issues permission for NSR transits, imposes strict admission criteria for navigation. This criterion is formed by comparing ice condition within marginal seas during shipping season with the ice-strengthening capabilities of the vessels. Table 2 shows the available navigation options for OW and light-ice strengthened vessel, for navigation season

July to mid-November. Consequently, table 3 illustrates navigation possibility for various ice-classed vessels for navigation window July to October.

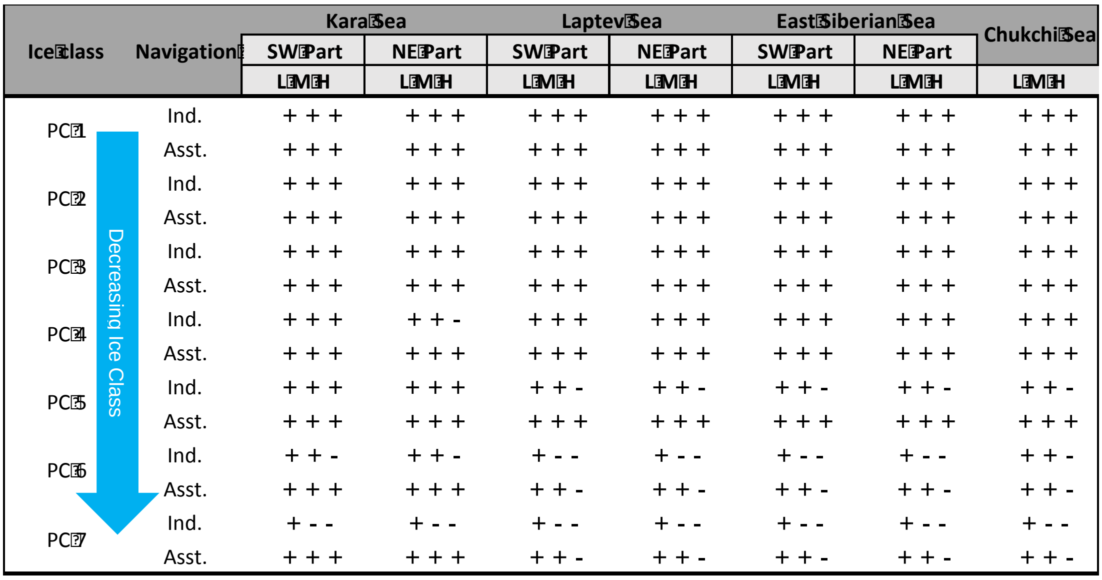
Table 2. Navigation admittance criteria for light-ice-strengthened and open water vessels



Ice class	Navigation	Kara Sea		Laptev Sea		East Siberian Sea		Chukchi Sea
		SW Part	NE Part	SW Part	NE Part	SW Part	NE Part	
		L M H	L M H	L M H	L M H	L M H	L M H	L M H
1A	Ind.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
	Asst.	+ + +	+ + +	+ - -	+ - -	+ - -	+ - -	+ + -
1B	Ind.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
	Asst.	+ + -	+ + -	+ - -	+ - -	+ - -	+ - -	+ - -
1C	Ind.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
	Asst.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
OW	Ind.	- - -	- - -	- - -	- - -	- - -	- - -	- - -
	Asst.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -

Source: Own elaboration based on The Northern Sea Route Administration

Table 3. Navigation admittance criteria for ice-classed vessels.



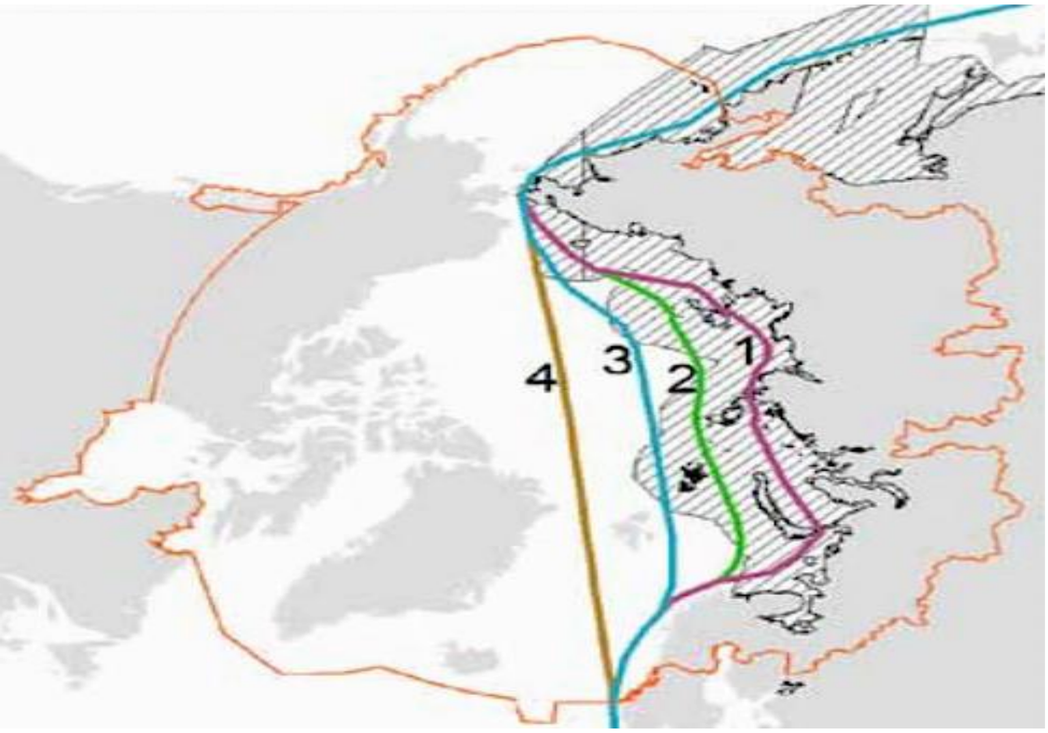
Ice class	Navigation	Kara Sea		Laptev Sea		East Siberian Sea		Chukchi Sea
		SW Part	NE Part	SW Part	NE Part	SW Part	NE Part	
		L M H	L M H	L M H	L M H	L M H	L M H	L M H
PC 1	Ind.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
	Asst.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
PC 2	Ind.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
	Asst.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
PC 3	Ind.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
	Asst.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
PC 4	Ind.	+ + +	+ + -	+ + +	+ + +	+ + +	+ + +	+ + +
	Asst.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
PC 5	Ind.	+ + +	+ + +	+ + -	+ + -	+ + -	+ + -	+ + -
	Asst.	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
PC 6	Ind.	+ + -	+ + -	+ - -	+ - -	+ - -	+ - -	+ + -
	Asst.	+ + +	+ + +	+ + -	+ + -	+ + -	+ + -	+ + -
PC 7	Ind.	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -	+ - -
	Asst.	+ + +	+ + +	+ + -	+ + -	+ + -	+ + -	+ + -

Source: Own elaboration based on The Northern Sea Route Administration

L	Low ice condition	Ind.	Independent navigation
M	Medium ice condition	Asst.	Icebreaker-assisted navigation
H	Heavy ice condition	+	Navigation is allowed
		-	Navigation is not allowed

As can be observed from the two table, ice conditions worsen as one gets deeper into the middle of NSR. The most challenging part of the NSR is along Laptev Sea and East Siberian Sea, due to the presence of fast-ice that builds up from coastlines to the sea. Thick concentration of fast ice that has been battered by wind and current, forming ridges and hummocks several meters thick (ABS, 2008). This poses a formidable obstacle for navigation, even for icebreaking vessels. Indeed, this very area had been the reason for the overwintering of Nordenskjöld expedition and several cargo vessels in the 1930s (Klyuchevskiy, n.d.).

Also from the tables, it is clearly indicated that higher ice- classed vessels have larger probability of undertaking voyages unassisted. Therefore, it also implies that high ice-classed vessels (PC 4 or higher) have higher degree of flexibility regarding the choice of routes. This not only would negate the icebreaking fee, but also negate the need for ice pilotage fee, which together currently make the NSR roughly twice as expensive as the Suez Canal (Liu & Kronbak, 2010) (Schøyen & Bråthen, 2010). The need for pilotage and icebreaking assistance also adds up to the number of days, as pilotage involves transit at the ports to allow embarking and disembarking of pilots. Meanwhile, icebreaking convoy leaves once every 8 days (The Northern Sea Route Administration).



Source: DNV (2010)

Figure 4. Alternative routes available from 2030-2050

However, it has been observed since the 1980's that Artic ice has been consistently made up of mostly first-year ice. Such ice type is more susceptible to melting, as opposed to the thicker and more robust multi-year ice (Lindsey & Scott, 2012). To this end, DNV (2010) has proposed alternative routes that can be undertaken by a PC 4 container vessel of 6,500 TEU capacity.

Presently, the only available options are route 1 and 2. Route 1 runs along the coastal route, the most orthodox option that imposes many vessel limitations. On top of that, as the coastal route lies within Russia's Exclusive Economic Zone (EEZ, indicated by the shaded area), admittance for NSR transits is currently subjected to NSRA decisions. Route 2 stretches north of the archipelagos. While this circumvents some of the shallow areas present in route 1, the fee structure for navigation is currently unclear (DNV, 2010). Starting from 2030 – 2050, two additional routes would be present. Route 3 is charted right outside the limit of Russia's EEZ, in attempt to avoid Russian NSR fees and tax regimes. This route is also the one with the most commercial potential as ice condition is similar to that of route 2, hence vessels of PC 4 and above could make use of this route. Lastly, route 4 is the Transpolar Sea Route (TSR), which runs directly above the North Pole. Hypothetically, TSR navigation would bring further 20% reduction as compared to the NSR (Baker, 2013). Utilisation of the TSR in the summer months is currently still limited to heavy icebreaker. However, as later will be assessed, it might even be commercially accessible in the late century.

The combinations of alternative routes and variable ice conditions have made calculations of reduction in sailing distance difficult to ascertain. Consensus among different studies is that NSR would be beneficial for countries above the equator. As such, advantage of NSR will be negated the further south the countries are located, for example, Vietnam. Therefore, Liu & Kronbak (2010), Schøyen & Bråthen (2010) and Bekkers et al. (2015) have calculated the distances between East Asia countries (China, Japan, South Korea and Taiwan) and North-western Europe (Norway, Netherlands and Germany) and the corresponding reductions in distance. Pruyn (2016) have made significant contribution by distilling the figures from the previous studies according to geographical regions for origins-destinations. The result is shown in table 4:

Table 4. The difference in distance travelled, according to geographical regions.

West	**East**	**SSR**	**NSR**	**∆**
Baltic region	China	21,005 km	13,256 km	-37%
Baltic region	Fareast Asia region	21,498 km	12,764 km	-41%
Hamburg-Le Havre region	China	19,942 km	14,770 km	-24%
Hamburg-Le Havre region	Fareast Asia region	19,996 km	14,277 km	-27%

Source: Own elaboration, based on Pruyn (2016)

It can be observed that significant distance reductions brought by NSR voyage is the greatest for origins-destinations pairings of high-latitude European countries with Far East Asia. It is further supported by the actual NSR transit statistics, where origin-destination countries are typically located between the 30° North up to the Arctic Circle (66° latitude), demonstrating the real-life practicality of using the Arctic route. Extending this analysis, the reduction in number of sailing days can then be computed. Assuming 15 knots average open water speed (without icebreaking support) for both routes as applied in the study by Schøyen & Bråthen (2010), the following figures are obtained:

Table 5. The difference in durations of sailing time, according to geographical regions.

West	**East**	**SSR**	**NSR**	**∆**
Baltic region	China	31.5 days	19.9 days	-11.6 days
Baltic region	Fareast Asia region	32.2 days	19.1 days	-13.1 days
Hamburg-Le Havre region	China	29.2 days	22.1 days	-7.1 days
Hamburg-Le Havre region	Fareast Asia region	30 days	21.4 days	-8.6 days

Source: Own elaboration, based on Schøyen & Bråthen (2010) and Pruyn (2016)

The calculations presented above only consider the reduction of sailing time purely from the aspects of speed and distance estimations. Significant reductions in transit days would bring many benefits. For one, it would minimise pipeline inventory cost and transportation cost, benefitting producer and consumer. As for shipowners, shorter sailing durations would, not only save fuel consumptions and other voyage-related expenses, but also increase the utilization rate of their fleets which would potentially increase earnings. However, as already briefed earlier, variable ice conditions could potentially add up to the distance, increasing the number of days sailing. Even during favourable summer conditions, moderately ice-classed vessels can independently sail the NSR at 12 knots, roughly additional 2 days in navigation. On the other hand, icebreaking assistance would further reduce vessel speed to 9 knots. At this speed, East – West voyage duration via the NSR would roughly equal to the duration of voyage via the Suez Canal Route, undermining the time saving qualities that NSR has been envisioned for. However, this condition also brings with it additional benefit of fuel saving, as fuel consumption is roughly equal to the square of vessel speed (Pruyn, 2016).

To conclude, NSR navigation at present imposes restrictions on size and ice-capability of vessels. The yearly variations in ice conditions and narrow shipping season still impedes widespread commercial utilization of the route, the result of which affects the number of transits along the route. Furthermore, substantial costs in navigating this route and strict admission criteria imposed may not play well against ship companies' intentions to make use of this route. Nonetheless, the warming of global temperature brings with it greater potential for accessibility of the route and the likelihood for bigger vessels to ply the route.

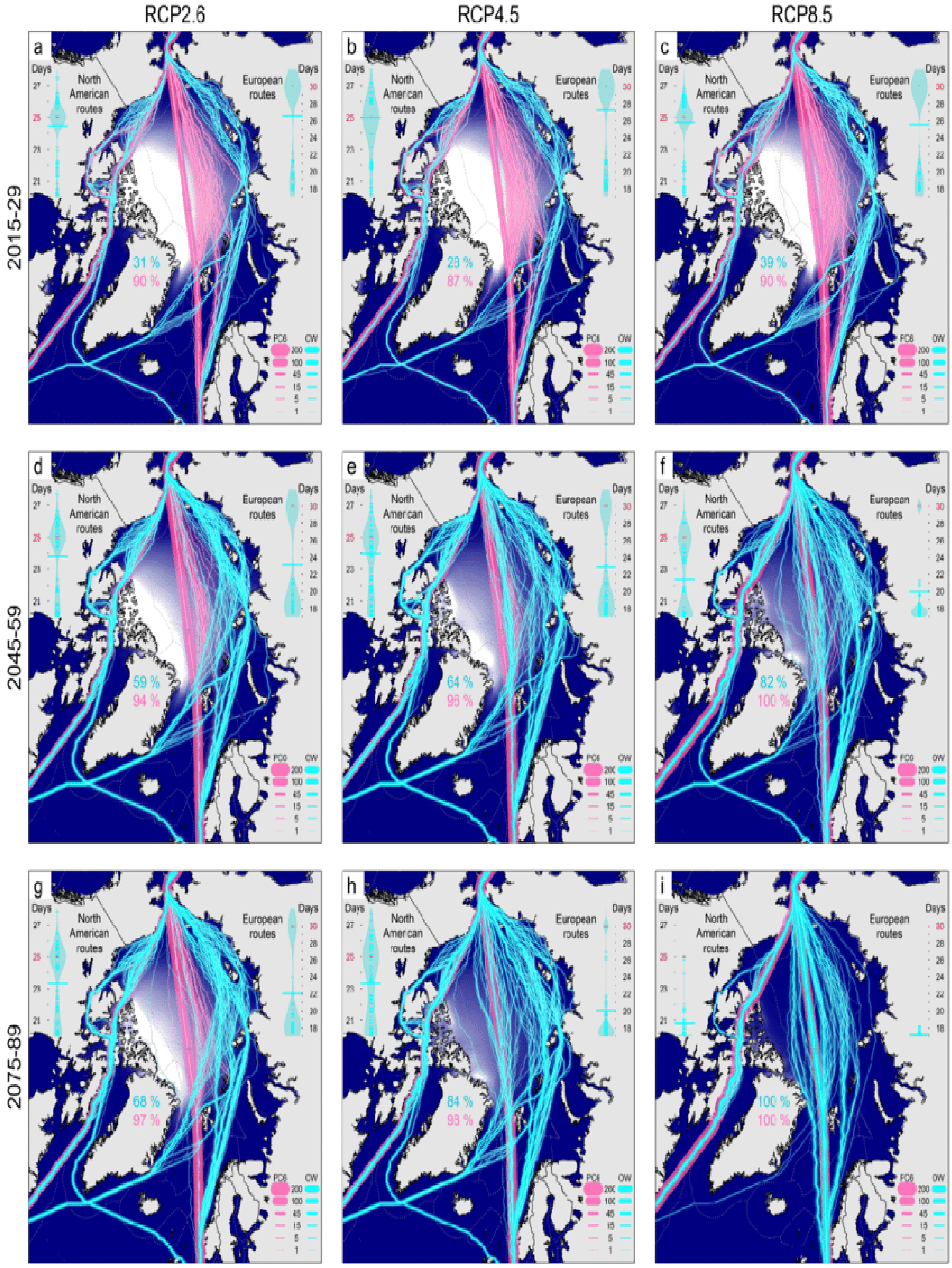
2.1.5 Climatology forecast and extension of navigability duration

Few studies, apart from studies done by Smith & Stephenson (2013) and Melia, Haines & Hawkins (2016), have successfully combined climate model with quantitative transportation study. Application of the Arctic Transportation Accessibility Model (ATAM) provides linkage between climate change projection with Arctic sea navigability scenarios. It is done by averaging previous simulations from several ocean-atmosphere-coupled General Circulation Models (GCMs). These GCMs were used to calibrate the future climate change scenarios, represented by Representative Concentration Pathways (RCPs).

