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LNG Shipping in the Arcitc

Analyzing the effects of the Northern Sea Route on the LNG market by examining the potential of trade between Asia, Russia, and Norway.

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This thesis was written as a part of the Master of Science in Economics and Business Administration at NHH. Please note that neither the institution nor the examiners are responsible − through the approval of this thesis − for the theories and methods used, or results and conclusions drawn in this work.

Executive Summary

This thesis wishes to estimate the trade potential for LNG across the Northern Sea Route. Additionally, it looks at price levels and import patterns for other actors to assess the overall impact this trade route will have on the LNG industry. As natural gas has become increasingly transported by ship, the price levels between regions have converged. For this analysis, that entails that LNG exports from Norway and Russia should not have large impacts on the price, but there will logically be a small price increase in Europe as their supply has increased competition, while the Asian prices will have a corresponding reduction.

The focus of the thesis are two exporting countries - Norway and Russia - alongside three importing countries - China, Japan, and South Korea. The thesis approaches the topic question by looking at existing trade patterns for these importers and creating regression models which then can be applied to the new shortened distances for Russia and Norway. Distance, alongside importer's annual imports, exporter's annual consumption, and exporter's known natural gas reserves were determined to be the best predictors.

While the thesis attempted to create both a combined model and individual models for each of the importers, issues with lack of available data caused the individual models to be far less reliable than hoped.

DESTINATION	ORIGIN	ACTUAL IMPORT	DICOR(1)
CHINA	Norway	0.0941	4.3555
CHINA	Russia	3.4489	18.2990
JAPAN	Norway	0.0861	7.0414
JAPAN	Russia	8.7181	20.6883
KOREA	Norway	0.0877	2.9145
KOREA	Russia	3.0791	17.0032

Table 4.3.1 - Estimates and actual values

The final estimates projected an overall large increase in LNG trade between the countries, but due to the sea route not being traversable year-round, these estimates are overshooting by up to 50-70%. Factors such as geopolitics, common investments, and demand seasonality can further influence the actual outcome, either increasing or decreasing the end volume of the trade.

Acknowledgments

My time at the Norwegian School of Economics comes to an end after the delivery of this thesis, and I am grateful for the time spent and the knowledge I have picked up during my time here. I would like to thank my supervisor, Gunnar Eskeland, for his assistance and guidance during my work on the thesis, as well as express gratitude for all other professors and teachers I have had during my master's period. Without the data from BP this thesis would never have been written, and I'd like to express my appreciation for them making it available. Finally, I would like to thank my friends and family for their support over the last few years.

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1. Introduction

Climate change will impact the world in numerous ways. Higher temperatures, rising sea levels, more extreme weather, and increased melting of the polar ice. While this brings a host of issues and will cause large migrations and devastate certain local flora and fauna, it does create some opportunities. Amongst these opportunities, we have the Arctic sea routes. As the Arctic ice melts, ships have gained an increasing ability to travel from Europe and Russia to Eastern Asia by travelling north of Russia. The main benefit of travel through this route, known as the Northern Sea Route or the Northeast Passage, is a large reduction in travel time, making the voyage both quicker and more affordable.

The two countries controlling the edges of the route are Norway and Russia, both are major players in the petroleum market and easier and more affordable access to the Asian market brings big economic opportunities with it. Japan, Korea, and China are all major importers of natural gas, and gaining better access to these markets opens lucrative avenues. As the world's focus on climate change increases, natural gas is considered an important transition fuel away from oil and coal. China, in particular, has a coal heavy energy mix, and their demand for natural gas are projected to increase drastically while the technology for renewable and cleaner sources of energy is being developed.

This thesis will try to assess the trade potential between Norway and Russia as exporters, and China, Japan, and South Korea as importers, and estimate the overall impact this trade option will have on the LNG market. Distance is considered a key aspect for LNG trade, and the shortened distances should affect the current trade volumes. By producing models from the importing countries existing LNG trade patterns, an estimation of what trade volume *should* be going across the Northern Sea Route. Combining this with projections for the accessibility of the route, as well as the coming increase in LNG demand in Eastern Asia, an outlook for the route's potential can be established.

First, the thesis will go over the LNG data that will be utilized, alongside external factors that can affect the final results. After establishing the groundwork, a series of models will be developed by analyzing the data before being applied to the adjusted distances for Norway and Russia. The results of the models will go through a sensitivity analysis before being assessed in comparison to the current figures, with the perspective of said external factors. Calculations will be handled in R.

2. Data and literature

2.1 Availiability of route

One of the main requirements for an analysis of the potential of shipping transit through the Northern Sea Route is getting an estimate of the expected number of days ships can traverse the route each year, which is crucial in calculations for both the economic and the environmental sides of Arctic shipping. *Projected 21st-century changes to Arctic marine access*provides us with a number of estimates, broken down for each region of the Northern Sea Route, as well as different classifications of vessels based on their ability to traverse icy waters. (Stephenson et al., 2013) These takeaways will be broken down into a set of tables, that provides an easy reference point for each classification of vessel in each region of the route. For classification purposes the report provides a formula for a vessel's ability to enter an ice regime. Such an ability is expressed by an IN, or an Ice Numeral, using the following formula:

$$IN = (C_a * IM_a) + (C_b * IM_b) + \cdots + (C_n * IM_n)$$

Ice Numerals were calculated by taking the concentration of different classes of ice(C_n), and a corresponding ice multiplier (IM_n). (Stephenson et al., 2013) The Ice Numeral is in the form of a non-zero integer ranging from -4 to 2, and a lower Ice Numeral represent a greater risk for a vessel to traverse the waters (but not necessarily an impossibility). An Ice Numeral was calculated for three different vessel classifications which were chosen to represent a range of capital investments.

- Polar Class 3 (PC3), an icebreaker capable of "year-round operation in second-year ice which may include multi-year ice inclusions"
- Polar Class 6 (PC6), a moderately ice-strengthened ship capable of "summer/autumn operation in medium first-year ice which may include old inclusions"
- Open-water (OW) ships with no ice-strengthening

The ice numerals for each vessel class in the different levels of ice coverage are as follows:

Ice Type	**PC3**	**PC6**	**OW**
Open water	2	2	2
Gray	2	2	1
Gray-white	2	2	-1
Thin first-year, first stage	2	2	-1
Thin first-year, second stage	2	2	-1
Medium first-year	2	1	-2
Thick first-year	2	-1	-3
Second-year	1	-3	-4
Multi-year	-1	-4	-4

Table 2.1.1 - Ice numerals for different levels of ice coverage (Stephenson et al., 2013)

In addition to calculating the ice numerals, the report also produced a breakdown for each vessel class' annual capacity to traverse the different regions of the Northern Sea Route, with standard deviations and projected increases.

The report also provides an estimate for the availability of the route as a whole, for each of the forecasted time periods adjusted for three different Representative Concentration Pathways; RCP4.5, RCP6.0, and RCP8.5.

	PC3		*PC6*		*OW*	
RCP4.5	Avg	σ	Avg	σ	Avg	σ
2011-2030	111	*18*	98	*26*	81	*27*
2045-2065	120	*6*	113	*13*	101	*21*
2088-2099	121	*4*	117	*9*	109	*15*
RCP6.0	Avg	σ	Avg	σ	Avg	σ
2011-2030	110	*18*	99	*24*	85	*26*
2045-2065	117	*11*	108	*19*	97	*23*
2088-2099	122	*3*	120	*6*	115	*10*
RCP8.5	Avg	σ	Avg	σ	Avg	σ
2011-2030	118	*11*	109	*20*	97	*26*
2045-2065	122	*3*	119	*8*	112	*13*
2088-2099	123	*1*	122	*1*	121	*3*

Table 2.1.2 – Projected annual accessibility, NSR (Stephenson, et al., 2013)

The table tells us that the route will be open roughly 25%-35% of the year for the next decade, depending on the vessel type. Depending on how global temperatures will develop the next century, the overall numbers for the less specialized types of vessels will approach the ones of the more specialized vessels. The main difference takes place in a reduction of the standard deviations, increasing the reliability of the route and consistency of trade going through the route. It is important to note that these numbers are for unaccompanied vessels, and with the assistance of ice breakers the route will be traversable longer.

2.2 Alternatives for shipping fuels to alleviate concerns of the route

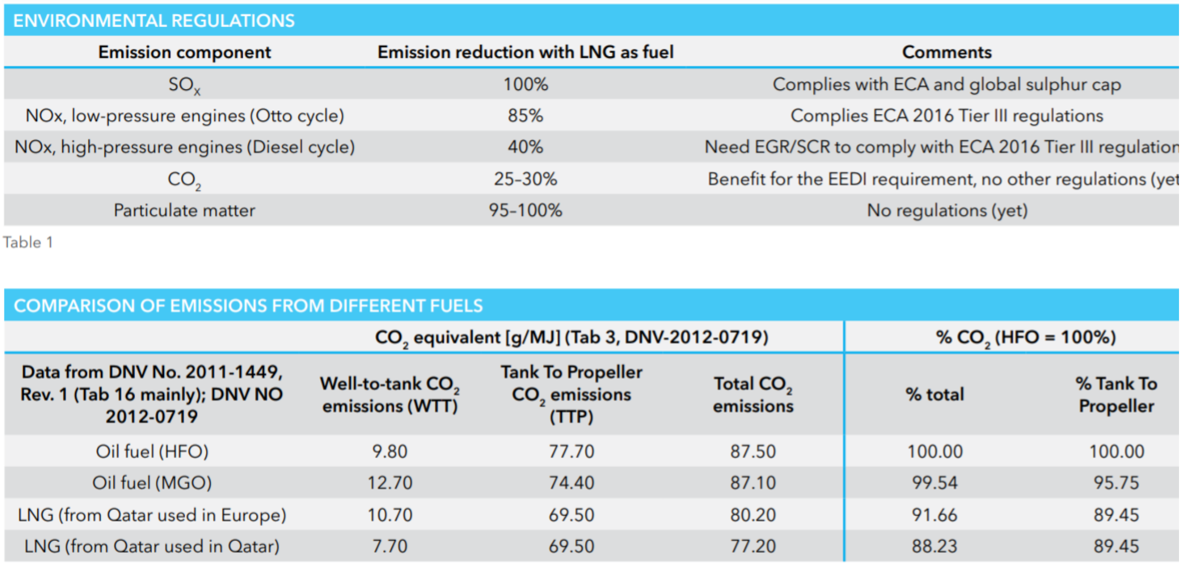
For the Northern Sea Route to be considered viable, the vessels traversing the route have to employ a suitable fuel. Due to the route's sensitive location, a rise in local pollution caused by an uptake in activity can bring dire consequences alongside it. With regards to snow and ice, the slow-acting long-term impacts of carbon emissions will be dwarfed in comparison to the vastly quicker effects local pollution in the form of particles, especially soot. (DNV GL, 2019) Whereas carbon emissions are opaque and resides in the atmosphere, soot and other particles will form a dark layer directly on top of the ice and snow. This layer will absorb sunlight and its heat, and heavily accelerate the melting of said ice- and snow layers. Less ice and snow will then bring with it a self-reinforcing effect where less sunlight (and its heat) will be reflected and cause higher temperatures, without any significant increase in global pollution being required. Therefore, it is of the utmost importance that any shipping traffic traversing ice- and snow-covered areas such as the Northern Sea Route will need to utilize fuels with as minimal amounts of sulfur and other local pollutants as possible for it to be even remotely environmentally sustainable.

Some necessary steps towards achieving this goal have already been taken in the form of the IMO2020 regulations which limits the amount of sulfur that is permissible in shipping fuels, signaling an important step away from the traditional use of heavy and dirty fuel such as bunker oil. As a part of the overall analysis, a report from DNV GL – Maritime will be employed to provide a better picture of the advantages and disadvantages of the different alternative fuels, including their level of pollutants, price, availability, and other logistical requirements.

The main takeaway from this report is that LNG is the best currently available substitute with regards to each of these factors. (DNV GL, 2019) The most important factor for our analysis is that LNG does not produce any SO_x emissions which, as established, is the most worrisome local pollutant for the Northern Sea Route. When it comes to energy output, LNG has higher energy per mass, but also significantly lower density compared to HFO resulting in roughly twice the volume per energy. The price of LNG can generally be predicted from the European and Japanese spot prices for natural gas (the Japanese price is directly tied to LNG as all gas in Japan gets imported in that state) and has consistently been below crude oil and HFO for the previous ten years, the regional gas and LNG prices will be discussed further and more thoroughly in a later section of the thesis. Since high-sulfur HFO is no longer allowed without a scrubber system, the costs of such fuel increases and LNG gets better in comparison. When it comes to infrastructure, most countries surrounding either side of the Northern Sea Route is either a producer/exporter or an importer of natural gas and LNG and employing it as fuel will be convenient.

LNG is both widely available and scalable which is its main advantage for increasing its role as a shipping fuel. (DNV GL, 2019) Capital expenditures are overall higher for LNG compared to HFO with scrubbers, but this difference is likely to lessen in the future if LNG usage for shipping vessels becomes more commonplace and competition between suppliers increase. On the operations side of the equation, LNG vessels have comparable costs to oil-fueled ships without scrubber technology. With the increased focus on cleaner fuels some ports are already offering discounts to LNG vessels, a practice that might spread, as well as the possibility of oil-fueled vessels to be charged more (which would have the same net effect as these discounts for comparisons sake).

From an emissions perspective, LNG is a clear cut above the others in terms of local emissions. (DNV GL, 2019) As mentioned LNG does not produce any significant amounts of SO_x or particle matter, lower levels of NO_x as well as lower carbon emissions. However, it is important to note that since most LNG fuel is methane-based and will thus be very sensitive to leakages and slips. This form of leakage can effectively cause the carbon emissions to reach similar levels as oil-based fuels. To remedy this issue there have been some successful testing with mixing in hydrogen in the fuel. This resulted in creating a renewable share of the energy mix, as well as causing an improvement in overall methane slips. This is already possible to do with existing marine dual fuel engines. The DNV GL report summed up the overall emission reductions by employing LNG in the table below.



ENVIRONMENTAL REGULATIONS		
Emission component	**Emission reduction with LNG as fuel**	**Comments**
SO_x	100%	Complies with ECA and global sulphur cap
NOx, low-pressure engines (Otto cycle)	85%	Complies ECA 2016 Tier III regulations
NOx, high-pressure engines (Diesel cycle)	40%	Need EGR/SCR to comply with ECA 2016 Tier III regulation
CO_2	25-30%	Benefit for the EEDI requirement, no other regulations (yet
Particulate matter	95-100%	No regulations (yet)

Table 1

COMPARISON OF EMISSIONS FROM DIFFERENT FUELS					
	CO_2 equivalent [g/MJ] (Tab 3, DNV-2012-0719)			**% CO_2 (HFO = 100%)**	
Data from DNV No. 2011-1449, Rev. 1 (Tab 16 mainly); DNV NO 2012-0719	**Well-to-tank CO_2 emissions (WTT)**	**Tank To Propeller CO_2 emissions (TTP)**	**Total CO_2 emissions**	**% total**	**% Tank To Propeller**
Oil fuel (HFO)	9.80	77.70	87.50	100.00	100.00
Oil fuel (MGO)	12.70	74.40	87.10	99.54	95.75
LNG (from Qatar used in Europe)	10.70	69.50	80.20	91.66	89.45
LNG (from Qatar used in Qatar)	7.70	69.50	77.20	88.23	89.45

Table 2.2.1 - Emission comparison LNG (DNV GL, 2019)

For the purposes of our thesis, the main takeaway from the report will be an increase in demand for LNG amongst major shipping nations, of which all five nations being evaluated qualifies as. Additionally, the lower emission numbers, local emissions especially, should alleviate some environmental concerns with employing the route. Seeing as local environmental effects is the main ethical concerns of employing the route, LNG can possibly become a required fuel type for any traversal of the route. Seeing as both Russia and Norway - who control the entry and exit points of the route - will likely utilize the route for LNG transport, establishing LNG as the standard fuel in the area will increase its practicality.

2.3 Natural gas trade – Current and future demand

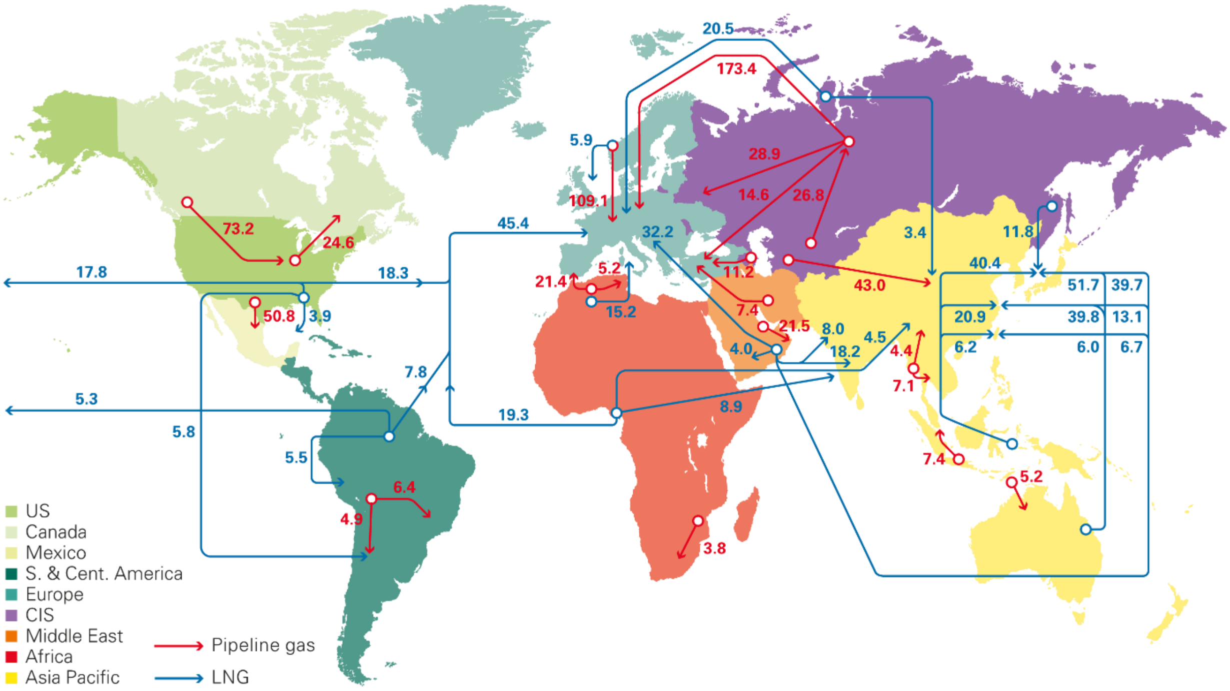


Table 2.3.1 - Natural gas trades (BP, 2020)

The main source of information with regards to natural gas trades, production, and consumption employed in this thesis is BP's annual report. (BP, 2020) Since the thesis' focus is on how the trade will be affected by the availability of the Northern Sea Route (or Northeast Passage) LNG trade is the main concern, more so than pipeline trade. Furthermore, due to the theisis focus, the main interest is in the biggest exporters at the European side of the NSR - Norway and Russia - and the biggest importers on the Asian end - China, Japan, and South Korea. Due to inconsistent country grouping into "Others" sometimes supplementary data was collected from the U.S. Energy Information Administration. (EIA, 2021)

By cataloging the natural gas patterns of these countries opportunities for trade between them can be identified, due to the shorter shipping distances utilization of the route will bring. While some LNG trade has already started going through this route, the trade using this route is still in its infancy and it is safe to assume any trade volume from this route is not representative for the actual trade potential, only as a proof of its feasibility. In addition to natural gas patterns, the report also provides the energy compositions of all aforementioned countries, as well as a large number of other countries in the world and the worlds' regions. (BP, 2020) This will be used to gauge future natural gas demands of the respective countries and their trade partners which will further alter their trade patterns. Due to the general direction of climate change concerns it is to be expected that each country will attempt to move their energy compositions away from coal to cleaner fuels. In short, higher presence of coal in a country's energy composition will be taken as an indicator of higher future demand for natural gas. This will be further discussed under the climate policy section.

2.3.1 China

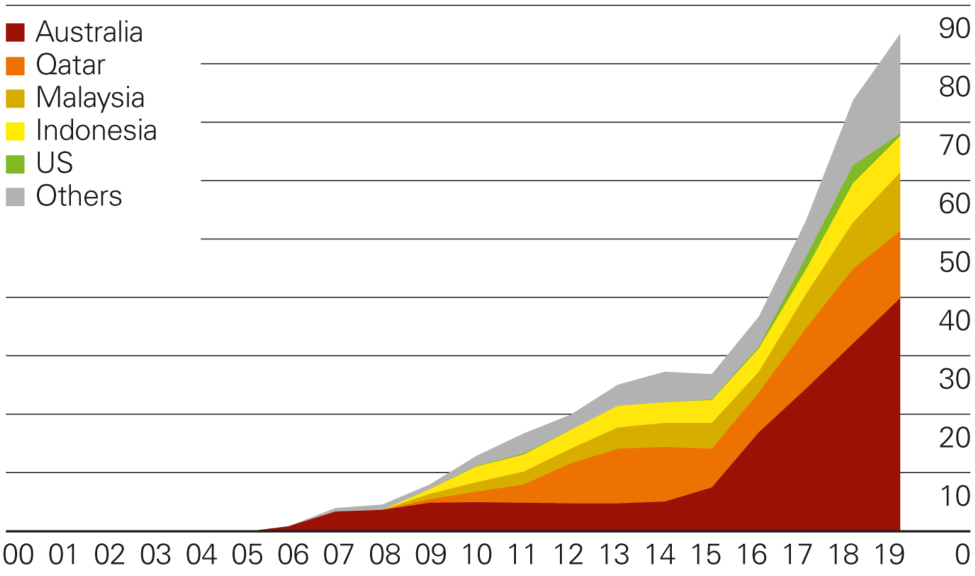


Figure 2.3.1.1 - Chinese LNG Imports (BP, 2020)

China has had a steep increase in LNG imports over the past decade, previously relying on pipeline case from Central Asia for their natural gas needs. (BP, 2020) As their needs for energy has increased, they have been forced to look further away to supply their demand. As such, most of the gas imports now come in the form of LNG, and future increases in natural gas imports is likely to follow the same pattern. Australia supplies almost 50% of China's LNG imports, while the rest are covered mainly by Pacific nations and the Middle East. While some imports form Russia is taking place, the amounts are still low.