RCP value corresponds with the increase in radiative forcing levels of greenhouse gases absorbed by the earth (measured in Watts/m^2). This proxy has been widely used in climate change studies, such as the Intergovernmental Panel on Climate Change (IPCC), as it is translatable into average increase in global temperature above pre-industrial level (van Vuuren et al., 2011) and often incorporated into emission scenarios. Smith & Stephenson (2013) uses RCP 4.5 and RCP 8.5 values, each representing medium-low and high emission scenarios. However, Melia, Haines & Hawkins (2016) uses RCP 2.6, RCP 4.5 and RCP 8.5, each associated with low, medium low, and high level of emission. They argue that RCP 2.6, or average global temperature rise by ~1.6±0.4°C above pre-industrial level, is consistent with the target set by the recent 21st Conference of the Parties (Paris COP 21) of the UN Climate Change Conference. As such, incorporating RCP 2.6 trajectory results in a more relevant navigability scenario in the light of the most recent regulatory framework on climate change.

Based on the RCPs proposed, optimal routes for NSR voyages are projected according to fastest-route algorithm. Two classes of vessels are presented: PC6 and OW, each representing medium ice-strengthening and lack thereof. Most important findings of this study, which is also illustrated by figure 5 are summarized below:

- **Early century projection (2015-2029):** 30% of September months in this period are navigable by OW vessels. Meanwhile, PC 6 vessels can traverse the route 90% of the time, with further possibility to employ the TSR. Under RCP 2.6 scenario, Europe – Asia voyage via NSR would take on average 27 days, with the minimum of 18 days.
- **Mid-century projection (2045-2059):** OW transits are viable for 60% of Septembers in this period. Majority of this would take place on the shortest variation of NSR, circumventing the width restrictions imposed by Borisa Vil'kitskogo Straits and Sannikova Straits (See Figure 3). For PC 6 vessel, the viability of transit is 97%. Europe – Asia voyage duration is 24 days on average. The TSR could be open for OW vessels for the first time under RCP 8.5 scenario
- **Late century projection (2075-2089):** 84% of OW transits are possible. For PC 6 vessels, transit viability is very close to 100%. Europe – Asia voyage can be done in 21 days on average, even under RCP 2.6. Under RCP 8.5, the Arctic Sea becomes open ocean.



Source: Melia, Haines & Hawkins (2016)

Figure 5. Optimal trans-Arctic routes in Septembers.

Notes: OW vessel routings are represented by electric-blue line; PC 6 by magenta line. NSR transit is referred here as “European Routes”.

At this junction, it is important to note that the study by Melia, Haines & Hawkins (2016) is solely based upon the observation of sea ice extent during September months. The nonlinear transition of the Arctic sea results in interannual variability. As such, the length of navigation days of the Arctic routes is notoriously hard to ascertain (Laliberté, Howell, & Kushner, 2016). According to Centre for High North Logistics (CHNL), transit voyage season would typically begin in early July to the second half of November, a total of 130 days. In 2011, 141 days of navigation were possible. Study conducted by DNV (2010) claims 100 days for OW vessels in early century, and 120 days in mid-century, both with assistance of icebreaking vessel. Melia, Haines & Hawkins (2016) have projected the length of shipping season for the different RCP scenarios for early, mid and late centuries. The lengths of navigability window in this study are assumed for unassisted shipping, implying unobstructed voyage without ice-breaking support. The result is summarized below: (full diagram is attached in Appendices 1 and 2, while numerical figures are in Appendix 3)

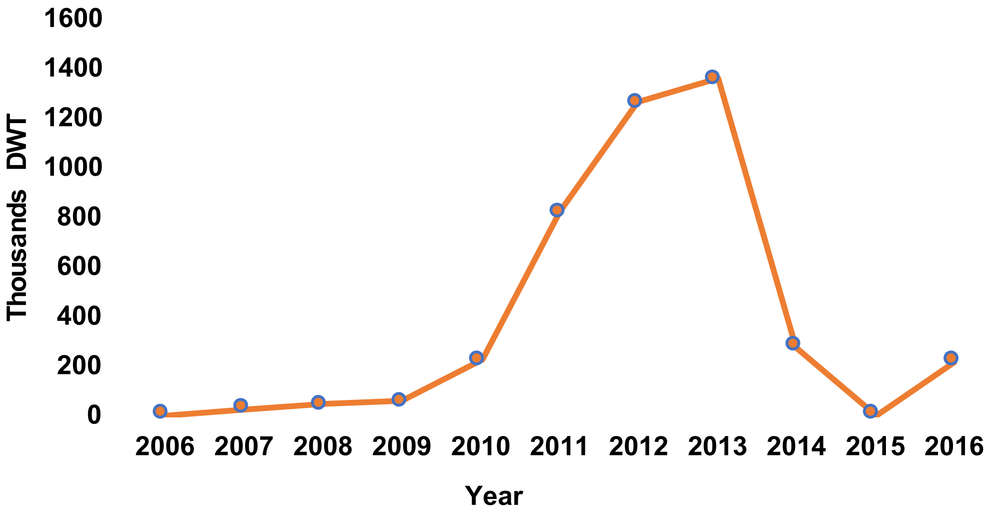
- **Early century projection (2015-2029):** Two-months (September – October) accessibility under RCP 2.6 for OW vessel. PC 6 vessel has four-months window, from July – November, also under RCP 2.6.
- **Mid-century projection (2045-2059):** Three-months accessibility (July – November) for OW vessel at RCP 2.6. For PC 6 vessel, six-months window is possible, also under RCP 2.6 scenario. RCP 8.5 would make the TSR accessible for 8 months with PC 6 vessel.
- **Late century projection (2075-2089):** Four-months navigability (June – November) window for OW vessels under RCP 2.6.

Concluding this section, the rising global temperature would without doubt opens up possibilities towards Arctic shipping. By mid-century, even under low-pollution scenario, large swaths of the Northern routes would be accessible to PC6 vessel, and for increasingly longer durations. However, such observations must be treated with caution. Variability of sea ice conditions are likely to remain up to late century (Shepherd et al., 2012). While PC 6 class vessel would further increase the feasibility of employing that route, the NSR cannot be regarded as open ocean as many have envisioned. As such, parallel accessibility of NSR as compared to the SSR is not going to happen until late century, and only under medium and high pollution scenario. This implies the complete melt of the Arctic ice, which would be a grim prospect for mankind as many countries, some of which would benefit from NSR the most, will have long been underwater (National Geographic, 2013)

2.1.6 Traffic development

As this thesis concerns with the possible impacts of re-routing vessels via the NSR, it is important to make the distinction between cargo transit traffic as opposed to the internal cargo traffic. Vessel transit concerns with the use of the entire length of NSR, and it consist only of laden vessels, implying its use as an East – West shortcut route.

Meanwhile, cargo traffic often would also refer to the shuttle shipment of materials and extracted resources within the Arctic region (Sungwong, 2016). The figures provided by the Northern Sea Route Administration must be treated with caution as it often includes internal shipping. While the development of oil and gas projects in the Arctic has increased the shipping tonnage within NSR, the same does not necessarily apply to the transit tonnage. As can be observed in Figure 6, NSR transit tonnage only picked up pace after the formalisation of NSR in Russia's national development plan in 2008. Tonnage traversing the entire course of NSR climbed steadily from 2010 and reached an all-time high in 2013, owing to the lowest-sea ice extent ever recorded during that period. Furthermore, high oil price during that period also explains majority of cargo that transited the NSR; oil and clean petroleum product from Far East Asia to Norway and Russia v.v. Healthy freight rates and high bunker prices during the period also spurred the transits. However, the situation was reversed in 2014 and transit along NSR reached the lowest point in 2015, explained by the cheap bunker price, slowing down of world economy and slumped freight rates (Staalesen, 2016). Nonetheless, in 2016 transit traffic rebounded slightly, with 19 transits totalling 214,500 tonnes of cargo, of which large proportion is made up of shipment of coal from Canada to Finland and pulp shipment from Northern Europe to East Asia (Humpert, 2017).



Source: Own elaboration, based on Balmasov (2013), Humpert (2017) and CHNL

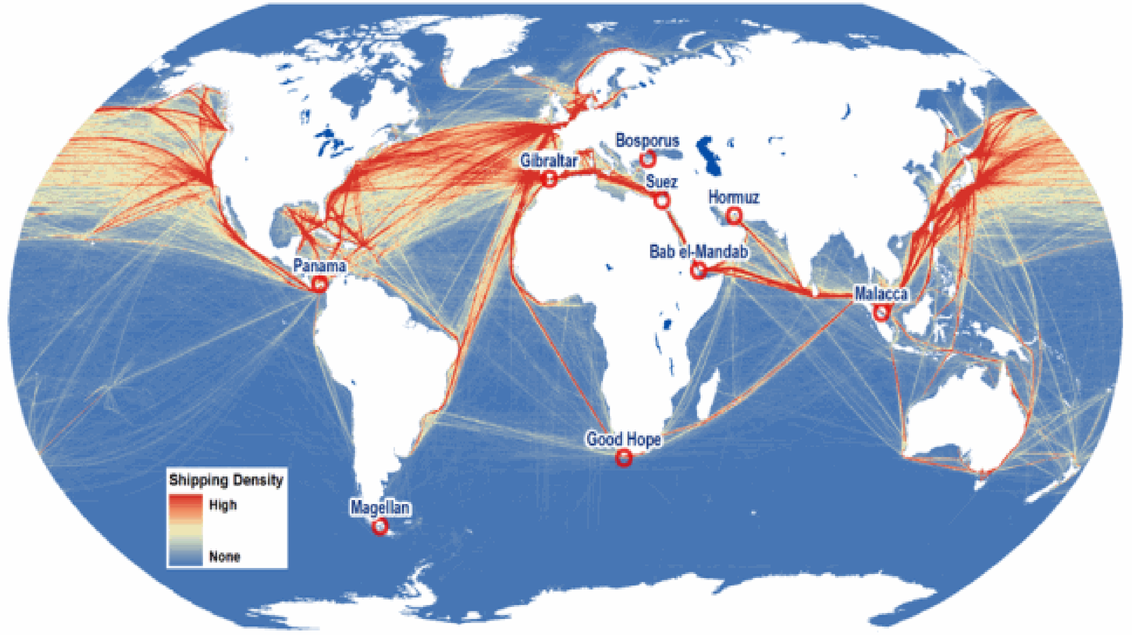
Figure 6. NSR cargo transit 2006-2016

2.2 The Southern Sea Route

2.2.1 Definition of the term

Although the term Southern Sea Route (SSR) may also refer to the East – West seaborne transportation lane via Cape of Good Hope in South Africa, in this thesis it would be used to describe the Asia – Europe v.v. via the Suez Canal Route. Voyage from Shanghai to Rotterdam covers distance of 19,942 km via the SSR, a journey that would take roughly 30 days. The route is one of the most important in international seaborne trade, perhaps partially shown by EU's trade with Asia, which accounts for 40% of EU total trade (European Comission, 2017). The SSR also serves as a lifeline for many countries as it connects natural resources-rich regions with energy-deprived industrial powerhouses. On top of that, the route is also home to many of the world's fastest growing economies.

SSR consists of some of the world's busiest shipping lanes; the Suez Canal, the Strait of Malacca and Mediterranean Sea, explaining the highest density of ship traffic in the world (see Figure 7). Up to half of the global seaborne trade in tonnage passes through the Malacca Strait (UNCTAD Review of Maritime Transport, 2011), while it is approximated that 8% of the world's trade pass through the Suez Canal (Bekkers et al., 2015). Perhaps highlighting its importance, certain nodes of the route have seen repeated features in the headlines. It has been used as political bargaining chip (Suez Crisis of 1956 and 1967), seen rampant piracy cases (off Somali Coast and along Malacca Strait), and is currently a potential location for a geopolitical instability (China's aggressive policy in Southern China Sea).



Source: Seawapa.com (2015)

Figure 7. Shipping density along the Southern Sea Route

2.2.2 Historical background

Before the founding of Suez Canal, merchant ships travelling from Western to Eastern hemisphere and v.v. had to sail around the Cape of Good Hope, then the only link between the Atlantic and Indian Ocean. Rotterdam – Shanghai via the Cape would stretch 25,550 km (Buixadé Farré et al., 2014a). The first European explorer to traverse the route was Portuguese Vasco da Gama in 1498, consequently paving the way for merchant shipping between Europe and Asia. This was then followed by swift colonisation of Asia Pacific regions by European powers.

Meanwhile, construction of the 160-km long Suez Canal was undertaken in 1859 by French – Egyptian consortium, La Compagnie Universelle du Canal Maritime de Suez. It was completed in 1896 after 10 years of hard labour, multiple difficulties and work suspensions (Suez Canal Authority, n.d.). The new canal shortens Europe – Asia voyage distance by 23% (Buixadé Farré et al., 2014b). It was agreed in the 1936 Anglo-Egyptian Treaty that Great Britain, owing to its maritime prowess and colonial aspirations, would be allowed to position its army along the canal. However, in an attempt to oust the British, president Nasser nationalised the canal into Egypt's hand. This was followed by the invasion of Egypt in 1956, but Egypt retaliated by closing the canal on the same year. Being the shortest connection between the Atlantic and Indian Ocean, Suez Canal's vital role in facilitating global trade enabled Egypt to use it as a political leverage during the 1967 war. The closure of the canal for the second time, which this time lasted for 8 years, contributed to the skyrocketing in worlds' oil price, closely shadowed by the severe economic crisis in the 1970s.

Similarly, as the shortest link between Pacific and Indian Ocean, Strait of Malacca's strategic importance in facilitating regional and international trade helped to write its illustrious history. Control of this narrow passage has been historically contentious, as first shown in the 7th century by the Kingdom of Srivijaya, the main power in the region. The kingdom imposed tariffs on merchant vessels plying through this water, which ensured its dominance in the region that helped it reign for the next four centuries (Dellios & Ferguson, 2005). Meanwhile, the growing international trade between Europe and Asia in the beginning of 16th century saw the power struggle between the Portuguese, Acehnese and Johor Sultanate, each trying to exert control on the route. The arrival of Dutch and its subsequent alliance with the Sultanate of Johor successfully toppled Portuguese footing in 1641 (Rusli, 2014). This trend continued with the ruling of British empire of the Malayan Peninsula in the 18th century, its subsequent ousting in World War II by the Japanese, and its victorious return after the war. To quote the word of Tomé Pires, a prominent 16th century Portuguese explorer, "Whoever is lord of Malacca has his hands on the throat of Venice". As would be covered in the next sub-chapter, this certainly rings true today.

On the other side of the world, the Mediterranean Sea is the final piece that completes the Southern Sea Route. The region has been touted as the birthplace of civilisation, rightfully so as it was the playground of the history's greatest empires: The Ottoman, Roman, Egyptian, and Hellenic (Sağlame, 2013). Reynaud (2009) identified three key levels of shipping traffic in the Mediterranean: as "maritime route" connecting the world's busiest trade lanes (Suez Canal to Straits of Gibraltar or Bosporus), as "crossroads" of fast growing continents amid globalisation (Europe, Asia and Africa), and as "landlocked sea" that enables trade among coastal Mediterranean countries.

2.2.3 Recent developments

Flourishing international economy is the driver for the development in global seaborne trade (UNCTAD, 2016). The resulting growth in vessel traffic during the last couple of decades has brought the problems of marine traffic congestion along parts of the SSR, most notably along the Strait of Malacca, Strait of Bab-el-Mandeb, and the Suez Canal. The result of this is increasing risk of collisions in Strait of Malacca, which has been predicted to reach its limit of 122,640 vessels in 2024 (Ho, 2009). In the case of Suez Canal, the ballooning ship traffic (and ship size) prompted the decision for the recent expansion. It consists of the deepening of the main canal and construction of second shipping lane, which now allows ships to travel in both directions. This cuts transit time considerably, from 18 hours down to just 11 hours (Saleh, 2015).