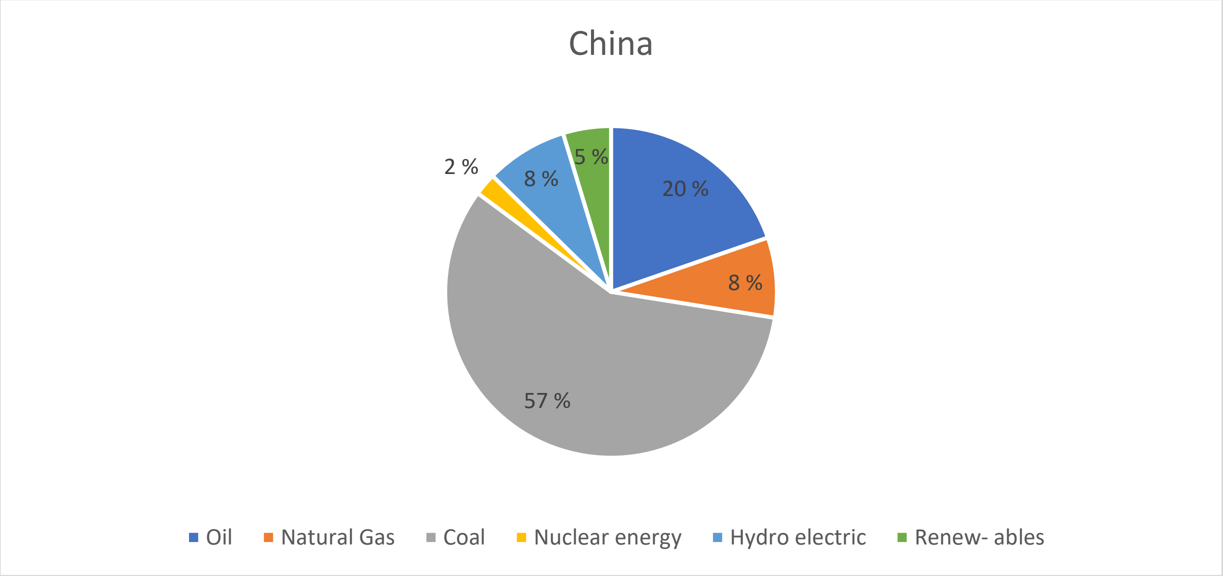


Figure 2.3.1.1 - Chinese Energy Mix (BP, 2020)

China’s energy generation relies heavily on coal. (BP, 2020) This has several adverse effects, both globally and locally, and China is heavily incentivized to reduce their usage of coal. (BBC, 2021) The main issue standing in the way is a desire to have a secure generation of energy, and coal is the cheapest source with low intermittency to provide this. Recently, China has been making moves in collaboration with Russia to secure a steady influx of natural gas from LNG plants along the Northern Sea Route and will likely increase their usage of natural gas to achieve a reduction in coal consumption, while continuing their large investments in renewable energy technology for their future energy needs.

2.3.2 Japan

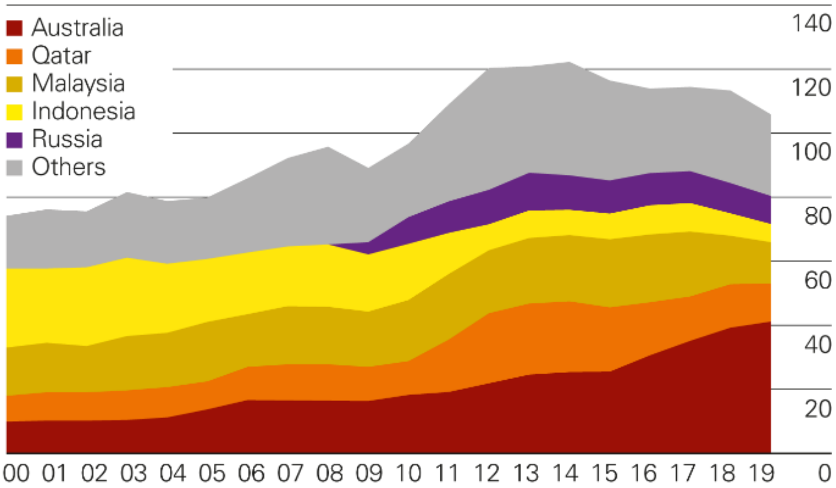


Figure 2.3.2.1 – Japanese LNG Imports (BP, 2020)

The above figure shows the LNG import patterns for Japan for the past two decades. (BP, 2020) As shown, Australia is the biggest importer and supplies close to 40% of all imports. Russian LNG constitutes slightly below 10% of the total imports, while the other main actors are the Southeast Asian countries Indonesia and Malaysia, as well as one of the main exporters of gas globally, Qatar.

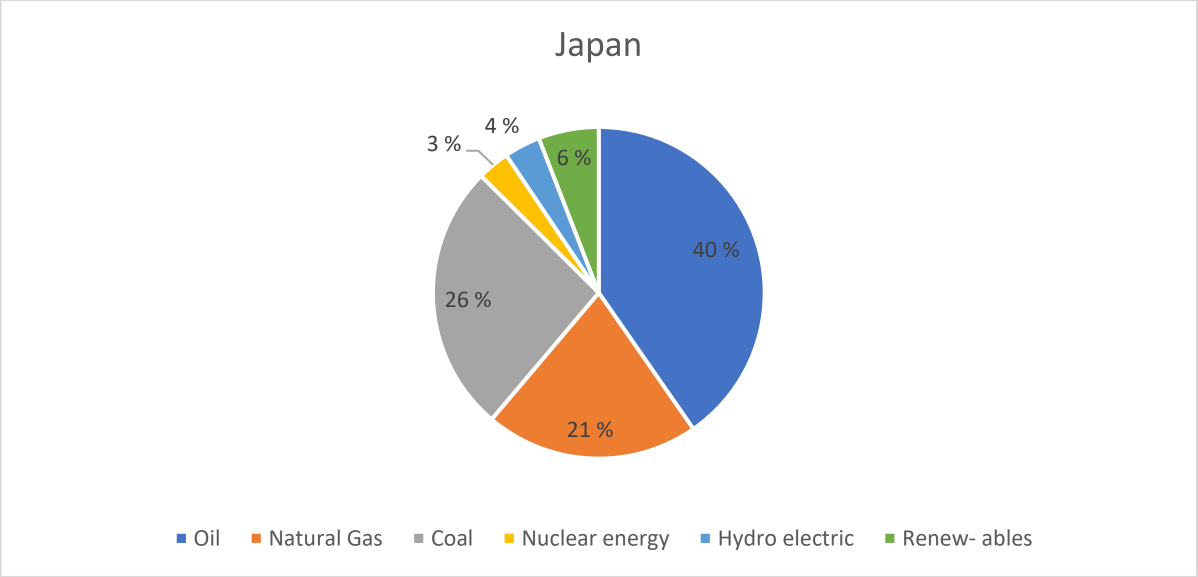


Figure 2.3.2.2 – Japanese energy mix (BP, 2020)

This pie chart shows the energy mix of Japan, and coal, oil and natural gas combine for 87% of Japan's overall consumption. (BP, 2020) While Japan formerly relied more on nuclear power, increased skepticism after the Fukushima disaster in 2011 caused most of its nuclear power plants to be temporarily shutdown and reevaluated. (Financial Times, 2014) During this period fossil fuels gained a stronger foothold in Japan's energy mix. Due to the increased focus on climate change and carbon emissions, Japan can be expected to lower their overall usage of fossil fuels, especially coal. While some of it will be covered by nuclear plants if they return to their old operating levels, there will still be some time before renewable energy technology is able to take on a larger portion of the energy burden. Natural gas, as the lowest emitting fossil fuel, is then likely to bridge the gap and work as a transmission fuel away from coal and oil. This leaves us to expect an increase in natural gas demand in Japan over the coming years.

2.3.3 South Korea

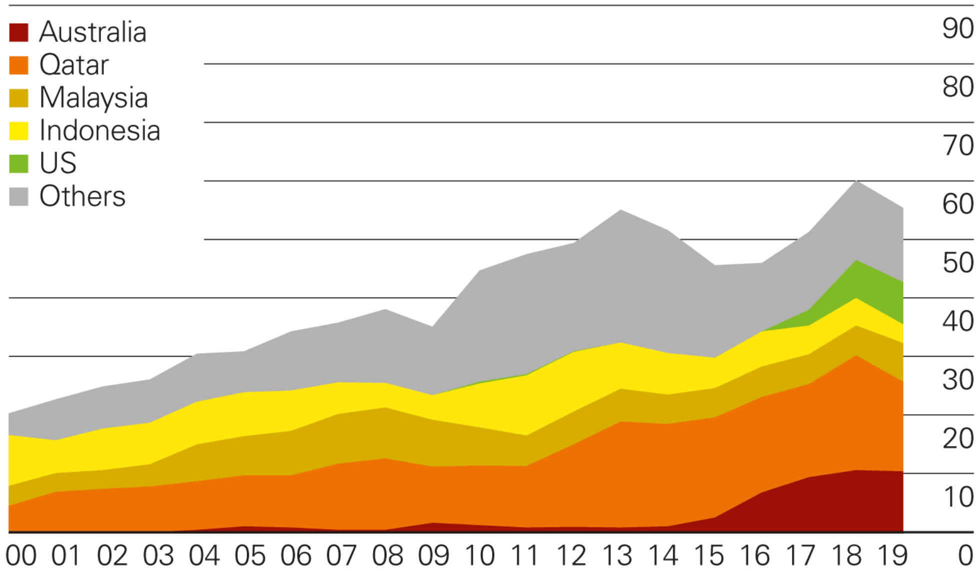


Figure 2.3.3.1 - Korean LNG Imports (BP, 2020)

South Korea has had a steady increase in LNG imports over the last two decades. (BP, 2020) Unlike China and Japan, their main contributor is Qatar, not Australia, although imports from

Australia have increased heavily since 2015. Otherwise, South Korea follows similar import patterns, mainly importing LNG from Southeast Asian/Pacific countries, and importing around 10% of their total from the US.