On the other hand, the rise in global seaborne trade along the SSR has unfortunately been accompanied by rife piracy cases off the Gulf of Aden and in Strait of Malacca region. Although attacks by Somali pirates had been recorded as early as 1995, it spiked in 2007 and went to an all-time-high in 2011, which coincided with the boom in global economy and maritime transportation (United Nations Conference on Trade and Development, 2014). Multi-national counter-piracy efforts have successfully brought down the number of attacks from 2013 onwards (Prins, Phayal, & Daxecker, 2017). The same trend was also observed on the Strait of Malacca; in 2014, piracy cases soared by 700 per cent from the level five years before (Winn, 2014), before finally was tamed in 2016 through joint cooperation between Malaysia, Indonesia and Singapore (The Straits Times, 2016). Among the most glaring observation regarding piracy cases from 2011-2015 is the fact that chemical/product tankers were the most pirated ship type (IMB, 2015). This perhaps could be explained by the relatively smaller dimension of vessels carrying disproportionately higher value of cargo, makes it easier to be boarded while simultaneously provides more leverage in the negotiation of ransom. Therefore, a less-congested and safer alternative maritime route serving the same origin-destination regions, could potentially replace the role of SSR as a maritime lifeline.

Coming back to the quote of Tomé Pires, securing access to Malacca Strait could spell the difference between survival and demise of a nation. However, such statement today would aptly refer to China more than Venice. As been briefed, enormous proportion of China's energy imports pass through the Strait of Malacca. The same also applies to the country's exports. China's dependency on the strait amounts to vulnerability that could be exploited by foreign powers, such as India and the US (Reddy, 2016). While China is within India's striking distance, proximity of the US Pacific Fleet and influence of US in the region certainly do not bode well with the security concern. This represents itself, as coined by former president Hu Jintao, the "Malacca Dilemma" (Pineda, 2012). While flexing the muscles of its navy would deter potential offenders, such prominent military display in volatile waterway could also possibly result in a naval blockade by its terrified neighbours, hence the dilemma (Lanteigne, 2008). Nonetheless, the Bridge and Road Initiative perfectly illustrates how the country circumvents this conundrum altogether; by creating alternative routes for their import and export activities, they withdraw itself from the "Malacca Dilemma". This stroke of genius has since then been followed by aggressive claiming of tiny islands and building of military bases in the Southern China Sea.

2.2.4 Technical aspects

Maritime trade along the SSR can be assumed to be unobstructed 365 days a year, as it is not affected by changes in seasons as in the case of the NSR. Nevertheless, vessel size restriction applies to this route, as a consequence of the chokepoints along the route; the Suez Canal and Strait of Malacca. The following table summarizes the physical restrictions of the route and their effects on vessel size dimensions and cargo carrying capacity.

Table 6. Vessel size restrictions along the SSR

	Draft	**Length**	**Beam**	**TEU Cap.**	**Tonnage Cap.**
Suez Canal (Suezmax)	20.1m (old) 24m (new)	~275m	77.5m	> 18,000 TEU	200,000 DWT
Strait of Malacca (Malaccamax)	21m	400m	60m	> 18,000 TEU	240,000 DWT

Source: Own elaboration, based on Suez Canal Authority and Lloyd's Register

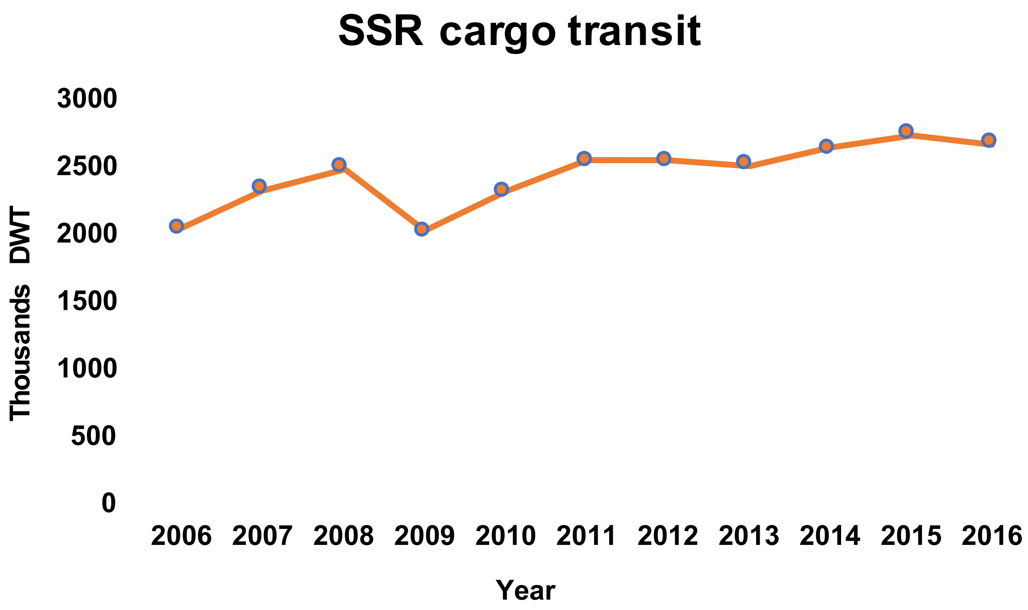
According to ITF (2015), average ship capacity that serves the Far East – North Europe trade corridor is 11,750 TEU, and projected to grow to 16,730 TEU by 2020. This would therefore be applicable for container ship traffic via the Suez Canal. Meanwhile, according to Suez Canal Authority (2016), average tanker size that transits through the canal is between 100,000 – 150,000 DWT, and 50,000 – 100,000 DWT for bulk carrier.

The threat of piracy along the Southern Sea Route, most notably off the Gulf of Aden, have contributed to the increase in various costs. This includes insurance cost, fuel costs (as result of evasive manoeuvring of vessels), and armed guards. According to UNCTAD (2014), the war risk status imposed on that route since 2008 has increased insurance cost from US$ 500 per vessel to US$ 150,000 per vessel. Consequently, cargo insurance per container has quadrupled from US$ 25 to US$ 100 per container. At the height of piracy activity in 2012, the estimated additional fuel bill as a result of evasive manoeuvring amounted to US$ 1.53 billion. Meanwhile as per 2016, armed guard protection for East Coast of Africa amount to US$ 726 million annually (Ocean Beyond Piracy, 2016).

2.2.5 Traffic development

The Suez Canal is the only administered transit points along the Southern Sea Route, which allows for the recording of transit cargo tonnage. Although the number of vessel transit in the Malacca Strait is considerably more substantial than the Suez Canal (refer to Appendix 6), the regional intra-Asia trade accounts for the bulk of the figure. As such, the Suez Canal transit serves as a better representative of the traffic between East – West trade, or the SSR cargo transit. Based on Figure 8, cargo transit along the SSR is relatively steady through 2006 – 2016, with the dip in 2008 – 2009 traffic reflecting the economic downturn in 2008. The highest percentage of vessel plying through the canal in 2015 – 2016 period is container vessels, followed by oil tankers. This reflects the importance of this node in seaborne global transportation of finished goods and raw materials.

Quick comparison of Figure 6 with Figure 8 reveals the fact that cargo transit through the SSR is on average 6 times higher than that of the average via the NSR. During the period of 2006 – 2016, on average 49 vessels transit the Suez Canal daily. This is a sharp contrast compared to the NSR, which even on its peak in 2013 receives only 49 vessel transits in a shipping season of 154 days (Humpert, 2014). However, NSR transits are potentially growing as have been signalled by the rapid progress in Arctic resource extraction projects and the renewed interests of Russia and China in utilising the route. All of which made possible with the decreasing sea ice extent projected in mid-century.



Source: Own elaboration, based on Suez Canal Authority (2016)

Figure 8. Suez Canal cargo transit 2006-2016.

3. Methodology

3.1 Global Simulation Model Methodology

Accessible Northern Sea Route would have global economic repercussion. It simultaneously affects multiple countries, with potential to impact sectoral productions, bilateral trade, and consumption patterns (Bekkers et al., 2015). This is understandable since navigation via the NSR brings shorter transit duration and costs, which represent the reduction in tariff equivalents. Therefore, its impact is similar to that of a trade policy. However, the degree of liberalisation of this 'tariff' is dependent upon the limitations of the NSR, such as restriction on vessel dimensions and cargo capacity, length of navigability window, and costs.

There are various modelling tools that can be employed for this analysis, namely the logit mode choice model, Computable General Equilibrium (CGE) model and the Global Simulation (GSIM) model. Logit mode choice is not very relevant for the scope of this thesis, as the model is better suited for the analysis of modal shifts (Aliveya, 2016). CGE model, while is commonly used for the analysis of economic impact of trade policies, requires extensive inputs and more advanced computing capability. This is so as the model also assess the intermediate linkages of multiple sectors and factors of production, and the interplay between them (Francois & Hall, 2003). Although this creates the impression that makes it the better model, it is unnecessary so. The complexity of it means that it is more difficult to convey the components of the model and its output to interested parties who are not familiar with it, for example, decision makers (André, Cardenete, & Carlos Romero, 2010). Most importantly, as transit via the NSR is usually destination traffic (implying no transhipment), inter-linkages between sectors will be less relevant considering the scope of the thesis.

On the other hand, the Global Simulation Model (GSIM) is a partial equilibrium econometric modelling tool that can be utilised to assess the impact of trade policies. It is industry focused, but nonetheless has global scope of application (Francois & Hall, 2003). As such, it can be regarded as a streamlined-version of CGE model. The relative ease of use of GSIM, owing to its minimum requirement of inputs and computation needs, makes it the most reasonable method to conduct this research. This is especially so considering the relatively narrow scope of this thesis and limited availability of information. Although practical assumptions used in the application of GSIM would inevitably result in some limitations, the insights gained from the analysis is sufficient to provide the big picture of the situation. Furthermore, the simplicity also allows for swifter, more straightforward and easily-conveyed analysis (Francois & Hall, 2003). Overall, GSIM model is chosen for this thesis as it is capable in highlighting the deviations in trade flows and possible re-routing of seaborne transportation, which are the main objectives of this research.

The GSIM model is formed upon the relative divergence in origin-destination trade correlations. It consists of three main input matrices. Firstly, the values of goods traded in between them, which represent the import demand. Secondly, the initial tariff and tariff equivalents and lastly, the final tariff and equivalents. On top of that, elasticities inputs, namely composite demand, supply and substitution elasticities are also needed to run the model. As for the outputs, GSIM churns out five outputs: the change in output, consumer surplus, producer surplus, net welfare effect and change in price.

3.1.1 Explanation of the model

The mathematical foundations of the GSIM model, as laid out by Francois & Hall (2003), will be presented next. To faithfully dissect the mechanism of the model, the elaborations will be grouped according to the model's elements, just as the authors did. Table 7 summarises the notations used in each equation.

Elasticities:

Import demand is defined as a function of industry prices and total expenditure on the product category (Francois & Hall, 2003):

$$M_{(i,v),r} = f\ (P_{(i,v),r}, P_{(i,v),s\neq r}, Y_{i,v}) \quad (1)$$

Where:

$M_{(i,v),r}$ = Demand for imported products *i* from region *r*, in importing region *v*

$P_{(i,v),r}$ = Internal price for products from region *r, in* importing region *v*

$P_{(i,v),s\neq r}$ = Price of other varieties

$Y_{i,v}$ = Total expenditure on imports of product *i* in importing region *v*

As for own-price demand elasticities, it is defined as such (Francois & Hall, 2003):

$$N_{(i,v)(r,r)} = \theta_{(i,v),r}E_m - \left(1 - \theta_{(i,v),r}\right)E_s \quad (2)$$

$$and\ \theta_{(i,v),r} = M_{(i,v),r}T_{(i,v),r} \,/ \sum_{s} M_{(i,v),s}T_{(i,v),s}$$

Where:

$N_{(i,v)(r,r)}$ = Own-price demand elasticity (indicated by notation (r, r))

$\theta_{(i,v),r}$ = Demand expenditure share

E_m = Composite demand elasticity

E_s = Substitution elasticity

On the other hand, cross-price elasticity is as such that (Francois & Hall, 2003):

$$N_{(i,v)(r,s)} = \theta_{(i,v),s}(E_m + E_s) \tag{3}$$

Where:

$N_{(i,v)(r,s)}$ = Cross-price elasticity (indicated by notation (r, s))

<u>Demand and supply specifications:</u>

The next step is to define the demand for national product varieties and national supply function, shown below (Francois & Hall, 2003):

$$P_{(i,v),r} = \left(1 + t_{(i,v),r}\right)P_{(i,r)} * = \ T_{(i,v),r}\ P_{(i,r)} * \tag{4}$$

Where:

$P_{(i,v),r}$ = Internal price for goods *i* from region *r* imported to region *v*

$P_{(i,r)} *$ = World price for goods leaving origin region *r*

$T_{(i,v),r}$ = Power of trade barriers (price mark-up imposed by trade barriers *t*)

Meanwhile, export supply to the world is expressed as a function of the world price (Francois & Hall, 2003):

$$X_{i,r} = f\left(P_{i,r} *\right) = \ ks_{i,r}(P_{(i,r)} *)^{es_{(i,r)}} \tag{5}$$

Where:

$X_{i,r}$ = Export supply of products *i* from region *r* to world markets

ks = Constant term

es = Elasticity of supply

Differentiating equations (1), (4) and (5) results in the following (Francois & Hall, 2003):

(6) $$\hat{M}_{(i,v),r} = N_{(i,v)(r,r)}\hat{P}_{(i,v),r} + \sum_{s\neq r} N_{(i,v)(r,s)}\,\hat{P}_{(i,v),s}$$

(7) $$\hat{P}_{(i,v),r} = \hat{P}_{i,r} * + \hat{T}_{(i,v),r}$$

(8) $$\hat{X}_{i,r} = E_{X(i,r)}\,\hat{P}_{i,r} *$$

Where ^ signifies proportionate change, such that $\hat{x} = \frac{dx}{x}$.

<u>Global equilibrium specifications:</u>

Market clearing condition is expressed as equation below (Francois & Hall, 2003):

(9) $$\begin{aligned} \hat{X}_{i,r} = \hat{M}_{i,r} => E_{X(i,r)}\,\hat{P}_{i,r} * \\ = \sum_{v} N_{(i,v)(r,r)}\,\hat{P}_{(i,v),r} + \sum_{v}\sum_{s\neq r} N_{(i,v)(r,s)}\,\hat{P}_{(i,v),s} \\ = \textstyle\sum_{v} N_{(i,v)(r,r)}\left[\hat{P}_{r} * + \hat{T}_{(i,v),r}\right] + \sum_{v}\sum_{s\neq r} N_{(i,v)(r,s)}\left[\hat{P}_{r} * + \hat{T}_{(i,v),r}\right] \end{aligned}$$

Change in producer surplus, ΔPS, is defined with equation presented below (Francois & Hall, 2003):

(10) $$\begin{aligned} \Delta PS_{(i,r)} &= R^{0}_{(i,r)}.\hat{P}_{i,r} * + \tfrac{1}{2}.R^{0}_{(i,r)}.\,\hat{P}_{i,r} *.\hat{X}_{i,r} \\ &= \left(R^{0}_{(i,r)}.\hat{P}_{i,r} *\right).\left(1 + \frac{E_{X(i,r)}\,\hat{P}_{i,r} *}{2}\right) \\ and\ E_{x(i,r)} &= \frac{\partial X_{(i,r)}}{\partial P_{(i,r)}}.\frac{P_{(i,r)} *}{X_{(i,r)}} \end{aligned}$$

Where:

$R^{0}_{(i,r)}$ = Benchmark export revenues, either between two countries or total

$E_{x(i,r)}$ = Elasticity of export supply

While change in consumer surplus, ΔCS, is defined with this equation (Francois & Hall, 2003):

(11)
$$\Delta CS_{(i,v)} = \left(\sum_{r} R^{0}_{(i,v),r} \,.\, T^{0}_{(i,v),r}\right) . \left({}^{1}\!/_{2}\, E_{M(i,v)} \hat{P}_{(i,v)}{}^{2} . sign\left(\hat{P}_{(i,v)}\right) - \hat{P}_{(i,v)}\right)$$
$$and\ \hat{P}_{(i,v)} = \sum_{r} \theta_{(i,v),r}\, \hat{P}_{r} * + \hat{T}_{(i,v),r}$$
$$and\ E_{m(i,v)} = \frac{\partial M_{(i,v)}}{\partial P_{(i,v)}} . \frac{P_{(i,v)}}{M_{(i,v)}}$$

Where:

$\hat{P}_{(i,v)}$ = Proportionate change in the price for composite imports

$E_{m(i,v)}$ = Aggregate elasticity of import demand

$R^{0}_{(i,r)} . T^{0}_{(i,v),r}$ = Expenditure at internal prices

Trade creation and diversion specifications:

Trade creation, $TC_{(i,v),r}$, is defined as trade initiated through own trade barriers reduction. It is expressed as (Francois & Hall, 2003):

(12)
$$TC_{(i,v),r} = M_{(i,v),r} \times \left[N_{(i,v)(r,r)} \hat{T}_{(i,v),r}\right]$$

Meanwhile, trade diversion, $TD_{(i,v),r}$, is interpreted as changes in trade, initiated through the adjustments in trade barriers on imports from third countries. It is defined as (Francois & Hall, 2003):

(13)
$$TD_{(i,v),r} = M_{(i,v),r} \times \sum_{s \neq r} N_{(i,v)(r,s)} \hat{T}_{(i,v),s}$$

Table 7. GSIM model notations

Indexes	
r,s	Origin regions
v,w	Destination regions
i	Goods designation
Parameters	
$\boldsymbol{E_s}$	Elasticity of substitution
$\boldsymbol{E_{m(i,v)}}$	Aggregate import demand elasticity
$\boldsymbol{E_{x(i,r)}}$	Elasticity of export supply
Calibrated coefficients	
$\boldsymbol{N_{(i,v)(r,r)}}$	Own price demand elasticity
$\boldsymbol{N_{(i,v)(r,s)}}$	Cross-price elasticity
$\boldsymbol{T_{(i,v),r}}$	The power of trade barrier
$\boldsymbol{\theta_{(i,v),r}}$	Demand expenditure share
$\boldsymbol{\phi_{(i,v),r}}$	Export quantity share
Variables	
$\boldsymbol{M}$	Quantity of imports
$\boldsymbol{X}$	Quantity of exports
$\boldsymbol{P}$	Composite domestic price
$\boldsymbol{P_{(i,r)}}^*$	World price for goods leaving origin *r*
$\boldsymbol{P_{(i,v),r}}$	Internal prices for goods from region *r* imported to region *v*
$\boldsymbol{t_{(i,v),r}}$	Trade barriers for goods from region *r* imported to region *v*

Source: Francois & Hall (2003)

3.1.2 Research application

For the application of this dissertation, GSIM model will be used to assess how retreating sea ice on the Northern Sea Route would affect trade flow along the Southern Sea Route. To serve this purpose, the regions where goods are loaded and unloaded will be determined according to past NSR transits (see Appendix 8), and other regions where utilisation of NSR would theoretically bring reductions in voyage distance. However, GSIM model is not able to forecast the change in trade when the initial trade value is zero (e.g. for some time periods of the NSR currently) because a strong percentage change increase of zero is still zero. This shortcoming is important considering that trade flows via the NSR is currently close to non-existent. The model would strongly underestimate the NSR effects.

Hence, we are using the GSIM model in reverse as employed by Fries (2014), where fix a point in time in the distant future and examine how *increasing* the NTMs (i.e. the sea ice extent increases), going back in time to today, would impact trade. We then reverse these results in presenting our analysis, going forward again in time. Hence we avoid the zero-problem and look at how melting ice caps would really impact the NSR (Fries, 2014).

Traded value between origin-destination countries via the SSR would be included in order to quantify how NSR would implicate them in terms of change in output and welfare, which later translates to the maritime trade impact. To achieve this, bilateral trade among the countries identified would have to be assumed to be seaborne trade. This depends on the countries' maritime transportation share of the total international trade, especially relevant for countries that are also connected by land.

Tariffs for the concerned regions will be determined through trade-weighted tariff computations. Meanwhile, initial tariff equivalents will be determined by the ad valorem trade and transportation cost to the total trade value. Consequently, the final tariff equivalents will be computed according to mid-century climatological projection and the scenarios built around it. The extent of tariff-equivalents liberalisation would depend on the three pollution scenarios; RCP 2.6, RCP 4.5 and RCP 8.5. For each scenario, the extent of liberalisations would rely on the length of navigation window, vessel size restriction, ice class requirement of the vessels, and the direct and indirect cost implications. The output of GSIM, expressed in terms of changes in trade values, will be converted into shipping volumes in terms of tonnage. This will then be used to quantify the change in shipping volumes along the SSR.

3.2 Data requirements

3.2.1 Bilateral trade values

The values of bilateral trade are sourced from the UN Comtrade database, based on the 2016 data that is currently available, or in the case of unavailability of it, will be substituted with 2015 figures. As the study is concerning the overall seaborne trade impact, all HS commodity codes are selected. To illustrate the impact of NSR on vessel traffic along SSR, trade flow between several origin-destination countries is divided into the two competing routes. This is done as follows:

- Western Europe - Far East NSR
- Western Europe - Far East SSR
- Baltic region - Far East NSR
- Baltic region - Far East SSR
- Western Europe - S. China Sea NSR
- Western Europe - S. China Sea SSR
- Baltic region - S. China Sea NSR
- Baltic region - S. China Sea SSR
- ROW - ROW

As already briefed, the reversed GSIM modelling implies that we are working 'backwards' as compared to the normal modelling procedure. Therefore, the current trade value would be 'multiplied' by the percentage change factor ascertained by

Bekkers et al., (2015), to account for future trade values. In their studies, these future trade values were determined by gravity modelling to account for the disappearing Arctic ice.

3.2.2 Initial tariff and tariff equivalents

The tariffs for the identified origin-destination regions will be determined through trade-weighted tariff calculation. For illustration, let us assume Region A which consists of Countries 1 and 2. If Country 1 has a 5% tariff and Country 2 a 10% tariff, and if Country 2 trades two times more than Country 1, then: $\frac{(2\times10\%)+(1\times5\%)}{3} = 8.3\%$ tariff applies for this region. The data on tariff is available from UNCTAD TRAINS, where we will be using the latest available data from 2014. Meanwhile, the weightage is determined through the values of the trade between the regions themselves. The results are laid out in appendix 13.

As for the Non-Tariff Measures (NTM), the trade cost equivalents of the competing maritime trade routes will be ascertained using the regionalised trade-weighted trade costs as ascertained in OECD & WTO (2015) for the NTM inputs (see Table 8). The application of this as proxies of NTM is reasonable since it already considers the various aspects that are also within the research scope of this thesis, namely indirect costs to trade, connectivity of seaborne transportation and the state of its infrastructures, on top of regulatory aspects as often stipulated in trade policy studies.

Table 8. Ad valorem trade-weighted trade costs between regions

	EU27	**ECA**	**ESA**	**LAC**	**MENA**	**NA**	**SA**	**SEA**	**WCA**
EU27	34.3								
ECA	67.3	64.8							
ESA	112	146	103.7						
LAC	109.5	158.4	186.2	93.6					
MENA	76	109.4	91	135	48.3				
NA	65.5	102.6	125	92.3	72.2	14.8			
SA	94.8	136.5	161.9	183.8	60.8	88.6	92		
SEA	88	119.5	155.1	127.9	69.4	71.9	103.6	68.8	
WCA	106.7	168.2	93.7	123.7	112.4	105.4	99.6	162	104.3

Source: OECD & WTO (2015)

Notes: ECA = Europe (other than EU27) and Central Asia, ESA = Eastern and Southern Africa, LAC = Latin America and Caribbean, MENA = Middle East and North Africa, NA = North America, SA = South Asia, SEA = Southeast and East Asia, WCA = Western and Central Africa.

This input, is lacking the direct maritime transportation cost component. To this end, a study by (Korinek & Sourdin, 2009) is referred to as the base of the ad valorem seaborne transportation cost. Korinek & Sourdin (2009) uses the WITS Maritime Transport Cost Database to ascertain the figures. The results are shown below:

Table 9. Ad valorem maritime transport cost

	Ad Valorem	Maritime Transport Cost ($/Ton)
Importing region		
Africa	25.62	69.41
Asia	8.57	51.56
EU27	10.11	124.89
MENA	7.78	66.19
North America	4.43	49.2
Oceania	6.8	78.47
South America	4.9	38.59

Source: Korinek & Sourdin (2009)

The next step is to ascertain the current NTM for the NSR. We will follow the same procedure by dividing the analysis into trade costs and maritime transportation cost. The difference between the NTM for SSR and that of NSR is determined by the various factors that we had assessed in the preceding chapters. For the purpose of this analysis, we will be comparing the use of PC 6 vessel for the Arctic route with OW vessel used in the SSR.

Trade cost

- Reduction in voyage time:
  Even though traversing via the NSR reduces Asia – Europe sailing distance by around 40%, the reduction in the number of days' voyage does not necessarily reflect this. Challenging sea ice conditions would result in delays, resulting in the more realistic transit duration of around 27 days (Pruyn, 2016). Comparing this with the average SSR voyage duration of 40 days, the reduction of 13 days via the NSR implies 32% reduction in sailing time. Hummels (2007) investigates the per-day tariff equivalents, which appropriately will be used for this analysis (see figure 10). Following this structure, a reduction of 13 days in transportation of goods from Japan to Rotterdam, for example, would result in $13 \times 0.8\% = 10.4\%$ decrease in the trade cost component as compared to the SSR.

Table 10. Per-day tariff equivalent for time saved during transportation

Region	Import	Export
High Income OECD	0.8	1.0
East Asia & Pacific	0.8	0.7
Europe & Central Asia	0.9	0.7
Latin America & Carribean	0.9	0.8
Middle East & North Africa	1.0	0.4
South Asia	1.5	0.6

Source: Hummels (2007)

- Length of navigability days:

The length of navigable day window of the NSR remains the Achilles heel towards widespread commercial use. Length of navigability for it is currently around 65 days, with 80% chance of navigation for PC 6 vessel (Melia et al., 2016). The weighted average for the annual navigability factor can be expressed as $80\% \times \frac{65}{365} = 14.2\%$. Assuming that seaborne trade would take place via the NSR whenever it is accessible, the remaining 85.8% would take place via the conventional route for the remaining days of the year.

- Vessel size restriction:

Following with comparison of vessel size that can feasibly sail through the two competing routes, we would employ assumption used by The Arctic Institute that specifies 80,000 DWT bulk cargo vessels and 4,500 TEU container ships employable on the Arctic route. This dimension is roughly 38% of the capacity of vessel that sail via the SSR (see section 2.1.4 and 2.2.4). The trade cost NTM therefore is $10.4\% \times 14.2\% \times 38\% = 0.56\%$ below baseline.

Maritime transport cost

- Fuel cost:

The employment of the NSR contributes to lower fuel consumption from the reduced voyage distance and slower sailing speed (Pruyn, 2016). A collaborative study between Arctic Climate Change, Economy and Society (ACCESS) and Nordic Bulk Shipping A/S in 2015 reveals 32% savings in bunker cost by re-routing the voyage of 75,000 DWT dry bulk vessel *Nordic Odyssey* from Kirkenes to Yokohama via the NSR. Vessel of such specification and dimension typically uses about 38 tons of fuel per day (ACCESS - Arctic Climate Change Economy and Society, 2015).

Assuming current (August 2017 – shipandbunker.com) IFO 380 bunker price in Rotterdam valued at US$ 300/ ton, fuel cost per NSR trip is: $38 \times 27 \times 300 =$ US$ 307,800 in fuel consumption. In comparison, fuel cost per trip via the SSR at $38 \times 40 \times 300 =$ US$ 456,000. We are considering 12 annual trip as assumed by Furuichi & Otsuka (2013), of which 14.2% (~2 trip) would take place via NSR and remaining 85.8% (10 trip) would take place via the SSR. The combined NSR/SSR choice results in fuel cost of US$ 5,175,600, compared to US$ 5,472,000 if the SSR is used exclusively.

- Capital cost:

Typically, ice class vessels would cost 5 - 7% more than their open water counterparts (Pruyn, 2016). Nordic Odyssey is a PC 6 ice class Panamax vessel and it costs US$ 65 million when new (ACCESS - Arctic Climate Change Economy and Society, 2015). Furuichi and Otsuka (2013) ascertained that a newly built 4,000 TEU container vessel costs US$ 47 million. Due to the limitation of data regarding new build vessel, we will assume the average of US$ 56 million for new PC 6 cargo vessel that can be employed on the Arctic route. As for the capital expenditure per day, we will also use the figure for Nordic Odyssey at US$ 7,500 per day, or US$ 2,737,500 annually (ACCESS – Arctic Climate Change Economy and Society, 2015). Assuming 6% premium imposed on PC 6 vessel, capital expenditure for OW vessel with the same dimension is therefore $2{,}737{,}500 \div 1.06$ = US$ 2,582,547 yearly.

- <u>Transit dues and other costs:</u>

According to Centre for High North Logistics information office, currently PC 6 vessels (Arc 5 according to Russian Register of Shipping) would require ice breaking assistance during heavy ice conditions in five zones: east and west of Laptev Sea, east and west of East Siberian Sea, and the Chukchi Sea (refer to Table 3). Correspondingly, *Nordic Odyssey* (40,142 GT) would pay US$ 275,289.68 in icebreaker assistance (NSRA, 2013, for more information on this: http://www.arctic-lio.com/nsr_tariffsystem). Annually, this result in $275{,}289.68 \times 2$ = US$ 550,579.36 in ice breaking assistance bill.

According to Furuichi & Otsuka (2013), NSR transit fee is charged at US$ 5 per gross tonnage of vessel. Using the example of *Nordic Odyssey*, the transit fee would be $5 \times 40{,}142 \times 2$ = US$ 401,420 annually. For the 10 voyages via the SSR when the NSR is not accessible, the transit fee would be $10 \times 190{,}107$ = US$ 1,901,070, reflecting the Suez fee of US$ 190,107 for vessel with such dimension (Wilhelmsen Suez Toll Calculator). Ice pilot fee is set at US$ 673 per day. With typical duration 14 days for ice pilotage (Pruyn, 2016), it amounts to US$ $14 \times 673 \times 2$ = US$ 18,844 annually. Meanwhile, insurance premium is valued at US$ 27.5 per GT per year. Therefore, *Nordic Odyssey* would pay US$ 1,103,905 in insurance. Total annual NSR transit cost is US$ 3,975,818.

In comparison, exclusive SSR voyage would entail annual transit fee $12 \times 190{,}107$ = US$ 2,281,284 annually. Insurance premium and anti-piracy measures would cost US$ 18 per GT per year (Pruyn, 2016), resulting in cost of US$ 722,556. The total SSR transit cost is then US$ 3,003,840. The summary of the costs is presented below:

Table 11. Cost comparison NSR vs SSR

	NSR	**SSR**
Fuel cost	US$ 5,175,600	US$ 5,472,000
Capital cost	US$ 2,737,500	US$ 2,582,547
Transit & other costs	US$ 3,975,818	US$ 3,003,840
Total cost	US$ 11,888,918	US$ 11,058,387

Source: Own elaboration

Ultimately, the transportation cost via the NSR is 7.5% higher than the baseline. In this analysis, it is important to note that maintenance and crew cost are purposely left out, as they are assumed to stay constant no matter which routes were chosen (Furuichi & Otsuka, 2013) & (Pruyn, 2016). This does not necessarily reflect the reality, as traversing through the NSR may involve extra maintenance cost and extra crew training cost. Nonetheless, comparison between the variable voyage costs is deemed sufficient considering the limited scope of the thesis. The findings are summarised in Appendix 14.

3.2.3 Elasticities

As have already been briefed, the GSIM econometric model requires three inputs of elasticities. They are substitution elasticity, industry supply elasticity and composite demand elasticity. Francois & Hall (2003) set the value for substitution elasticity at 10 while supply elasticity is set at 1.5, which accordingly will be used in the modelling. As for import demand elasticity, recent studies conducted by Bensassi et al. (2016) arrives at elasticity value of -0.9 when perfect navigability of the NSR is assumed, purely from the aspect of distance reduction. In other words, this implies the ignoring of variable navigation duration and the additional icebreaking and insurance costs. Elasticity estimation by Feyrer (2009) will instead be used for this thesis. In his paper, he looked at the Suez Canal blockades of 1967 and 1975 to investigate the implication of distance (and transportation cost) on trade. He arrives at elasticity figures between -0.15 to -0.46. Since the NSR is an alternative route to the Suez Canal route, this observation seems reasonable. Furthermore, the more moderate estimation suits best for the varying degrees of NSR accessibility that is the research niche of this thesis.

3.3 Liberalisation scenarios for final tariff equivalents

As the degree of navigability of the Arctic route will be dependent upon the rise in global temperature in the medium term, mid-century climatological projection will be applied for the NTM liberalisation. This will be divided into three scenarios: ‘low pollution’, ‘medium pollution’ and ‘high pollution’ scenarios (RCP 2.6, 4.5 and 8.5 respectively). ‘Low pollution’ scenario (which is the one that implicates SSR countries the least) will be based on mid-century climatological and navigational projections under minimum rise in global temperature, in line with the current target of 2°C set by the recent Paris Agreement. ‘Medium pollution’ scenario implies medium radiative forcing scenario. Meanwhile, ‘high pollution’ scenario (the one that will implicate SSR most negatively) will account for the mid-century projections under maximum forcing.

As we are using the GSIM model *in reverse*, we will be working backwards and gradually increase the NTMs instead of decreasing the NTMs as usually done with normal GSIM model. This is done so as to simulate how the future trade values would be negatively implicated if the ice in the Arctic is returning. The result would give the mirror image of the situation where the NSR is becoming more accessible with the disappearing ice in the future (Fries, 2014).

Scenario 1: Mid-century at RCP 2.6

Mid-century projection at RCP 2.6 brings the voyage time via the NSR to 24 days (Melia et al., 2016). Saved voyage time is now 16 days as compared to SSR. This brings $16 \times 0.8\% = 12.8\%$ reduction in trade cost component of the NTM. With length of navigability days of 90 days, the new annual navigability factor is $80\% \times \frac{90}{365} = 19.7\%$. As vessels are still restricted to the coastal line (see figure 5), 46% size reduction as opposed to SSR is assumed. The trade cost NTM is therefore $12.8\% \times 19.7\% \times 46\% = 1.16\%$ below baseline.