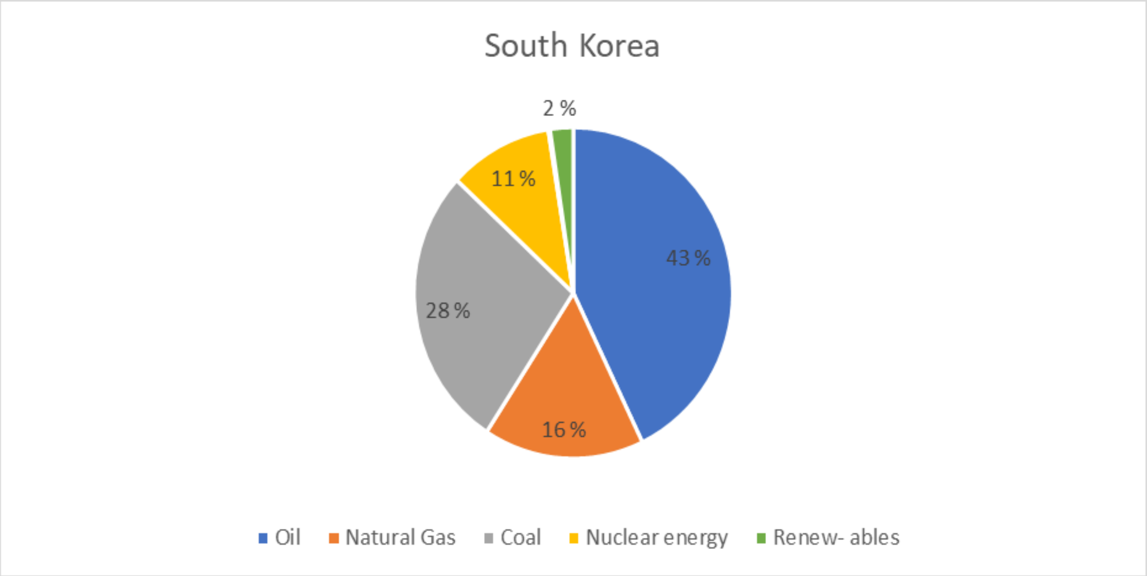


Figure 2.3.3.2 - Korean energy mix (BP, 2020)

South Korea’s energy mix composition is similar to the Japanese, but with a stronger presence of nuclear energy compared to natural gas. (BP, 2020) Seeing as no Fukushima-type events has happened in South Korea, the nuclear power production never halted and natural gas did not have the same opportunity to grab a stronger foothold to compensate. Even so, an increase in natural gas consumption is to be expected in the country, as the same concerns with regards to local and global pollution with coal and oil persists, with natural gas functioning as a transition fuel while the intermittency issues of renewables are being improved. Worth noting is the lack of hydroelectricity in South Korea, limiting carbon free energy generation options for the country.

2.4 Representative ports for distance parameters

Since the hypothesis of this thesis relies on distance as an important factor for LNG trade volume, the distance between selected ports in the countries have to be determined. For most of the countries involved the largest port and/or the port closest to the capital was chosen, but for some case the port was decided to be most representative for current and future LNG trade. For smaller countries this is less of a concern as differences in distance between ports in for example Kuwait will be negligible compared to their overall distance from the importing countries. For larger countries like Norway, Russia, and Australia, a more thorough assessment must be made. After deciding on a port, the distances were procured from Sea-Distances.org and compiled in the table underneath. (Sea Distances, 2021)

Chosen Ports and their Distances (nm)				
Country	Port	China	Japan	S. Korea
US	*Los Angeles*	5708	4854	5230
Peru	*Callao*	9304	8424	8826
Trinidad	*Port of Spain*	9750	8878	9253
Norway	*Kirkenes*	6546	5510	6167
Russia	*Sabetta*	5874	5071	5381
Oman	*Muscat*	5379	6046	5645
Qatar	*Doha*	5845	6512	6111
UAE	*Dubai*	5667	6334	5933
Algeria	*Algiers*	8754	9421	9020
Egypt	*Port Said*	7251	7918	7517
Nigeria	*Lagos*	10254	10918	10523
Australia	*Darwin*	2765	3033	2934
Brunei	*Kuala Belait*	1732	2390	2004
Indonesia	*Tanjung Perak*	2661	3112	2884
Malaysia	*Port Klang*	2447	3114	2713
PNG	*Port Moresby*	3403	3444	3555
Japan	*Tokyo*	1048	0	669
China	*Shanghai*	0	1048	492
S.Korea	*Busan*	492	669	0

Table 2.4.1 - Selected Ports and their distances in nautical miles

2.4.1 Russia

For Russia, the decision on which port to use is particularly difficult. Since the country spans the entirety of the entire from Europe and across to the Eastern edge of Asia, which port is decided upon will have major impacts on the results of the analysis. There are a multitude of factors that can influence the choice, including geographical location, existing trade, and strategic location. While the gas reservoirs are located across most of Russia’s area, the Yamal Peninsula seems particularly relevant for our thesis. The Yamal Peninsula is home of a large portion of Russia’s oil and gas fields, and major ports, like Sabetta, is being actively funded by Chinese investors, specifically for the purpose of securing a steady source of LNG for China. (Staalesen, 2016) When combining this with its location directly on the Northern Sea Route, Sabetta seems like a natural choice for the Russian port in our calculations. While not all, or even most, of Russia’s exports to East Asia is being sent from this port, it should fulfill the purposes needed for this analysis.

2.4.2 Norway

While Norway is a considerably smaller country in area, it still possesses a lengthy coastline. Similarly to Russia, the choice of representative port will be impactful for our analysis, and can be chosen by a multitude of factors. Norway’s petroleum industry has its base of operations in the Western regions of Norway, and choosing a location in that area, either Bergen or Stavanger, is a valid decision. However, the petroleum fields on the Norwegian continental shelf that are being considered for development are further North. Additionally, China have set their eyes on Kirkenes as their entry to Europe for their shipping purposes via the Northern Sea Route. (Eliassen & Pena, 2019) Given the plans and potential for Kirkenes as a major port with a highly important role for the Northern Sea Route as well as direct involvement from one of the importers that this thesis is targeting, it will ultimately be the Norwegian representative for this analysis.

2.4.3 Australia

The last of the ports that need special consideration is the Australian representative. Similarly to Russia, Australia covers a large area with potentially large differences in distance to the importers. Seeing as Australia is not located anywhere near the Northern Sea Route, the strategic value of the location is less of a concern. Inspecting the petroleum reservoirs of Australia, as shown in the graphic below, the majority is concentrated near the Northwestern part of the country and continental shelf. (Andebou et al., 2015) The locations of the reservoirs are very convenient with regards to international trade, as most of Australia’s LNG trade partners are in said direction, including China, Japan, and South Korea. For the choice of the representative port for Australia, Darwin was ultimately decided upon. Darwin is the largest city in Northern Australia, and stands out as a natural choice.

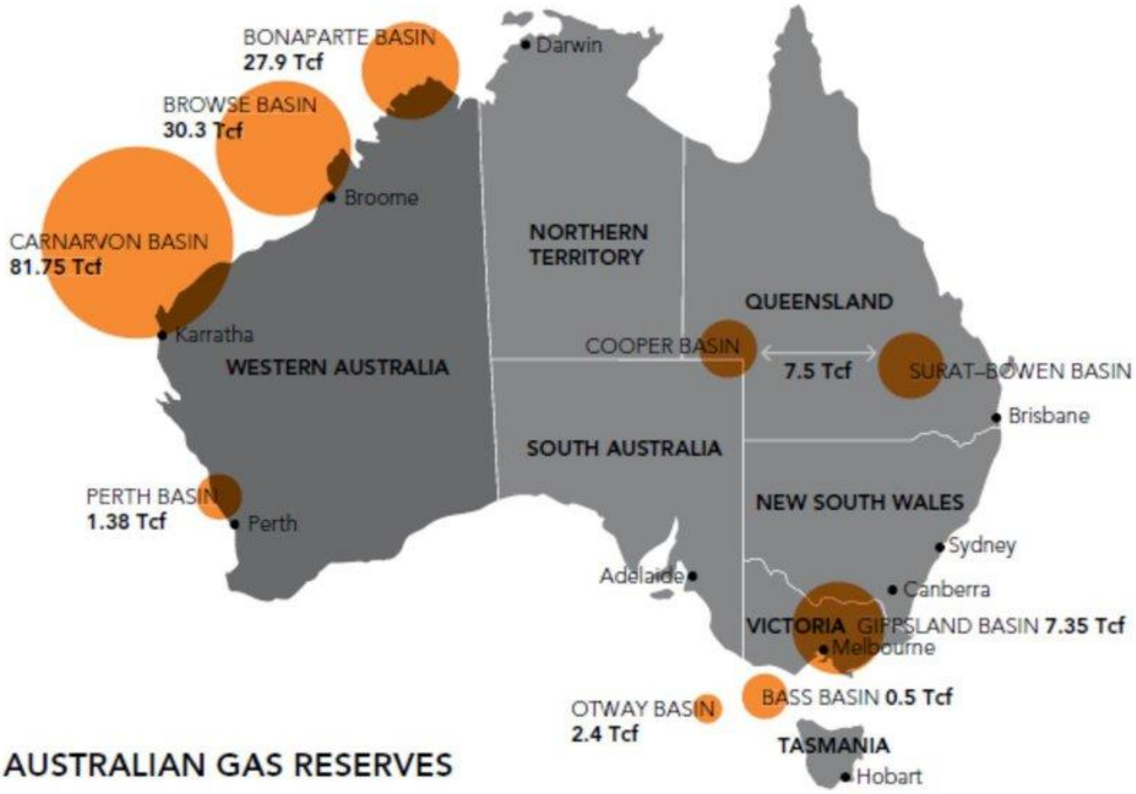


Figure 2.4.3.1 - Australian Gas Reserves (Andebou et al., 2015)

2.5 Price levels in Europe and Asia

When discussing trade patterns between several markets, the price levels in each market needs to be considered. If a rational exporter can choose between two markets with different price levels, they will always sell to the highest bidder, given logistics costs not exceeding the price differences. If both markets are competing for the same supply, the prices will eventually converge and level out when a new equilibrium has been established. Between the Asian and European gas markets, the competition has been limited in the past, as pipeline gas has distance as a major cost driver, but with the rise of LNG technology and continuous technological improvements and larger scale of operations driving prices down, the markets are more connected than ever before.