As for the maritime transportation cost components, we assume bunker price to stay at US$ 300 / ton for consistency sake. This must be treated cautiously as the tightening of emission regulations more likely leads to the use of the more expensive Ultra Low Sulphur Fuel Oil or LNG. Taking 24 days NSR voyage duration results in NSR fuel cost of $38 \times 24 \times 300 =$ US$ $273{,}600$. Assuming 12 annual voyages as before, $19.7\% \times 12 = 2.4$ voyages would be via NSR, while remaining 9.6 voyages have to be carried out via the SSR. This results in $(2.4 \times 273{,}600) + (9.6 \times 456{,}000) =$ US$ 5,034,240 in fuel cost via the NSR.

While the capital costs for both routes would remain the same, transit dues and would adjust with the increasing accessibility of NSR. NSR transit due will be at $5 \times 40{,}142 \times 2.4 =$ US$ 481,704. When NSR is not accessible, re-routing costs $9.6 \times 190{,}107 =$ US$ 1,825,027. Ice pilot amounts to $14 \times 673 \times 2.4 =$ US$ 22,612 annually, while insurance remains the same at US$ 1,103,905. The summary of the costs is expressed in Table 12 below. At RCP 2.6, NSR utilisation will only be 1.3% higher than baseline.

Table 12. Cost comparison NSR vs SSR at RCP 2.6

	NSR	SSR
Fuel cost	US$ 5,034,240	US$ 5,472,000
Capital cost	US$ 2,737,500	US$ 2,582,547
Transit & other costs	US$ 3,433,248	US$ 3,003,840
Total cost	US$ 11,204,988	US$ 11,058,387

Source: Own elaboration

The result of NTM liberalisation at RCP 2.6 is attached in the Appendix 15.

Scenario 2: Mid-century at RCP 4.5

Radiative forcing at RCP 4.5 results in 21-days voyage time via the NSR (Melia et al., 2016). The saving in voyage duration, as compared to SSR, is 19 days, bringing $19 \times 0.8\% = 15.2\%$ reduction in trade cost component of the NTM. As the NSR is now navigable for 101 days, the annual navigability factor is $80\% \times \frac{101}{365} = 22.1\%$. Mid-century at RCP 4.5 also allows the possibility of non-coastline shipping lane (see Route 3 in Figure 4), resulting in vessel that is 75% the capacity of the SSR from the less draft restriction (see section 2.1.4). Therefore, the reduction in NTM for trade cost due to the shorter journey amounts to $15.2\% \times 22.1\% \times 75\% = 2.5\%$.

The ship size that can navigate the NSR will be assumed to be 100,000 DWT Aframax vessel (75% the capacity of Suezmax). Newbuild price for Aframax OW vessel is US$ 44 million in 2017 (Compass Maritime, 2017). PC 6 vessel of the same dimension is ascertained to cost $44\, million \times 1.06 =$ US$ 46.6 million, following the same assumption used previously. Typical vessel would consume 50 tons of bunker fuel per day, and its gross tonnage comes at approximately 65,000 GT (Wartsila, 2012).

NSR fuel cost per voyage will be $50 \times 21 \times 300 =$ US$ 315,000, while that of the SSR is $50 \times 40 \times 300 =US 600,000. With 12 annual voyage as assumed before, and annual navigability factor of NSR at 22.1%, the vessel would sail $22.1\% \times 12 = 2.6$ voyages via the NSR and the remaining 9.4 voyages via the SSR. This results in $(2.6 \times 315{,}000) + (9.4 \times 600{,}000) =$ US$ 6,459,000 in fuel cost. If SSR is used exclusively, this results in $12 \times 600{,}000 =$ US$ 7,200,000.

Comparing the capital cost with the smaller vessel, the PC 6 Aframax vessel will have yearly capital cost of $\frac{2{,}737{,}500 \times 46.6}{56} =$ US$ 2,277,991. Consequently, OW Aframax vessel is assumed to have yearly capital cost of $2{,}277{,}991 \div 1.06 =$ US$ 2,149,048 annually. The non-coastline shipping lane is outside of the 200nm Russian Exclusive Economic Zone. As such, transit fee and ice pilotage fee of the NSR are negated. The insurance cost for NSR is $65{,}000 \times 27.5 =$ US$ 1,787,500. Suez Canal fee is found to be US$ 209,116 (Wilhelmsen Suez Toll Calculator). When the NSR is not accessible, the vessel will transit via the SSR 9.4 times, resulting in fee of $209{,}116 \times 9.4 =$ US$ 1,965,690. Total NSR transit fee is therefore US$ 3,753,190. Using the SSR exclusively results in fee of $209{,}116 \times 12 =$ US$ 2,509,392. The insurance and anti-piracy measures result in $65{,}000 \times 18 =$ US$ 1,170,000. This results in SSR transit fee of US$ 3,679,392. The summary of the costs is shown in Table 13 below. At RCP 4.5, NSR utilisation will be 4.13% lower than baseline.

Table 13. Cost comparison NSR vs SSR at RCP 4.5

	NSR	SSR
Fuel cost	US$ 6,459,000	US$ 7,200,000
Capital cost	US$ 2,277,991	US$ 2,149,048
Transit & other costs	US$ 3,753,190	US$ 3,679,392
Total cost	US$ 12,490,181	US$ 13,028,440

Source: Own elaboration

The result to this analysis is attached in Appendix 16.

Scenario 3: Mid-century at RCP 8.5

At RCP 8.5, OW vessel will be able to pass through the NSR. Voyage time via the NSR will be 19 days, bringing 21-days saving compared to the SSR. This brings $21 \times 0.8\% = 16.8\%$ reduction in trade cost component of the NTM. With navigable days now at 118 days, the annual navigability factor is $80\% \times \frac{118}{365} = 25.8\%$. Vessel size will be assumed to have the same dimension as the SSR (Suezmax vessel of 150,000 DWT), due to the large swaths of accessible Arctic routes (see Figure 5). The NTM reduction of the trade cost is therefore $16.8\% \times 25.8\% = 4.3\%$.

OW Suezmax vessel newbuild price is currently US$ 54 million (Compass Maritime, 2017). The daily bunker consumption of such vessel is 56.7 ton per day (Brodosplit, 2007) and it would have gross tonnage of 97,500 GT. NSR fuel cost per voyage will be $56.7 \times 19 \times 300 =$ US$ 323,190, while that of the SSR is $56.7 \times 40 \times 300 =$ US$ 680,400. With 12 annual voyage as assumed before, and annual navigability factor of NSR at 25.8%, the vessel would sail $25.8\% \times 12 = 3$ voyages via the NSR and the remaining 9 voyages via the SSR. This results in $(3 \times 323{,}190) + (9 \times 680{,}400) =$ US$ 7,089,570 in fuel cost from choosing the Arctic route. If SSR is used exclusively, it results in $12 \times 680{,}400 =$ US$ 8,164,800 in bunker cost.

The yearly capital expenditure cost, through comparison with cheaper vessel in the previous scenario, will be $\frac{54{,}000{,}000 \times 2{,}277{,}991}{44{,}000{,}000} =$ US$ 2,795,716. As the Arctic route becomes increasingly free of ice, the insurance premium will be set at US$ 5 / GT per year as ascertained by Furuichi & Otsuka (2013). This brings annual insurance cost of $5 \times 97{,}500 =$ US$ 487,500. In comparison, the insurance fee of SSR is $18 \times 97{,}500 =$US$ 1,755,000. Furthermore, NSR transit and ice pilotage fees are negated as vessels would have the liberty to choose routes outside of Russian jurisdiction. When the NSR is not accessible for 9 voyages, the SSR will be chosen. However, Suez Canal fee will be discounted by 65% to take into account the rising competition with NSR. This is not too far-fetched considering that the 65% discount is already offered for VLCC from specific ports (Wilhelmsen Suez Toll Calculator). Thus, the canal fee for such vessel is US$138,111. The transit fee for when the NSR is not accessible is therefore $9 \times 138{,}111 =$ US$ 1,242,999. Meanwhile, using the SSR exclusively results in annual transit fee of $12 \times 138{,}111 =$ US$ 1,657,332.

Table 14 below summarises the cost components. NSR utilisation at RCP 8.5 will result in transportation cost element being 19% lower than baseline. Appendix 17 summarises the changes of NTM at RCP 8.5.

Table 14.Cost comparison NSR vs SSR at RCP 8.5

	NSR	**SSR**
Fuel cost	US$ 7,089,570	US$ 8,164,800
Capital cost	US$ 2,795,716	US$ 2,795,716
Transit & other costs	US$ 1,730,499	US$ 3,412,332
Total cost	US$ 11,615,785	US$ 14,372,848

Source: Own elaboration

4. Results and analysis

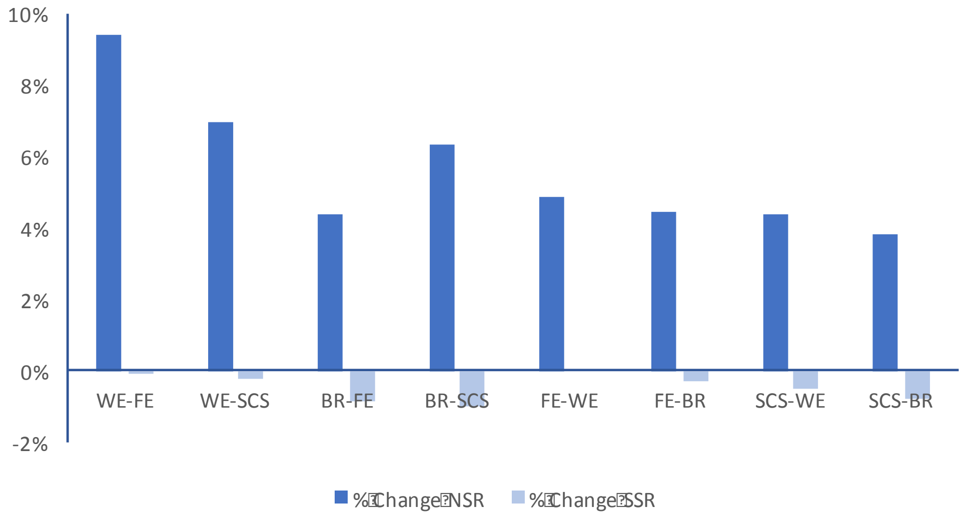
As the melting of Arctic ice caps is not going to happen overnight, this thesis assesses the maritime trade implication of retreating sea ice based on climatological projections. This is employed according to the Arctic Transportation Accessibility Model (ATAM) on mid-century climate forecast, developed by Smith & Stephenson (2013) and Melia et al. (2016). The projections are illustrated on three Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5 and RCP 8.5, that stand for low, medium and high radiative force levels respectively. These correspond with the projections of the rise in global temperatures. Therefore, incorporating these scenarios into the GSIM model captures the gradual navigability of the Arctic route and its implication on seaborne trade along the Northern Sea Route and its conventional alternative– the Southern Sea Route. We solve the GSIM model in reverse to avoid the zero-problem and get reliable estimates on NSR traffic.

The first three sections look at the results of the three different scenarios. For each scenario, we will assess the percentage change in NSR/SSR maritime trade, and the changes in exports and imports for the regions. This will be followed by a section comparing all the scenarios, in terms of the change in maritime trade routes, producer and consumer surplus, welfare, and output are also presented.

4.1 RCP 2.6 Scenario

4.1.1 Maritime trade impact

For the mid-century at RCP 2.6 scenario, the shift towards the use of NSR is the strongest for the Western Europe – Far East origin-destination pairings, an increase of 9.4%. In comparison, Western Europe – South China Sea shift to NSR is considerably weaker (but still significant) at 6.9%. This highlights the fact that usage of SSR is still relatively more competitive for the South China Sea region – when looking at differences in relative distances between the regions. In addition, the Baltic Region – Far East trade via the NSR would increase by 4.3%. Interestingly, the Baltic Region – South China Sea origin-destination pairings show strong substitution towards the use of NSR, leading to a 6.3% increase in traffic. This echoes the historical shipment of Naphta from Norway to Taiwan in 2012 and shipment of heavy oil from Murmansk to Singapore in 2013, which as the results suggest, could be observed again in the future.

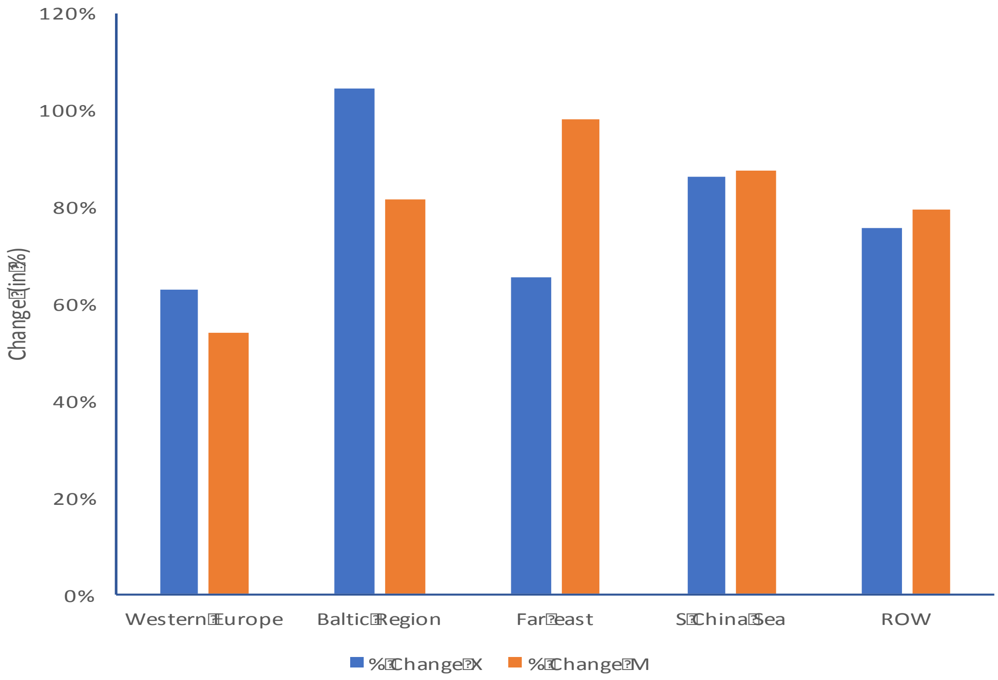


Source: Own elaboration

Figure 9. Change in maritime trade routes at RCP 2.6

At the same time, we can see that substitution away from the SSR is still hardly noticeable, accounting for mere 0.04% to 1.02% decrease overall. This suggests that under RCP 2.6, the SSR does not lose too much from the more accessible NSR but that the effect is felt mostly inside the regions as intra-regional trade drops. In short, new trade via the NSR will go up without taking away significant shares of SSR traffic.

4.1.2 Change in exports and imports



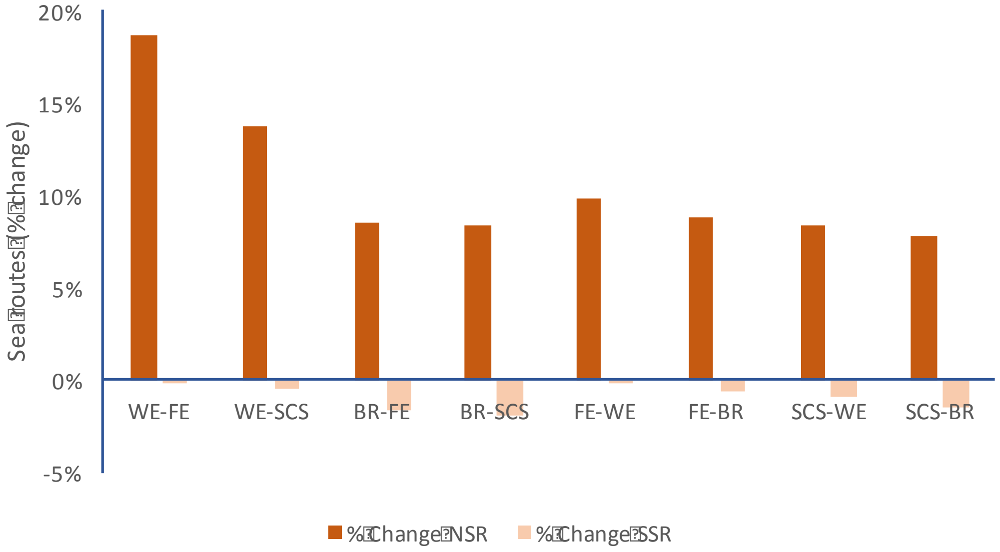
Source: Own elaboration

Figure 10. Change in exports and imports at RCP 2.6

Under the RCP 2.6 scenario, the highest gain in exports is experienced by the Baltic Region, in line with the fact that energy extraction and transportation from the area (Russia, Norway) stands to win the most from the gradual accessibility of the NSR. Consequently, the increase in imports is the highest for the Far East region, confirming the desire towards increasing the use of NSR by Far East countries, especially for the importation of energy commodities. Therefore, this result suggests that at mid-century under RCP 2.6, we would observe increasing export from the Baltic Region and import in Far East is due to the more accessible Arctic route, suggesting that seaborne trade between these regions would likely to happen via the NSR. The fact that the Baltic Region would transport more to the Far East than it would transport to Western Europe explains this observation.