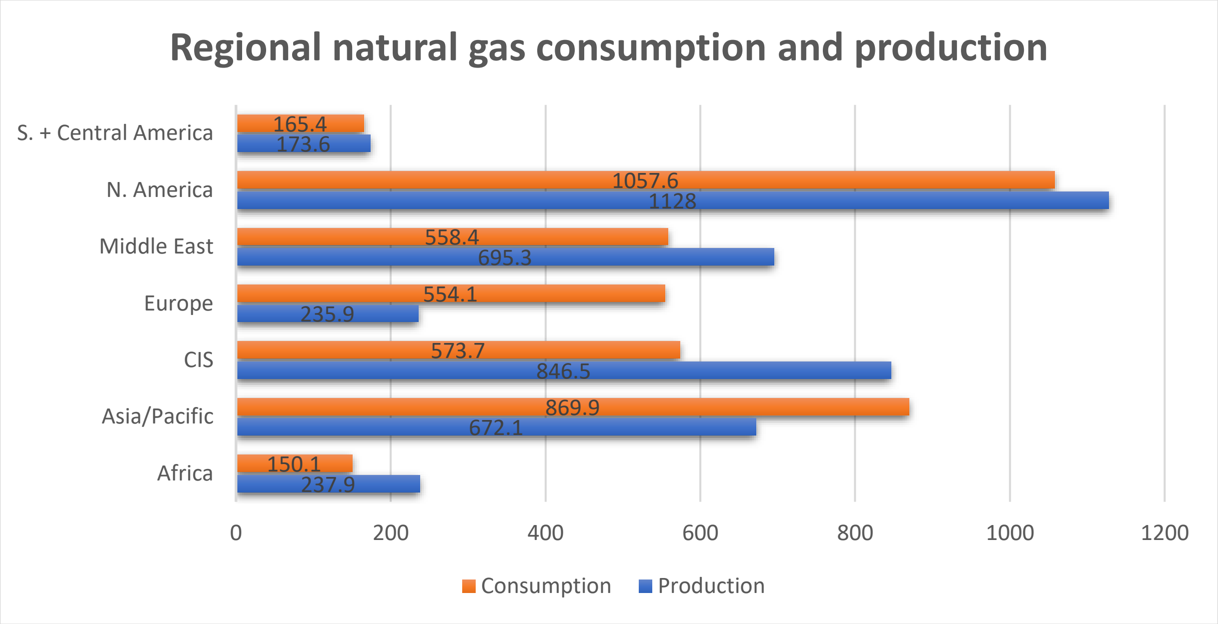


Figure 2.5.1 – Regional natural gas and consumption (BP, 2020)

To get a better grasp of why the European and Asian markets are competing, the graph above shows the overall production and consumption of natural gas, broken down by region. (BP, 2020) The graph tells us that the only two net importing regions are Asia/Pacific and Europe, of which China, Japan and South Korea are contributing far more to consumption than production. The gap between consumption and production are generally supplied by the Middle East and CIS regions, which are located between the two importing regions, and thus causing direct competition for the supply.

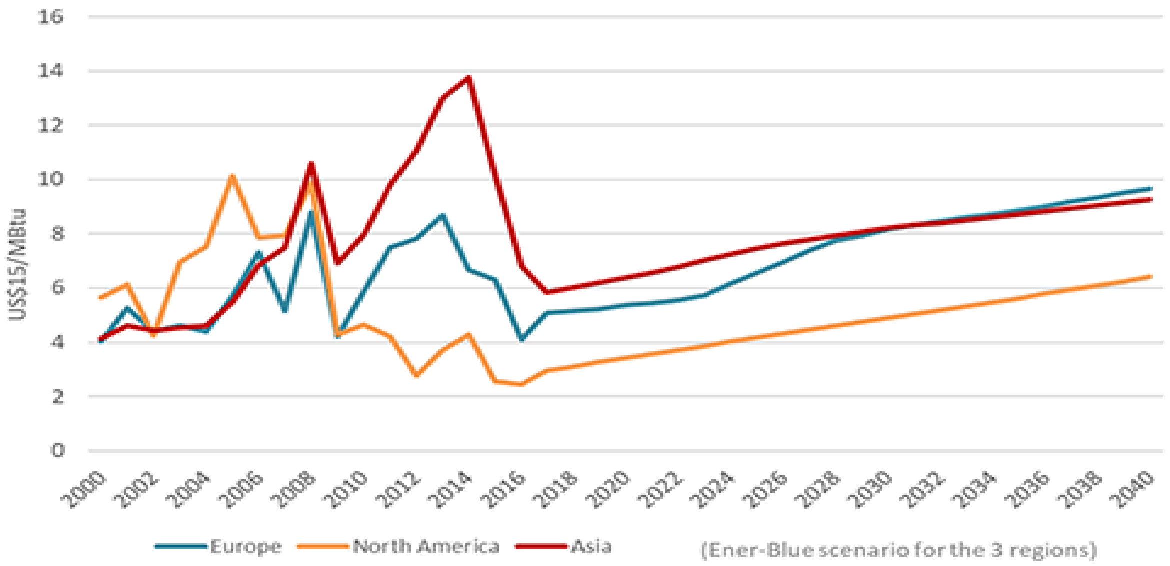


Figure 2.5.2 - Natural gas price forecast (Enerdata, 2018)

The above graph shows the price developments for natural gas in the last two decades. (Enerdata, 2018) While the price levels in the US have significantly decreased with fracking technology allowing the US to be energy independent, the Asian and European prices are still connected and price shocks in the Asian markets echo in the prices of the European. While the Japanese and Korean prices are generally above the European ones, they are converging, and are projected to equalize by 2030.

2.6 Climate policies and political concerns

While the traditional merit curve focus on the costs of producing energy from certain fuels with existing infrastructure, the Earth's merit curve ignores monetary costs and instead focuses on the emissions produced. (Bloomberg NEF, 2017) While the leftmost side is similar, with renewables and nuclear power being the cheapest after the infrastructure is in place, the fossil fuels are drastically different. Coal, while the cheapest, also emits the most and when focusing on reducing carbon emissions, coal should be the last choice in fossil fuels. The purpose of carbon taxing is to make the two curves match, and make coal comparatively more expensive. The effects of such an effort would be an overall reduction in carbon emissions, traded for higher financial costs.

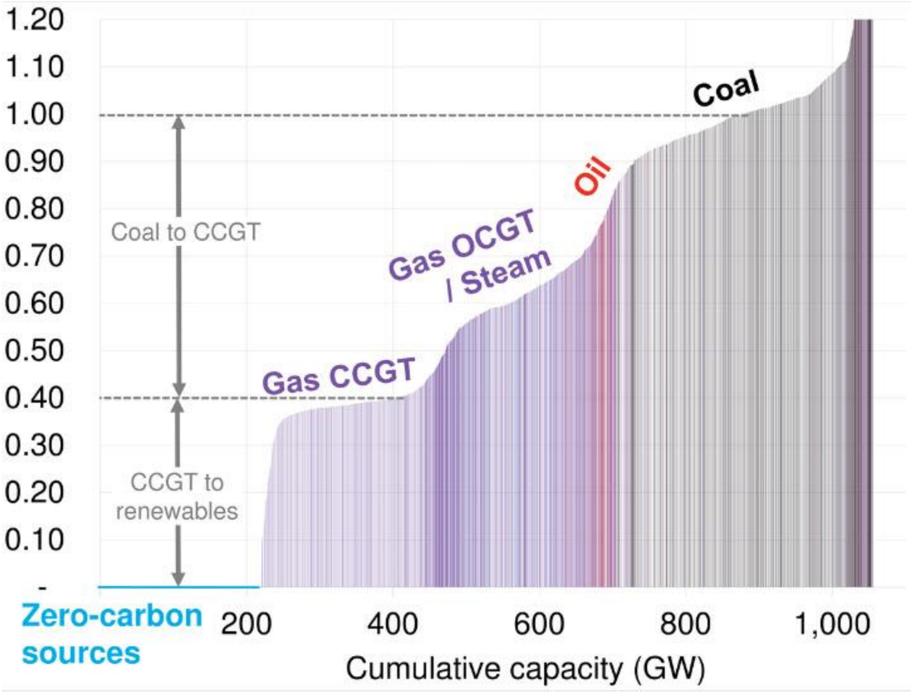


Figure 2.6.1 - Earth's Merit Curve (Bloomberg NEF, 2017)

2.6.1 Russia

Unlike most of the world, Russia is not adverse to climate change and Vladimir Putin has directly stated that he believes climate change can be beneficial to the Russian economy. (Thomson Reuters, 2017) This is both due increased potential for shipping in the Arctic regions allowing their large quantities of oil and gas to reach the world market more easily, as well as Russia's vast area potentially becoming more arable. (Digges, 2019) Arctic shipping is especially important, as Russia are in a precarious position from a geopolitical standpoint.

Other than the CIS region, the main recipients for Russia's oil and gas is Europe. Having an economy largely centered around petroleum makes Russia more vulnerable to sanctions from the EU. Due to being geopolitical adversaries of EU and the US, Russia has already been affected by sanctions, causing them to look eastward to lessen the impact of any future sanction attempts. (Astrasheuskaya, 2019)

2.6.2 China

With China's meteoric rise into a global superpower, an enormous energy demand has followed. This has led to China being extremely reliant on coal to fuel their economy, which has had many adverse effects on the country's wellbeing. Due to their extreme use of coal China alone is estimated to be responsible for 27% of the world's carbon emissions. (BBC, 2021) This usage of coal has not only had global affects, but also brought along severe consequences for the air quality. China is ranked 4th worst in the world in terms of air quality, and this is primarily due to their heavy usage of coal. (The World Air Quality Project, 2021) To improve their air quality, China is heavily incentivized to reduce their consumption of coal for power generation, and natural gas will be an important transition fuel until more energy secure renewable technology is developed.

3. Methodology

The models of this paper will be based on the idea that under an open market, distance will be a major cost driver for LNG trade. With a more easily traversable Northern Sea Route the distances for Russia and Norway to access the largest importers in Asia will be shortened, thus their trade volumes should increase. By using the trade patterns of the three importers we have chosen to focus on, we will make a series of regressions to determine the importance of distance with regards to international LNG trade. In other words, by cataloguing the last few years' trade volumes of for example Japan, we can produce equations that will allow us to determine how much Japan, China, and Korea should be importing from Russia and Norway with a properly developed and traversable Northern Sea Route, given that their already existing import patterns being representative.

To create our models, we first compiled the last 4 years of import data for China, Japan and South Korea. (BP, 2020) For every year each "Export-Import couple" get its own row. Every row contains: the importer, the exporter, the year, the amount imported, the distance between the two countries, the yearly total imports of the importer, the yearly total natural gas consumption of the exporter, the yearly total natural gas consumption of the importer, and the known natural gas reserves of the exporter. The table below shows an excerpt of China's 2016 imports to demonstrate.

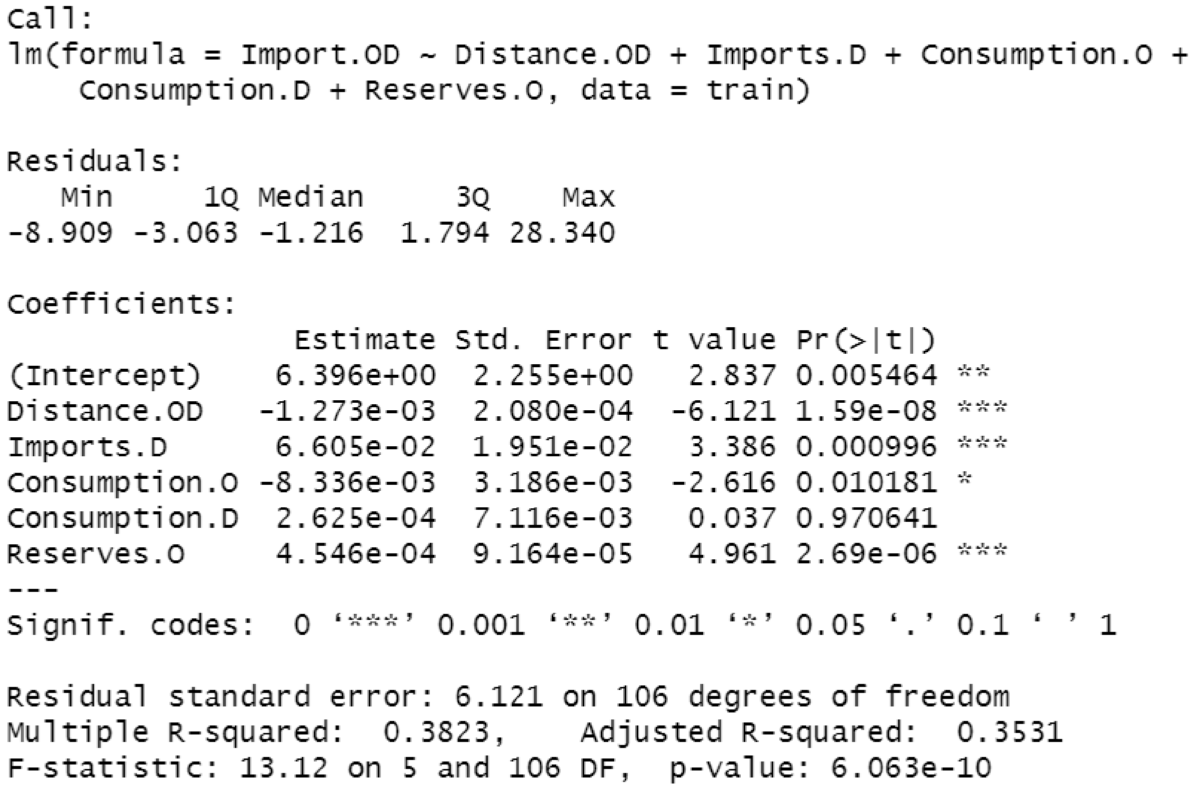
DESTINATION	ORIGIN	YEAR	IMPORT OD	DISTANCE OD	IMPORTS D	CONSUMPTION O	CONSUMPTION D	RESERVES O
CHINA	Norway	2016	0.2498	6546	36.7606	4.3724	209.4411	1750.1745
CHINA	Russia	2016	0.3358	5874	36.7606	420.6464	209.4411	34833.2525
CHINA	Oman	2016	0.0788	5379	36.7606	22.8405	209.4411	664.4625
CHINA	Qatar	2016	6.5289	5845	36.7606	40.2094	209.4411	24915.0382
CHINA	Egypt	2016	0.0888	7251	36.7606	49.3541	209.4411	2137.7125
CHINA	Nigeria	2016	0.3513	10254	36.7606	18.0000	209.4411	5201.4441
CHINA	Australia	2016	15.7283	2765	36.7606	41.7261	209.4411	2389.5955
CHINA	Indonesia	2016	3.6550	2661	36.7606	44.6308	209.4411	2909.2250
CHINA	Malaysia	2016	3.3745	2447	36.7606	44.9930	209.4411	946.6812

Table 3.1 - Chinese LNG imports

While including total exports and production would allow for a more accurate training model, it would likely lead to overfitting as both production and exports would be directly tied to the trade volumes we are looking to estimate. In other words, if the shorter voyage distance leads to higher trade volumes of LNG to China from Norway and Russia, having set figures for production and exports would directly counteract any estimates attempted.

For our models we have decided to use regression analysis using multiple linear models. In the interest of gaining the best possible estimates, we want to create several sets of models. One set with all of our data simultaneously, and one set for each importer. Furthermore, we split up the dataset into a training set and a test set before applying the model to a set made with the 2019 data for Norway and Russia in relation to the importers, with the individual import amounts left blank. While Norway and Russia have imported to these countries during the timespan we're analyzing, we choose to disregard these instances (while not removing them from the totals) as they are not considered representative for the shorter distance we employ in the analysis, and would thus skew the models. The totals will be considered the importers' demand for natural gas, and estimates we make would not add to the total, but allocate how much of the total Norway and Russia should cover with an active Northern Sea Route.

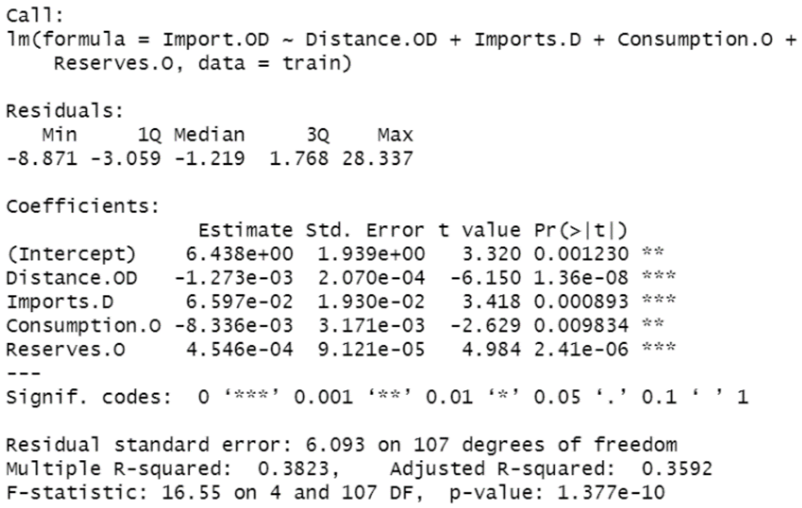
3.1 Preliminary analysis of complete dataset



```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Consumption.D + Reserves.O, data = train)

Residuals:
   Min     1Q Median     3Q    Max
-8.909 -3.063 -1.216  1.794 28.340

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    6.396e+00  2.255e+00   2.837 0.005464 **
Distance.OD   -1.273e-03  2.080e-04  -6.121 1.59e-08 ***
Imports.D      6.605e-02  1.951e-02   3.386 0.000996 ***
Consumption.O -8.336e-03  3.186e-03  -2.616 0.010181 *
Consumption.D  2.625e-04  7.116e-03   0.037 0.970641
Reserves.O     4.546e-04  9.164e-05   4.961 2.69e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.121 on 106 degrees of freedom
Multiple R-squared:  0.3823,    Adjusted R-squared:  0.3531
F-statistic: 13.12 on 5 and 106 DF,  p-value: 6.063e-10
```

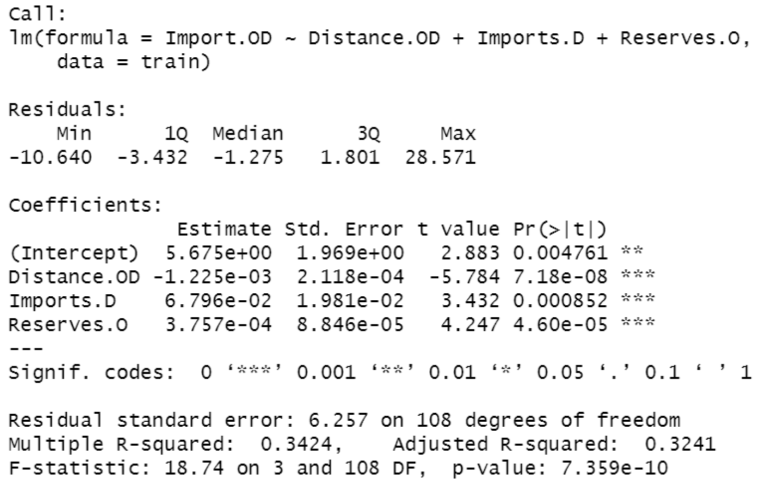
Figure 3.1.1 - Summary of Initial Model

To start off our analysis, we ran a regression model using the complete set of parameters. The initial model returned distance (D), total imports(I), and exporter’s reserves(R) as highly significant parameters, while the exporter’s consumption(Co) was deemed significant, but to a lesser degree. Importer’s consumption(C) was deemed insignificant, which is likely due to the presence of the importer’s total imports, which includes the relevant portion of the consumption. In other words, a country like China, who has their own significant production of natural gas, will consume far more than they import, but only the imported portion will be relevant to our analysis. After determining the significant parameters, we assembled a set of models with different parameter combinations. We ended up with four models. DICoR (1), DIR(2), DR(3), and DCoR(4). For the two models including exporter’s consumption(Co), the parameter had one degree of increase in significance.