4.2 RCP 4.5 Scenario

4.2.1 Maritime trade impact



Source: Own elaboration

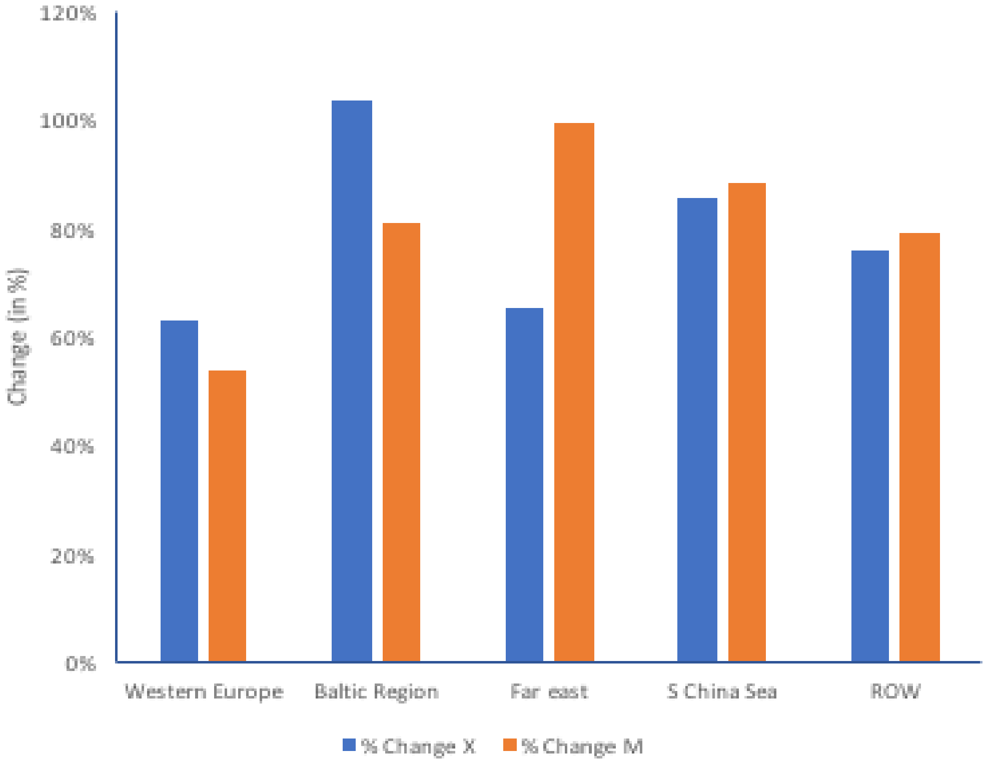
Figure 11. Change in maritime trade routes at RCP 4.5

The mid-century projection at RCP 4.5 reveals the fact that maritime trade between Western Europe – Far East via the NSR is set to increase by 18.8%. On the other hand, Far East – Western Europe seaborne trade (the other way around) via the NSR would increase by 9.9%. The observation highlights the fact that reduction of NTMs (in terms of transportation and trade costs) is not symmetrical. Referring to Tables 8, 9 and 10, we can see that certain importing regions 'value' the savings in transportation time differently, hence explaining the different reductions. Continuing with the analysis, Western Europe – South China Sea trade via the NSR would experience 13.8% increase, which is still considerable weaker than that of Western

Europe – Far East. In addition, the result also shows that Baltic Region – Far East trade via the NSR shows marginally stronger increase than the Baltic Region – South China Sea. This confirms the argument on diminishing benefit of the NSR the further south origin-destination pairings are located.

SSR substitution at RCP 4.5 is still not substantial. It is observed that an accessible NSR brings about a 0.1% to 1.9% decrease in traffic along the SSR. The highest SSR substitution is observed for the Baltic Region – South China Sea v.v. pairings, accounting for a 1.9% and 1.5% decrease in SSR usage respectively. This suggests the likelihood of destination shipping via the NSR between these regions in the future. Also trade flows that do not use NSR or SSR change. This follows the same reasoning as in the previous scenario. In addition, we can also observe that for the Baltic Region – Far East pairing, a 1.6% decrease of maritime traffic along the SSR is projected due to the substitution with the NSR as the preferred maritime trade lane.

4.2.2 Change in exports and imports



Source: Own elaboration

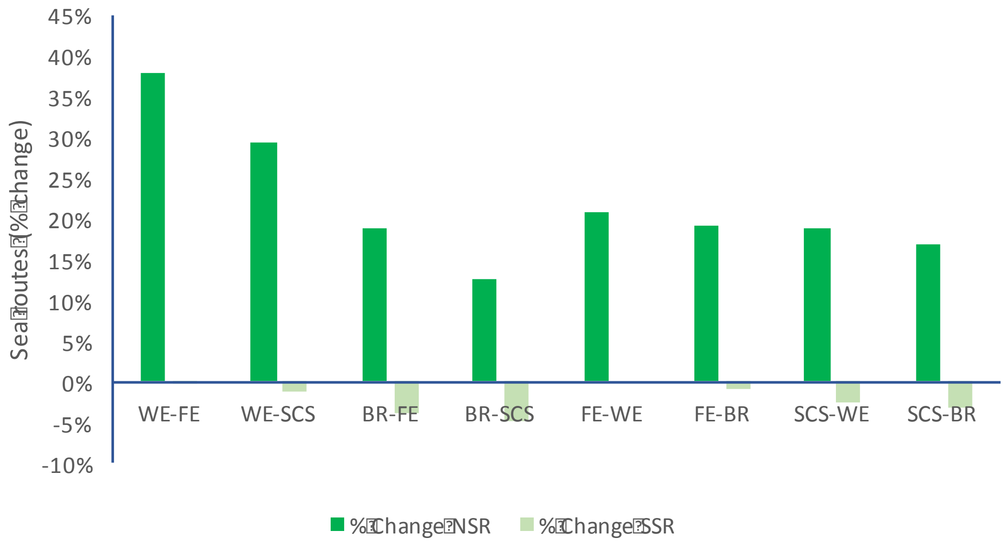
Figure 12. Change in exports and imports at RCP 4.5

At radiative forcing level at RCP 4.5, trade increases significantly because of lower trade costs (due to NSR). Compared to the previous scenario, we see that imports in the South China Sea region increase substantially with the increasing accessibility of the NSR. This can be explained by the economic linkage to the regions that benefit most from the usage of NSR (e.g. the Far East), and the fact that intra-Asia trade is projected to grow in the future. The same argument on economic linkage also applies for imports to Rest of World. Furthermore, the increase in exports and imports in the ROW can be traced back to the lowering of global trade cost brought by the more accessible NSR.

4.3 RCP 8.5 Scenario

4.3.1 Maritime trade impact

From the maximum radiative forcing level RCP 8.5, we see that trade via NSR is set to increase substantially. This is understandable since this scenario imposes the least restrictions on the usage of NSR, in terms of volume that can be transported over the route, and the decrease in costs and fees associated with NSR transit voyage. The strongest impact is noticeable in Western Europe – Far East, Western Europe – South China Sea, and Far East – Western Europe. They account for 37.9%, 29.5% and 19.2% increase respectively. Trade between Baltic Region – Far East via the NSR is now higher than that of Baltic Region – South China Sea, further substantiating the argument on the diminishing benefit of NSR the further south origin-destination pairings are located.

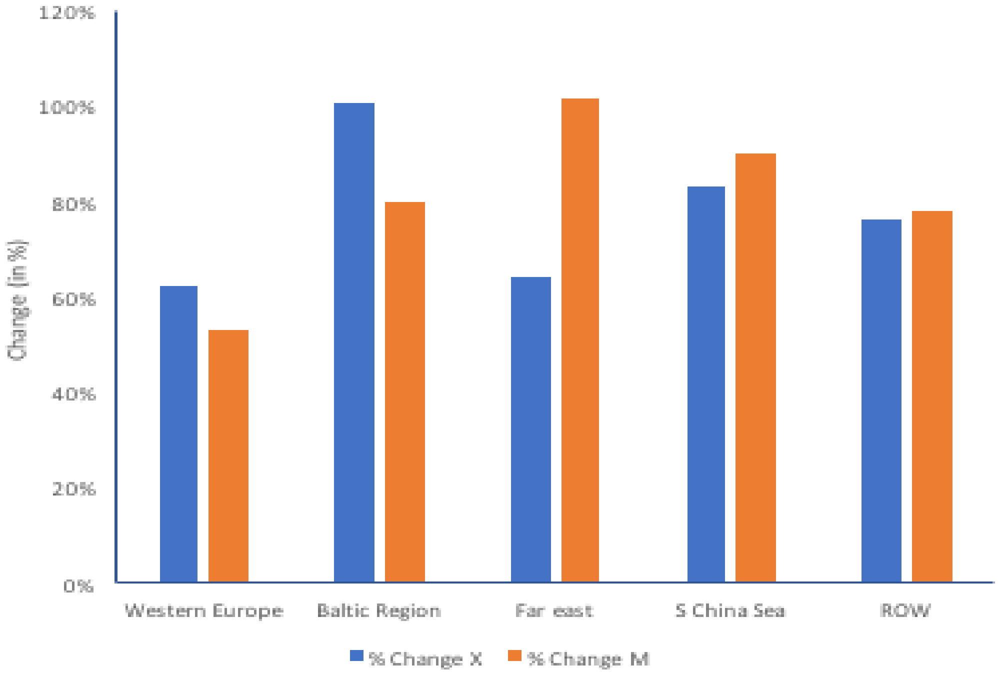


Source: Own elaboration

Figure 13. Change in maritime trade routes at RCP 8.5

On the flip side, the increase in usage of NSR does not necessarily translate to significant losses for the SSR as the global maritime trade route. It is observed that the decrease in SSR traffic for Baltic Region and Far East decreases by almost 5%.

4.3.2 Change in exports and imports



Source: Own elaboration

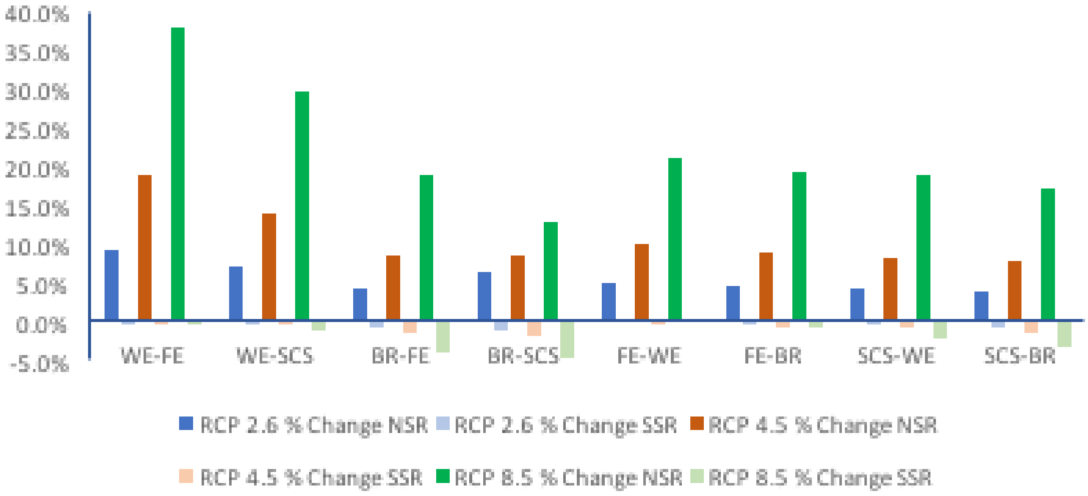
Figure 14. Change in exports and imports at RCP 8.5

Consistent with the two previous scenarios, greater accessibility of the NSR increases both exports and imports in the regions identified. At this junction, it is worth emphasising the fact that higher usage of NSR contributes to the lowering of trade and transportation costs. This would have a global repercussion due to the economic linkages between the regions that benefits directly from the NSR and the global trade partners to those regions.

4.4 Comparison of scenarios

4.4.1 Maritime trade impact

Side-by-side comparison of all the scenarios reveal the fact that RCP 8.5 scenario brings the strongest maritime trade effects to the NSR and substitution of the SSR. This has so far been consistent with the reality that at this maximum radiative forcing level, the NSR becomes less restrictive and relatively cheaper to be utilised, fuelling the debates that NSR could one day take over Suez Canal’s throne as the busiest international maritime trade node. The results, however, show that even at RCP 8.5, the decrease in SSR traffic only amounts to 16%. This value in real terms would not drastically change the current vessel transit along the SSR. This finding can be explained by the fact that the growth in NSR maritime trade is spurred by less trade within the regions and between regions that do not use NSR or SSR, and by new trade that is not in direct competition with the SSR. This point is illustrated by the Western Europe – Far East pairings which experience the highest percentage change in NSR maritime trade. Furthermore, this is also attributable to the lower intra-regional trade. The shift from SSR to NSR is also much stronger in the Western Europe and Baltic Region to the Far East, as compared to Western Europe and Baltic Region to the South China Sea. This is so as the SSR is still more competitive route for these pairings, considering longer voyage distance if NSR were to be used to serve these origin-destination pairings.



Source: Own elaboration

Figure 15. Maritime trade routes comparison

4.4.2 Producer and consumer surplus

It is apparent across all scenarios that producer surplus is always positive, indicating producers' gains from the lowering of transportation cost brought by accessible NSR. The strongest effect is observed for producers in Western Europe and Rest of World, each achieving US$ 5.4billions producer surplus under RCP 2.6 scenario. Rest of World stands to win because economies are linked to the regions that are the focused in this study, and as such, they will gain if those regions gain. To add on, consumers in the Far East reap most gains, also due to the lower transportation cost that brings down consumer price. On the contrary, consumers in South China Sea region clearly are not entitled to the same levels of gains due to the fact that this region would not benefit much from the opening of NSR (the SSR is still the shortest and least expensive route for them).

As for the negative consumer surpluses in the Western Europe and the Baltic Region, they are explained by the higher prices brought by increasing demand of their products elsewhere outside the regions. For Western Europe, an additional effect is that the Baltic Region – because of melting ice caps – gains competitiveness towards Asia because of the shorter NSR route vis-à-vis Western Europe. Consistent with the higher degree of NSR accessibility under the maximum radiative forcing scenario, the change in producer and consumer surpluses are at the strongest under RCP 8.5. Western Europe producers under this scenario would experience a 128% increase in their surpluses when compared to the RCP 4.5 scenario. However, this happens at the expense of consumer surplus, where the loss is now about two times the level of RCP 4.5.

Table 15. Change in producer and consumer surplus (USD Billions)

	RCP 2.6		**RCP 4.5**		**RCP 8.5**	
	Producer surplus	**Consumer surplus**	**Producer surplus**	**Consumer surplus**	**Producer surplus**	**Consumer surplus**
Western Europe	5.4	-7.9	11.1	-16.0	25.4	-36.6
Baltics	2.4	-1.2	4.7	-2.4	11.1	-5.7
Far East	2.6	25.0	5.4	52.5	12.9	135.2
S China Sea	2.2	-1.5	4.3	-3.1	10.6	-7.2
ROW	5.4	-0.2	11.1	-0.4	25.7	-0.8

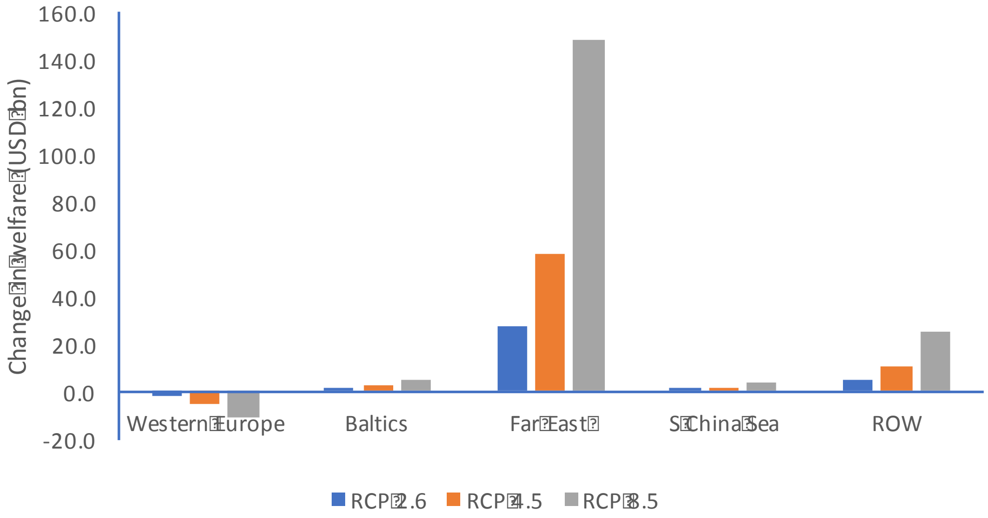
Source: Own elaboration

4.4.3 Welfare effects

The change in total welfare is observed to be the highest in the Far East, attributed to the large gains for producers and consumers as briefed in the previous section. The region would experience gain by US$ 27.7 billions under RCP 2.6, and US$ 148 billions under maximum forcing scenario at RCP 8.5. ROW also stands to gain up to US$ 24.8 billions under RCP 8.5, suggesting the positive global implication of accessible NSR. A noticeable increase is also observed in the South China Sea and the Baltic regions. This is brought about by the lowering of global trade cost as the NSR is becoming less costly to use. On the other hand, welfare effects in the Western Europe region stand to lose as the loss of consumer welfare from higher prices (due to increase in demand) is not offset by the gains for producers.