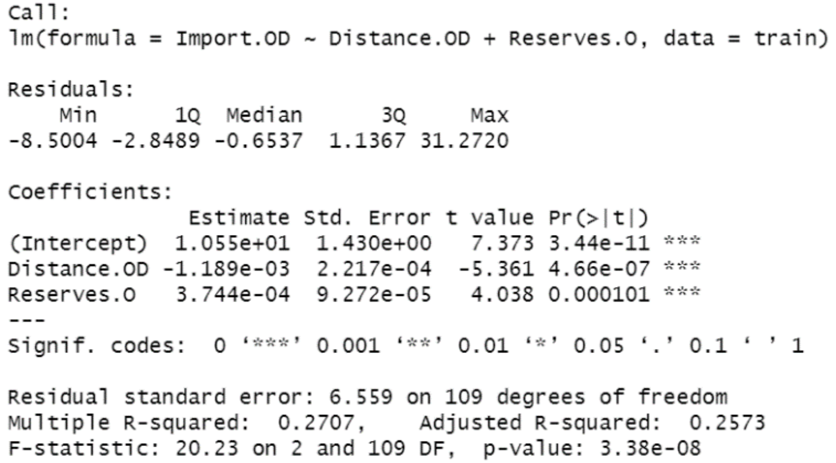
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Reserves.O, data = train)

Residuals:
   Min     1Q Median     3Q    Max
-8.871 -3.059 -1.219  1.768 28.337

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    6.438e+00  1.939e+00   3.320 0.001230 **
Distance.OD   -1.273e-03  2.070e-04  -6.150 1.36e-08 ***
Imports.D      6.597e-02  1.930e-02   3.418 0.000893 ***
Consumption.O -8.336e-03  3.171e-03  -2.629 0.009834 **
Reserves.O     4.546e-04  9.121e-05   4.984 2.41e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.093 on 107 degrees of freedom
Multiple R-squared:  0.3823,    Adjusted R-squared:  0.3592
F-statistic: 16.55 on 4 and 107 DF,  p-value: 1.377e-10
```

Figure 3.1.2 - Summary of DICoR(1) - All



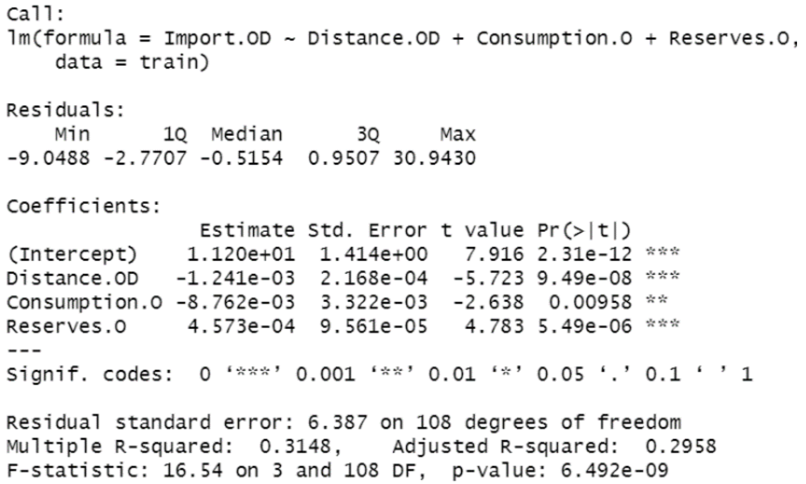
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Reserves.O,
    data = train)

Residuals:
    Min      1Q  Median      3Q     Max
-10.640  -3.432  -1.275   1.801  28.571

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  5.675e+00  1.969e+00   2.883 0.004761 **
Distance.OD -1.225e-03  2.118e-04  -5.784 7.18e-08 ***
Imports.D    6.796e-02  1.981e-02   3.432 0.000852 ***
Reserves.O   3.757e-04  8.846e-05   4.247 4.60e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.257 on 108 degrees of freedom
Multiple R-squared:  0.3424,    Adjusted R-squared:  0.3241
F-statistic: 18.74 on 3 and 108 DF,  p-value: 7.359e-10
```

Figure 3.1.3 - Summary of DIR(2) - All



```
Call:
lm(formula = Import.OD ~ Distance.OD + Reserves.O, data = train)

Residuals:
    Min      1Q  Median      3Q     Max
-8.5004 -2.8489 -0.6537  1.1367 31.2720

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.055e+01  1.430e+00   7.373 3.44e-11 ***
Distance.OD -1.189e-03  2.217e-04  -5.361 4.66e-07 ***
Reserves.O   3.744e-04  9.272e-05   4.038 0.000101 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.559 on 109 degrees of freedom
Multiple R-squared:  0.2707,    Adjusted R-squared:  0.2573
F-statistic: 20.23 on 2 and 109 DF,  p-value: 3.38e-08
```

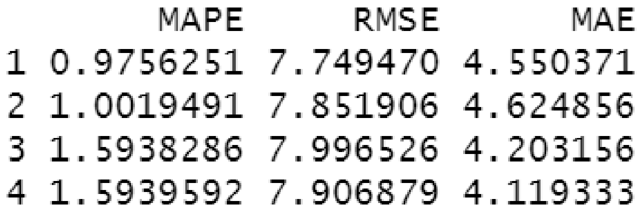
Figure 3.1.4 - Summary of DR(3) - All



```
Call:
lm(formula = Import.OD ~ Distance.OD + Consumption.O + Reserves.O,
    data = train)

Residuals:
    Min      1Q  Median      3Q     Max
-9.0488 -2.7707 -0.5154  0.9507 30.9430

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.120e+01  1.414e+00   7.916 2.31e-12 ***
Distance.OD   -1.241e-03  2.168e-04  -5.723 9.49e-08 ***
Consumption.O -8.762e-03  3.322e-03  -2.638  0.00958 **
Reserves.O     4.573e-04  9.561e-05   4.783 5.49e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.387 on 108 degrees of freedom
Multiple R-squared:  0.3148,    Adjusted R-squared:  0.2958
F-statistic: 16.54 on 3 and 108 DF,  p-value: 6.492e-09
```

Figure 3.1.5 - Summary of DCoR(4) - All

After the models had been assembled, using our training dataset, we applied them to the test dataset by predicting the import volumes which allows us to check their accuracies. After generating the predictions, we could now validate the results mathematically and visually, while also allowing us to check any major inaccuracies if they occurred. First, we calculated the mean absolute percentage error (MAPE), the rooted mean square error (RMSE) and the mean absolute error (MAE) for each model. As shown in the table below, the models performed similarly, but model 1 and 2 did marginally better on MAPE and RMSE. However, on MAE these models performed the worst, possibly indicating that models 3 and 4 got closer on one or more instances of large import volumes.



```
       MAPE     RMSE      MAE
1 0.9756251 7.749470 4.550371
2 1.0019491 7.851906 4.624856
3 1.5938286 7.996526 4.203156
4 1.5939592 7.906879 4.119333
```

Figure 3.1.6 - Validation of models for complete dataset

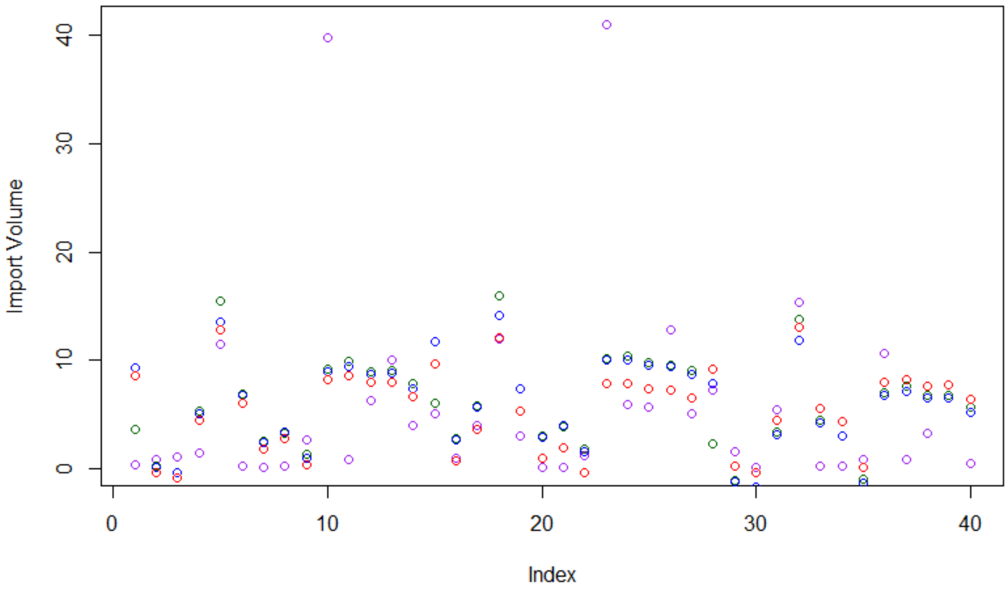
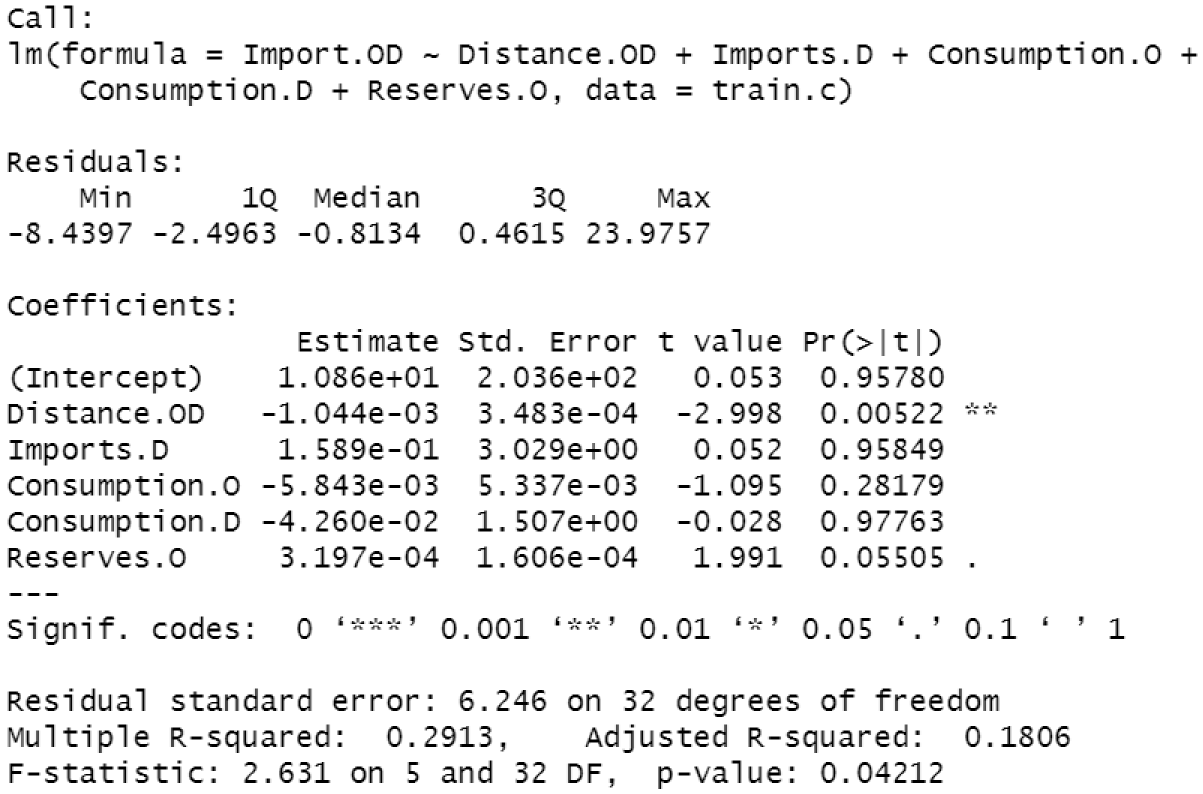


Figure 3.1.7 - Scatterplot of actual values and predictions - complete dataset

The above graphic of the test set data and its corresponding predictions shows the actual amounts in purple, with (1) in green, (2) in blue, (3) in red, and (4) in black. The visual inspection reveals one major issue. None of the models do well when handling large outliers. By looking at the actual values for the test set, we find that both of these outliers are Australia, and its LNG trade with China and Japan. As we know, Australia has been the biggest LNG source for both China and Japan, exporting more than three times the amount of the next largest exporter. The cause for the models' poor handling of Australia is likely due to its natural gas reserves being ranked in the middle of the pack amongst exporters, and are in pure volume dwarfed by countries like Qatar, Russia and the US. As we need to include reserves in our models to avoid overestimating smaller actors in close geographical proximity and decided not to include an exporter's total exports due to aforementioned reasons, these outliers will have to be accepted as necessary and the errors from the validation of the models will have to be viewed with that in mind under evaluation.