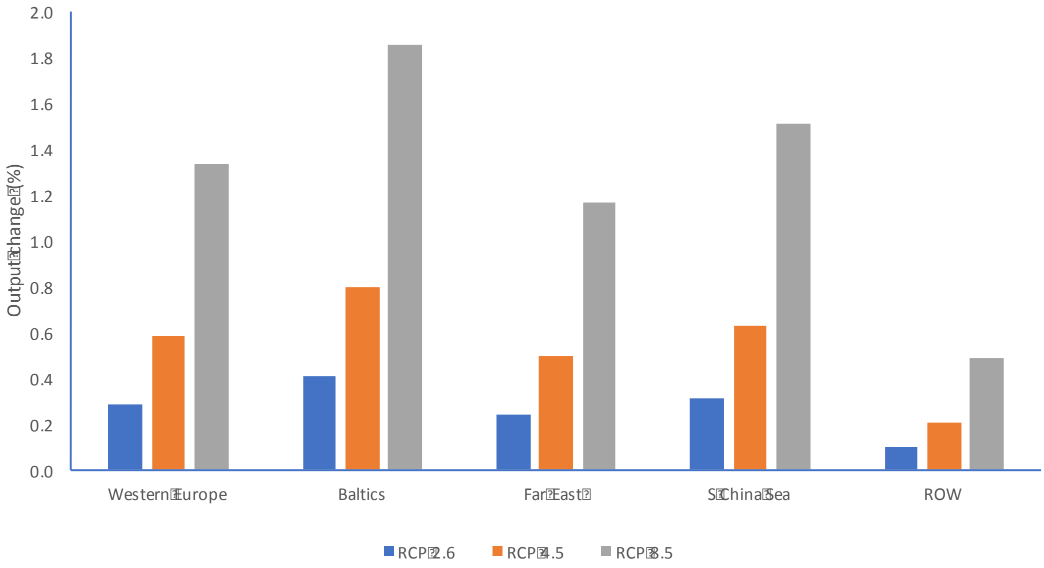
4.4.4 Change in output

In terms of output, all regions benefit from a navigable NSR. The increase in production is linked to the observed increases in producer surplus, which translates in improvement of GDP. The highest output gains across the three scenarios is observed in the Baltic Region, in line with the desire for countries in this region, for example Russia, to employ the Arctic route to better facilitate the movement of oil and gas extracted in the Northern Polar region. The high percentage change in output for South China Sea region also could indicate the indirect benefit from the employment of NSR. It is perhaps explained better by the growth projection for developing economies in South China Sea region, for example Vietnam and Singapore, which in addition would receive a slight boost with the opening of NSR.



Source: Own elaboration

Figure 16. Welfare comparison



Source: Own elaboration

Figure 17. Output comparison

5. Conclusions

5.1 Key findings

Comparison across all scenarios reveal that higher navigability of the NSR leads to gradual increase in NSR utilisation. This effect is observed to be the strongest in mid-century projection at radiative forcing level RCP 8.5.

The model results show that the Western Europe – Far East origin-destination pairing would see the highest increase in NSR utilisation. This is applicable under all the scenarios, which eventually amounts to an increase of 37.9% under the maximum forcing scenario at RCP 8.5. However, this is not accompanied by a substantial decrease in SSR utilisation (only a 0.2% decrease compared to current levels), which suggests that utilisation of the NSR by this pairing is contributed by new trade and that new trade does not go through the SSR.

The substitution effect of SSR to the NSR is the strongest for the origin-destination pairings of the Baltic Region and South China Sea. This is indicated by the decrease of SSR usage by 4.7% at RCP 8.5. Although this at first seems startling, it echoes the historical usage of NSR for shipment of liquid bulk energy from Norway and Russia, to countries as far south as Singapore. The result is in line with the fact that up to now, ship transit along the NSR is mostly determined by destination i.e. it does not involve transhipment. Therefore, model outputs suggest that this trend could happen more in the future.

As for the overall trade impact along the SSR, a decrease in maritime trade by 3.7% is observed under the RCP 2.6 scenario. The extent of the decrease is 7.4% under RCP 4.5, and 16% under RCP 8.5. As such, the impact on the Southern Sea Route is not as substantial as often touted in the media, and nowhere near the projected 75% decrease in Suez Canal transit suggested in previous economic study.

The utilisation of NSR also brings with it overall positive gains in producer surplus, as it entails the lowering of transportation cost and price of producer inputs. The producer gains are highest for Western Europe and Rest of World across all scenarios. On the other hand, the Western Europe region experiences a decline in consumer surplus due to the increase in prices brought about by higher quantities demanded globally. As for consumers in the Far East, they stand to be the biggest benefactors in terms of consumer surplus, which is also reflected in the fact that the region experiences the highest import percentage change because of a more accessible NSR. The lowering of transportation costs is the contributing factor to this observation.

Moving on to welfare effects, the Far East region is set to be the biggest benefactor of melting ice caps. It amounts from US$ 27.7 billion at RCP 2.6, to US$ 148 billion under the RCP 8.5 scenario. The Rest of World also stands to gain in terms of welfare (from US$ 5.3 billion at RCP 2.6 to US$ 24.8 billion under the RCP 8.5 scenario). This supports the worldwide implication of a more accessible NSR. On the contrary, welfare in the Western Europe region would be projected to decrease by US$ 2.4 billion under RCP 2.6, up to US$ 11.2 billion at RCP 8.5. This can be explained by the fact that the gain in producer surplus comes at the expense of consumer surplus. They are faced with higher consumer prices, because of higher demand and increased competition with the Baltic Region for Far East and South China sea markets.

In terms of output, which describes the change in GDP, all countries are set to benefit from the opening of NSR. The impact is the highest for the Baltic Region, with a 1.9% increase in GDP. This is consistent with the projection towards a higher degree of NSR utilisation by economic actors in this region (and increased competitiveness of the Baltic Region vis-à-vis Western Europe on the Asian markets) to better facilitate the extraction and transportation of natural resources located in the Arctic region. The South China Sea region is expected to receive a GDP boost by 1.5%, which can be attributed to the indirect benefits from lowering of global transportation costs because of the opening of NSR and by cheaper imports.

In conclusion, increasing navigability of the NSR by mid-century results in increasing utilisation. Initially at RCP 2.6, the increase in utilisation amounts to 9.4%, which gradually increases to 18.7% and 37.9% under RCP 4.5 and RCP 8.5 respectively. However, this is not accompanied by substantial decrease in maritime trade along the SSR. Even at the highest radiative forcing level, the SSR only stands to lose 16% of its vessel traffic. This confirms changes in trade patterns within the regions, and the emergence of new trade that does not compete directly against the SSR usage. Analysis of the result also reveals the fact that opening of NSR would have global implication in terms of global output and welfare, therefore confirming the initial hypothesis that the lowering of trade and transportation costs due to diminishing ice would benefit global trade.

5.2 Limitations of research

Any study assessing future accessibility of the NSR would have to make use numerous assumptions. For one, the unpredictable nature of sea ice disappearance does not bode well towards establishing a common starting point. Furthermore, the lack of statistical data and limited information on transit fees and costs may not give accurate settings for the trade cost liberalisation scenarios. Although this study has benefitted from using the most up-to-date climatological projections and cost-benefit studies, the fact that the phenomenon is still happening would mean that the future is uncertain and projections may be off.

Next, as the state of infrastructure in the NSR is still being developed, NSR transits are not likely to involve transhipment at least in the near future. It is still currently restricted to destination shipping, where the origin and destination are clearly defined. As such, an overall trade assessment only gives a general picture but certainly lacks the specific details. This could result in slightly biased outcomes of the study, depending on how infrastructure develops. For example, the highest change of NSR utilisation from Western Europe to Far East can be attributed to energy shipments and not on manufactured products and vice versa. There is some degree of uncertainty as to which of these economic sectors would contribute most towards widespread use of the NSR. Nonetheless, as we are concerned on the mid-century projections, it is likely that the mega port of Arkhangelsk and the connecting Bolkur railway would be ready by then. It is then safe to assume that there will be transhipment in the NSR.

Lastly, as this thesis is only concerned with studying the maritime trade aspect, it only takes into account the trade and transportation cost factors for the setting of NTM. The fact that current trade flows via the NSR are still very small could also be due to current high discrepancy in technical standards between the regions assessed, that impose the barriers to trade. Hence, the benefits towards opening of the NSR as projected must be treated with caution as it does not necessarily mean that there are no underlying trade barriers to begin with that could affect these outcomes.

5.3 Suggestions for further research

As already discussed, the undergoing improvement of NSR still casts a big uncertainty on how the future employment of the route would look like. It is likely that the increasing potential toward its widespread use would trigger competitive pricing for the Suez Canal. Hence, it is therefore recommended for future studies to consider the various pricing scenarios of the two competing routes. A reduction in Suez Canal dues would increase competitiveness of the SSR route vis-à-vis the NSR route, partially (or fully) offsetting the melting ice cap effect (at least at first).

Furthermore, higher accessibility of the Arctic route in the future also would open up various route options within the NSR. One example is the TSR, which cuts a further 20% of the voyage distance. Therefore, it is recommendable to look into this scenario in further studies.

Lastly, the employment of NSR in the future is likely to be accompanied by increases in bilateral trade agreements between the Arctic interested parties. This could have more impact than the reduction in trade and transportation cost equivalents and therefore deserves to be analysed further.

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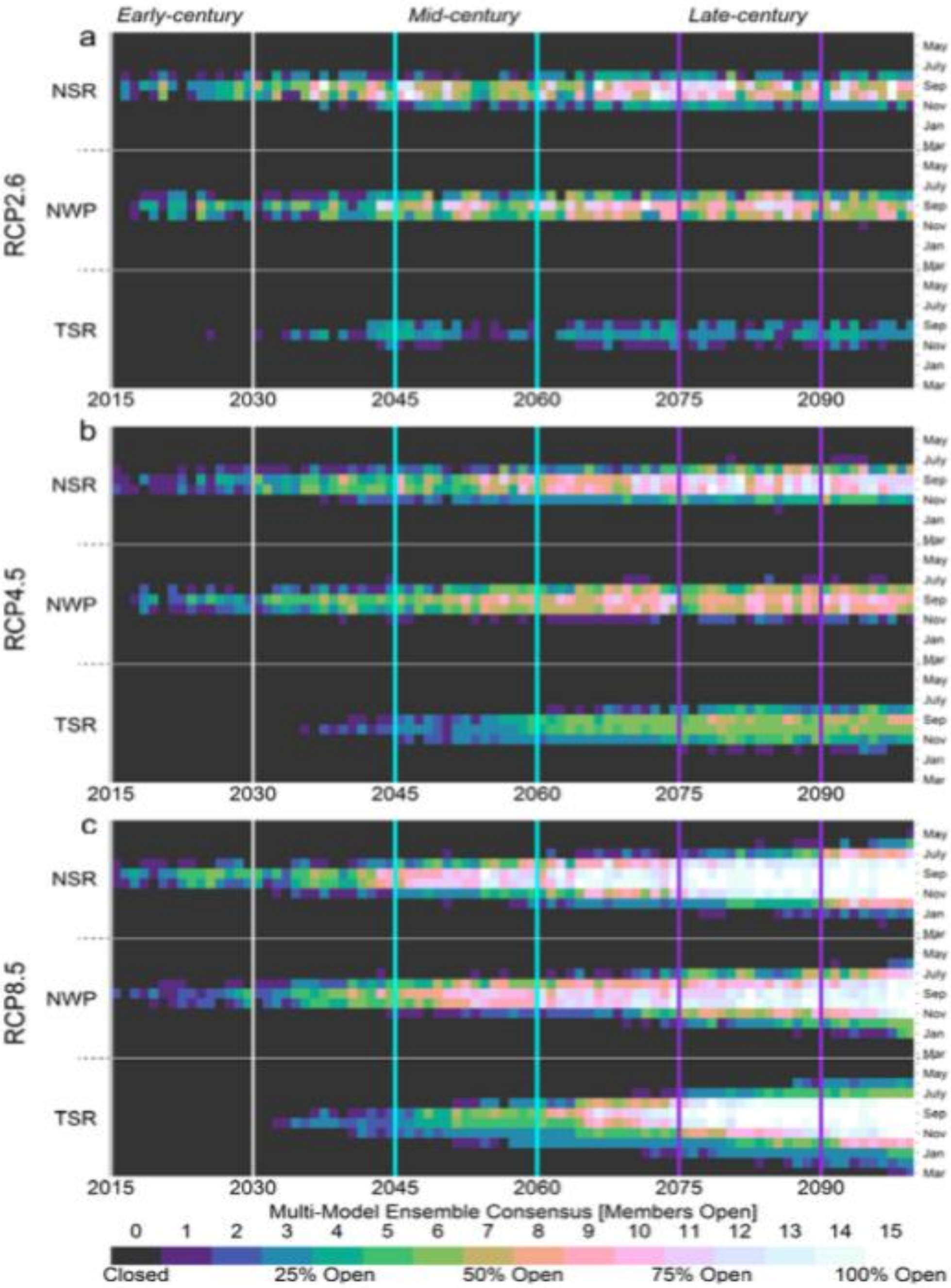
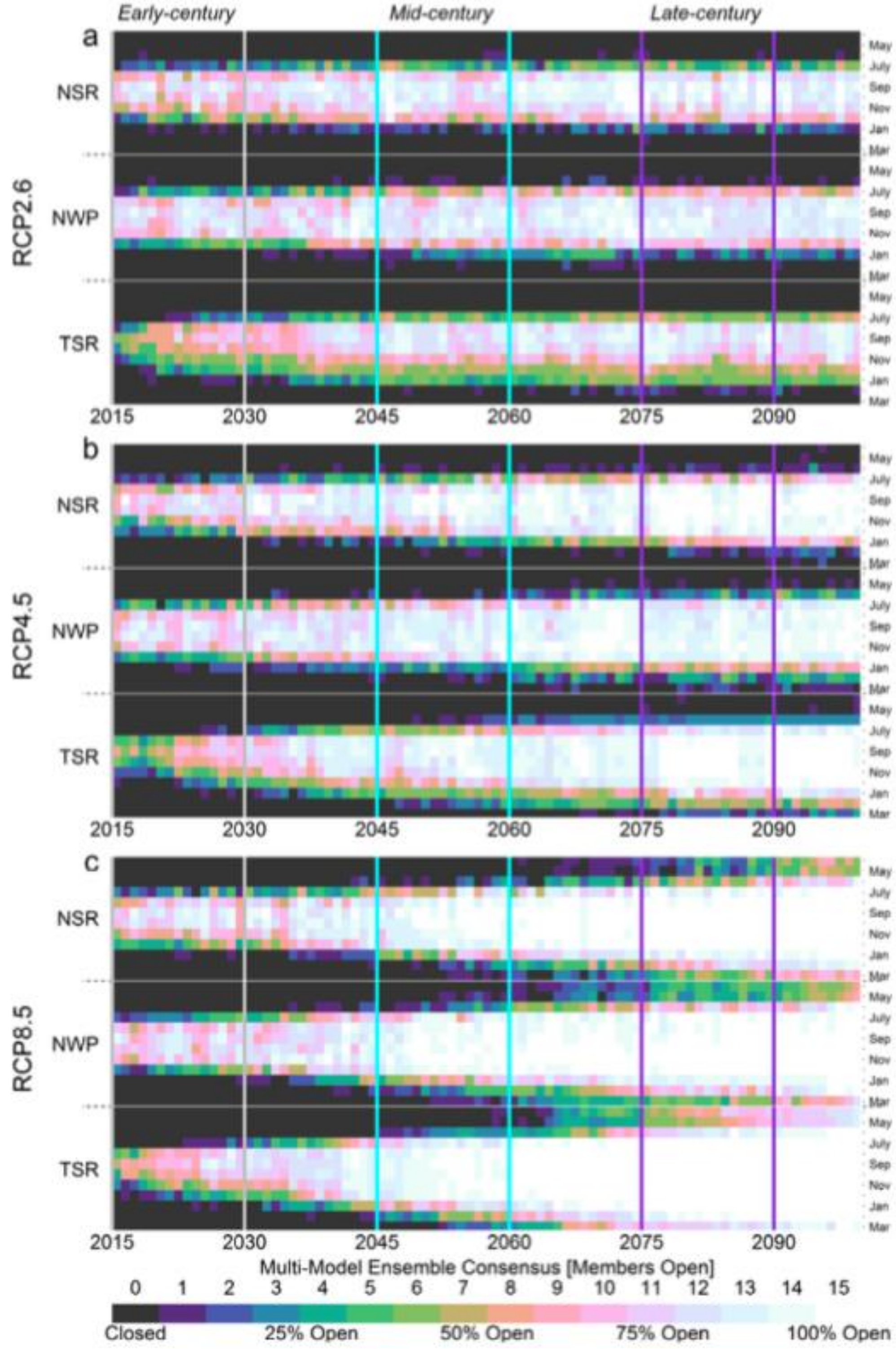
Appendices

Appendix 1: Extension of navigation window for open water (OW) vessel



Source: Melia, Haines & Hawkins (2016)

Appendix 2: Extension of navigation window for Polar Class 6 (PC6) vessel



Source: Melia, Haines & Hawkins (2016)

Appendix 3: Average number of NSR navigability days under different pollution scenario (at 80%-90% probability of independent navigation)

Early century	**Mean (days)**
RCP 2.6	65
RCP 4.5	78
RCP 8.5	77
Mid century	
RCP 2.6	90
RCP 4.5	101
RCP 8.5	118
Late century	
RCP 2.6	120
RCP 4.5	125
RCP 8.5	192

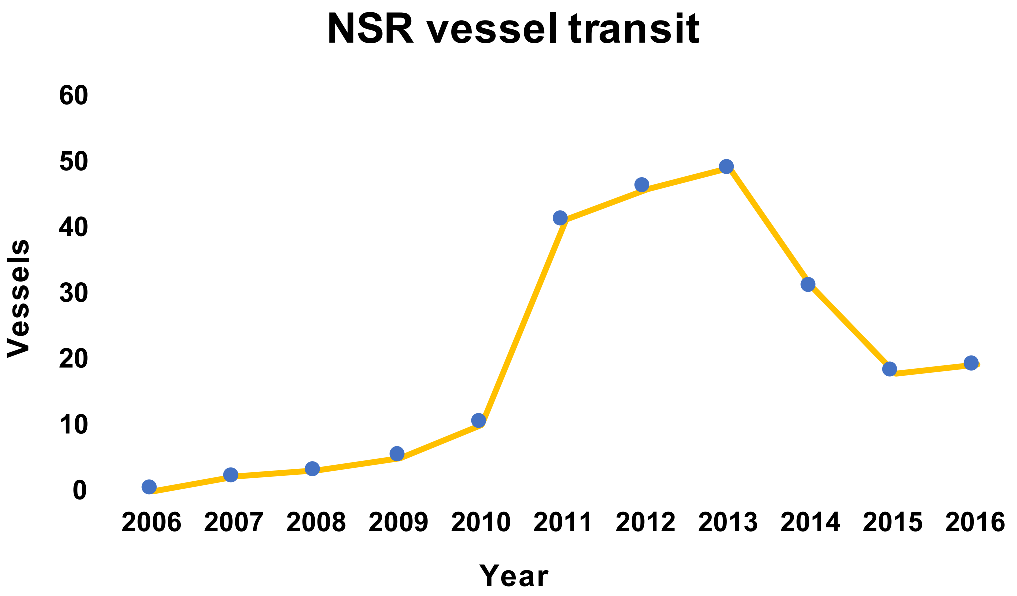
Source: Own elaboration, based on Melia et al. (2016) and Khon et al. (2017)

Appendix 4: Projected average sailing time for NSR

Source	**Early century**	**Mid centruy**	**Late century**
Melia et al (2016)	27	24	21
Khon et al (2017)	20	15	N.A

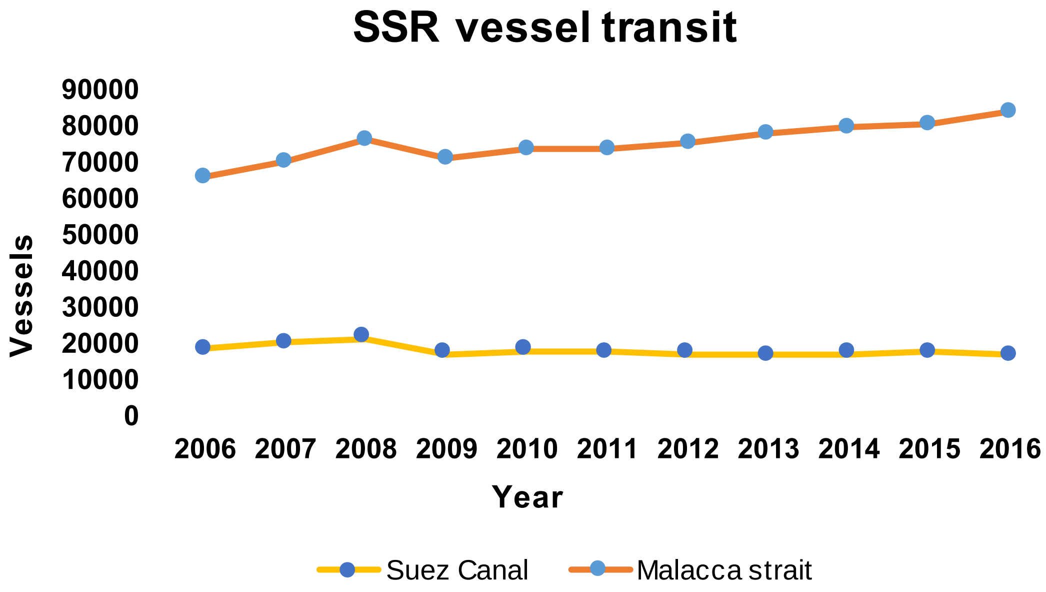
Source: Own elaboration, based on Melia et al. (2016) and Khon et al. (2017)

Appendix 5: Vessel transit along the NSR



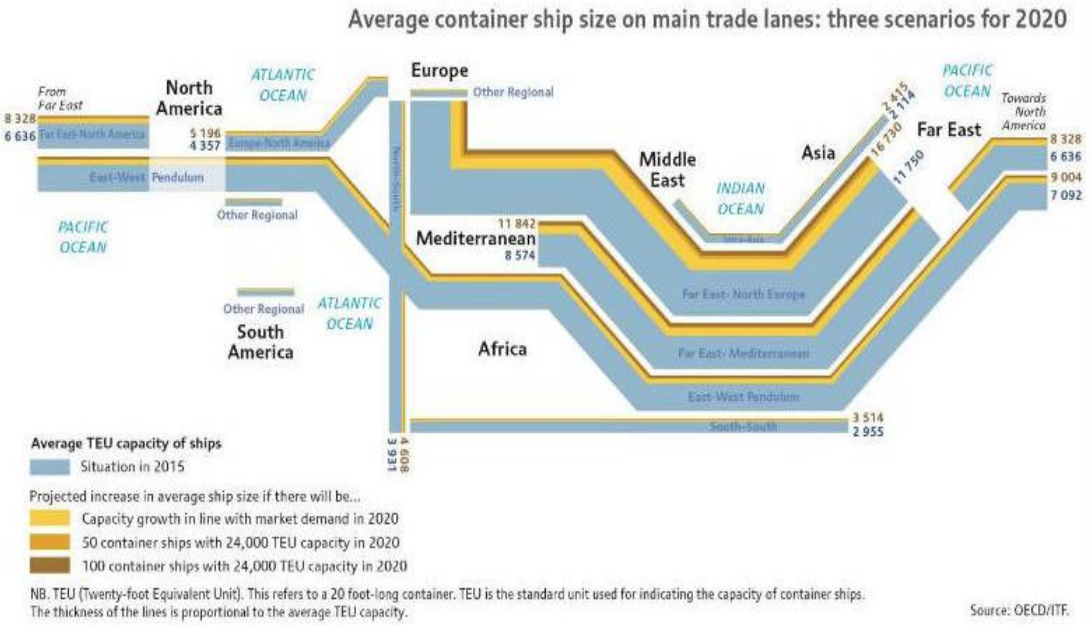
Source: Source: Own elaboration, based on Balmasov (2013), Humpert (2017) and CHNL

Appendix 6: Vessel transit along the SSR



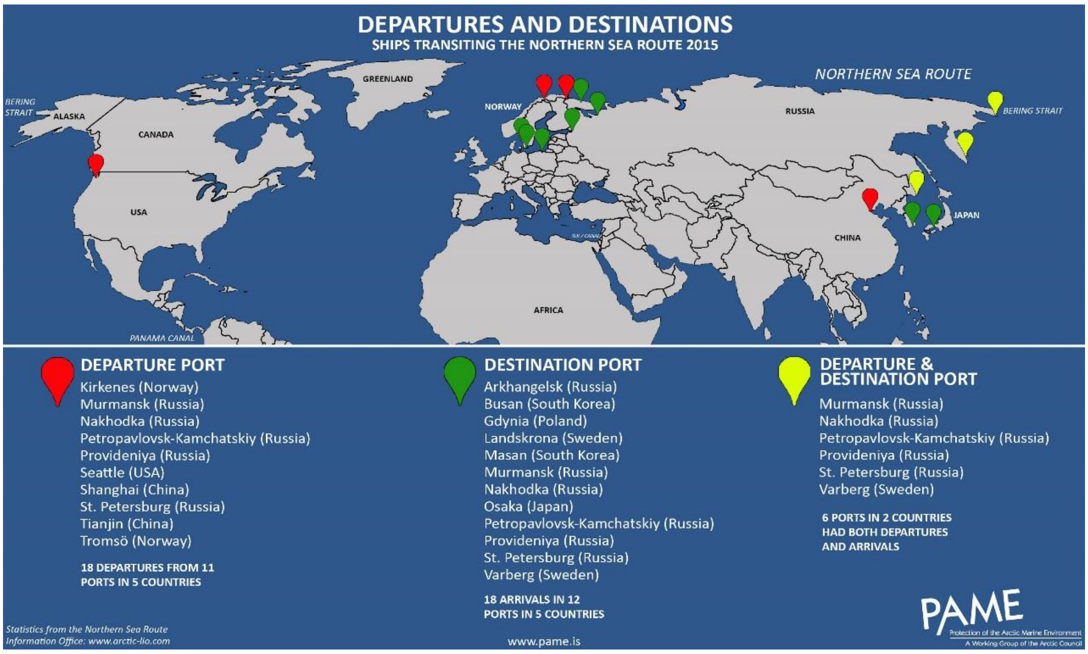
Source: Own elaboration, based on Suez Canal Authority (2017) and Nippon Maritime Centre (2017)

Appendix 7: Average container ship size for East-West seaborne trade corridor



Source: International Transport Forum (2015)

Appendix 8: Historical origin-destination regions and countries that used NSR transits



Source: PAME (2016)

Appendix 10: Regions assessed in the study

Western Europe	UK Netherlands France Germany Belgium Ireland Czechia Austria Switzerland Spain Portugal Italy
Baltic Region	Russia Norway Denmark Sweden Finland Estonia Latvia Lithuania Poland Belarus
Far East	S. Korea Japan China
South China Sea	Taiwan Vietnam Hong Kong Philippines Malaysia Singapore Thailand

Appendix 11: Numbers assigned to the regions (legend to Appendix 12 – 18)

1. Western Europe internal
2. Western Europe SSR
3. Western Europe NSR
4. Western Europe rest
5. Baltic region internal
6. Baltic region SSR
7. Baltic Region NSR
8. Baltic region rest
9. Far east internal
10. Far East SSR
11. Far East NSR
12. Far East rest
13. S China Sea internal
14. S China Sea SSR
15. S China Sea NSR
16. S China Sea rest
17. ROW

Appendix 12: Future trade values (in Billions USD)

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	2486.1154	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	269.0974	0	0	0	297.93	0	0	0
3	0	0	0	0	0	0	0	0	0	0	341.1007	0	0	0	349.7439	0	0
4	0	0	0	0	0	0	0	390.8569	0	0	0	0	0	0	0	0	461.70568
5	0	0	0	0	205.80201	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	489.2822	0	0	0	28.679	0	0	0
7	0	0	0	0	0	0	0	0	0	0	574.3747	0	0	0	28.30688	0	0
8	0	0	0	395.907988	0	0	0	0	0	0	0	0	0	0	0	0	51.656709
9	0	0	0	0	0	0	0	0	581.289	0	0	0	0	0	0	0	0
10	0	272.7585	0	0	0	84.35323	0	0	0	0	0	0	0	0	0	0	0
11	0	0	337.4395	0	0	0	110.4579	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	785.3344	521.15036
13	0	0	0	0	0	0	0	0	0	0	0	0	396.1559	0	0	0	0
14	0	361.3676	0	0	0	17.44371	0	0	0	0	0	0	0	0	0	0	0
15	0	0	413.2682	0	0	0	22.0217	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	634.998371	0	0	0	0	68.993906
17	0	0	0	2947.79275	0	0	0	351.2114	0	0	0	1053.32276	0	0	0	64.94177	9528.8596

Appendix 13: Trade weighted tariffs for the identified regions

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.0181	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1.097	1	1	1	1.0341	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1.097	1	1	1	1.0341	1	1
4	1	1	1	1	1	1	1	1.0723	1	1	1	1	1	1	1	1	1.0627
5	1	1	1	1	1.0815	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1.0816	1	1	1	1.0558	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1.0816	1	1	1	1.0558	1	1
8	1	1	1	1.0792	1	1	1	1	1	1	1	1	1	1	1	1	1.0579
9	1	1	1	1	1	1	1	1	1.0951	1	1	1	1	1	1	1	1
10	1	1.0913	1	1	1	1.0667	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1.0913	1	1	1	1.0667	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.0946	1.0601
13	1	1	1	1	1	1	1	1	1	1	1	1	1.0438	1	1	1	1
14	1	1.00159	1	1	1	1.0124	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1.00159	1	1	1	1.0124	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1.1025	1	1	1	1	1.0614
17	1	1	1	1.0493	1	1	1	1.02382	1	1	1	1.071	1	1	1	1.023	1.0543

Appendix 14: Current NTM

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.444	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1.9657	1	1	1	1.999	1	1	1
3	1	1	1	1	1	1	1	1	1	1	2.0351	1	1	1	2.682	1	1
4	1	1	1	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1.838
5	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	2.2807	1	1	1	2.314	1	1	1
7	1	1	1	1	1	1	1	1	1	1	2.3501	1	1	1	2.997	1	1
8	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1	1.2567
9	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1	1	1	1
10	1	1.9657	1	1	1	1.9811	1	1	1	1	1	1	1	1	1	1	1
11	1	1	2.0351	1	1	1	2.0505	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1.154
13	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1
14	1	1.9675	1	1	1	1.9829	1	1	1	1	1	1	1	1	1	1	1
15	1	1	2.0369	1	1	1	2.052	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1.909
17	1	1	1	1.444	1	1	1	1.7741	1	1	1	1.909	1	1	1	1.7737	1.857

Appendix 15: NTM at RCP 2.6

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.444	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1.9657	1	1	1	1.999	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1.9671	1	1	1	2.0004	1	1
4	1	1	1	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1.838
5	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	2.2807	1	1	1	2.314	1	1	1
7	1	1	1	1	1	1	1	1	1	1	2.2821	1	1	1	2.3154	1	1
8	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1	1.2567
9	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1	1	1	1
10	1	1.9657	1	1	1	1.9811	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1.9671	1	1	1	1.9825	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1.154
13	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1
14	1	1.9675	1	1	1	1.9829	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1.9689	1	1	1	1.9843	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1.909
17	1	1	1	1.444	1	1	1	1.7741	1	1	1	1.909	1	1	1	1.7737	1.857

Appendix 16: NTM at RCP 4.5

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.444	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1.9657	1	1	1	1.999	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1.8976	1	1	1	1.9327	1	1
4	1	1	1	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1.838
5	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	2.2807	1	1	1	2.314	1	1	1
7	1	1	1	1	1	1	1	1	1	1	2.2144	1	1	1	2.2477	1	1
8	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1	1.2567
9	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1	1	1	1
10	1	1.9657	1	1	1	1.9811	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1.8994	1	1	1	1.9148	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1.154
13	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1
14	1	1.9675	1	1	1	1.9829	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1.9026	1	1	1	1.9166	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1.909
17	1	1	1	1.444	1	1	1	1.7741	1	1	1	1.909	1	1	1	1.7737	1.857

Appendix 17: NTM at RCP 8.5

Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.444	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1.9657	1	1	1	1.999	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1.7327	1	1	1	1.766	1	1
4	1	1	1	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1.838
5	1	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	2.2807	1	1	1	2.314	1	1	1
7	1	1	1	1	1	1	1	1	1	1	2.0477	1	1	1	2.081	1	1
8	1	1	1	1.7741	1	1	1	1	1	1	1	1	1	1	1	1	1.2567
9	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1	1	1	1
10	1	1.9657	1	1	1	1.9811	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1.7327	1	1	1	1.7481	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1.154
13	1	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1
14	1	1.9675	1	1	1	1.9829	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1.7345	1	1	1	1.7499	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1.7737	1	1	1	1	1.909
17	1	1	1	1.444	1	1	1	1.7741	1	1	1	1.909	1	1	1	1.7737	1.857