3.2 Preliminary analysis of datasets subset by importer

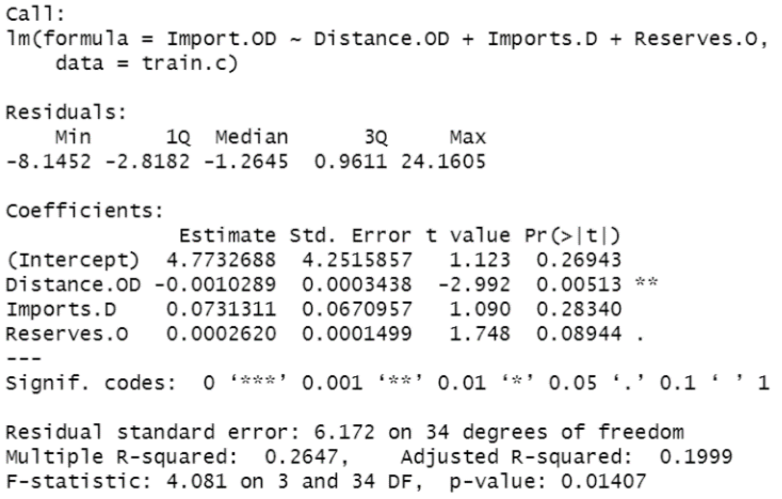
3.2.1 China



```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Consumption.D + Reserves.O, data = train.c)

Residuals:
    Min      1Q  Median      3Q     Max
-8.4397 -2.4963 -0.8134  0.4615 23.9757

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.086e+01  2.036e+02   0.053  0.95780
Distance.OD   -1.044e-03  3.483e-04  -2.998  0.00522 **
Imports.D      1.589e-01  3.029e+00   0.052  0.95849
Consumption.O -5.843e-03  5.337e-03  -1.095  0.28179
Consumption.D -4.260e-02  1.507e+00  -0.028  0.97763
Reserves.O     3.197e-04  1.606e-04   1.991  0.05505 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.246 on 32 degrees of freedom
Multiple R-squared:  0.2913,    Adjusted R-squared:  0.1806
F-statistic: 2.631 on 5 and 32 DF,  p-value: 0.04212
```

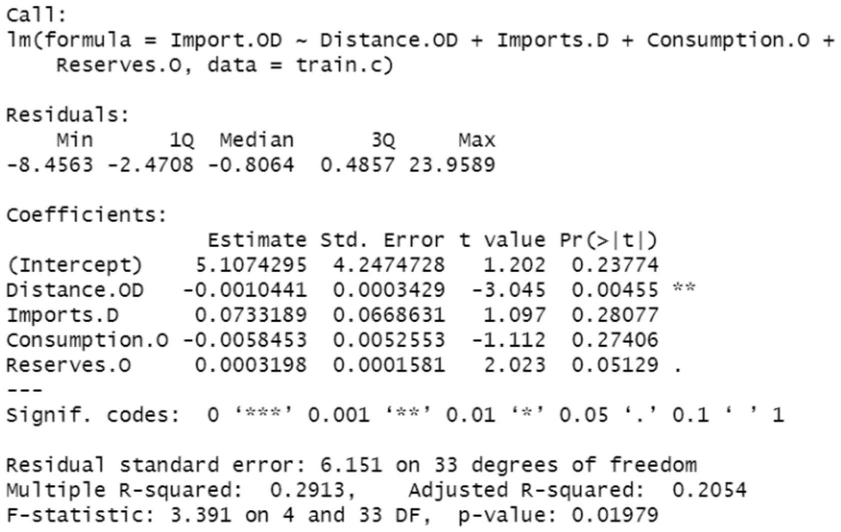
Figure 3.2.1.1 - Summary of Chinese subset - all

The summary of the initial model with all parameters is immediately concerning. While distance is deemed significant, the only other parameter showing a small degree of significance is the exporter’s natural gas reserves. For imports and domestic consumption, they have less variation due to the dataset being limited to only Chinese imports over three years. Since we are going to employ a dataset with new values for imports and consumption, we will not disregard these parameters, and still recreate the models from our analysis on the full dataset, with this smaller subset.



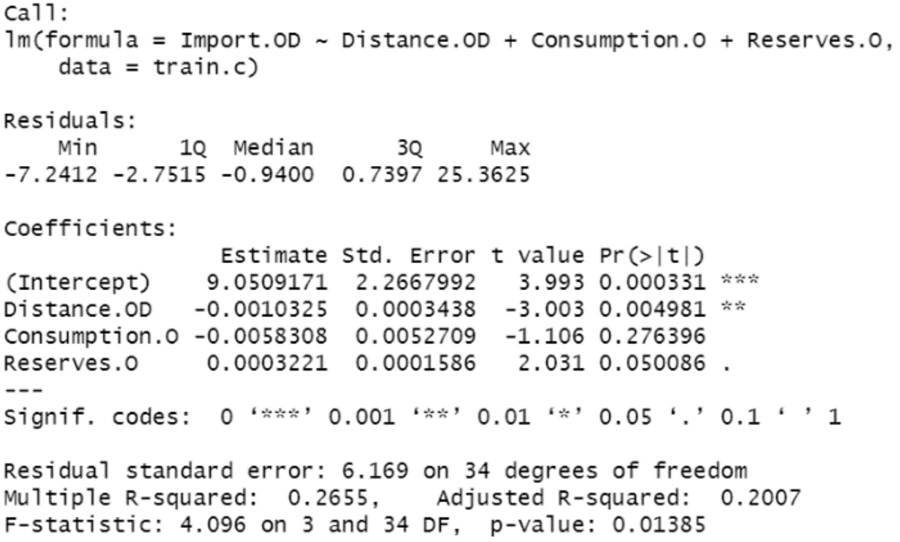
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Reserves.O,
    data = train.c)

Residuals:
    Min      1Q  Median      3Q     Max
-8.1452 -2.8182 -1.2645  0.9611 24.1605

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.7732688  4.2515857   1.123  0.26943
Distance.OD -0.0010289  0.0003438  -2.992  0.00513 **
Imports.D    0.0731311  0.0670957   1.090  0.28340
Reserves.O   0.0002620  0.0001499   1.748  0.08944 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.172 on 34 degrees of freedom
Multiple R-squared:  0.2647,    Adjusted R-squared:  0.1999
F-statistic: 4.081 on 3 and 34 DF,  p-value: 0.01407
```

Figure 3.2.1.3 – Summary of DIR(2), China



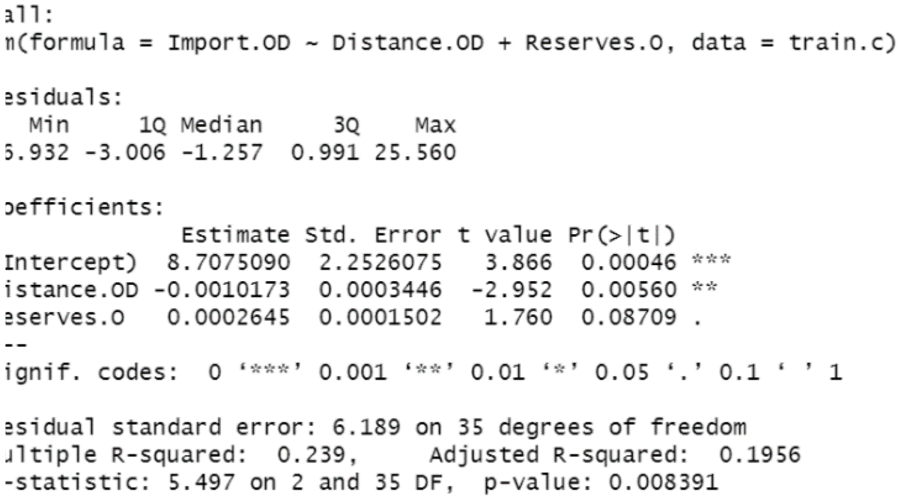
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Reserves.O, data = train.c)

Residuals:
    Min      1Q  Median      3Q     Max
-8.4563 -2.4708 -0.8064  0.4857 23.9589

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    5.1074295  4.2474728   1.202  0.23774
Distance.OD   -0.0010441  0.0003429  -3.045  0.00455 **
Imports.D      0.0733189  0.0668631   1.097  0.28077
Consumption.O -0.0058453  0.0052553  -1.112  0.27406
Reserves.O     0.0003198  0.0001581   2.023  0.05129 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.151 on 33 degrees of freedom
Multiple R-squared:  0.2913,    Adjusted R-squared:  0.2054
F-statistic: 3.391 on 4 and 33 DF,  p-value: 0.01979
```

Figure 3.2.1.2 – Summary of DICoR(1), China



```
Call:
lm(formula = Import.OD ~ Distance.OD + Consumption.O + Reserves.O,
    data = train.c)

Residuals:
    Min      1Q  Median      3Q     Max
-7.2412 -2.7515 -0.9400  0.7397 25.3625

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    9.0509171  2.2667992   3.993 0.000331 ***
Distance.OD   -0.0010325  0.0003438  -3.003 0.004981 **
Consumption.O -0.0058308  0.0052709  -1.106 0.276396
Reserves.O     0.0003221  0.0001586   2.031 0.050086 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.169 on 34 degrees of freedom
Multiple R-squared:  0.2655,    Adjusted R-squared:  0.2007
F-statistic: 4.096 on 3 and 34 DF,  p-value: 0.01385
```

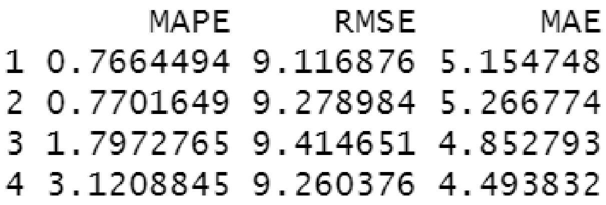
Figure 3.2.1.5 – Summary of DCoR(4), China



```
all:
n(formula = Import.OD ~ Distance.OD + Reserves.O, data = train.c)

esiduals:
  Min     1Q Median     3Q    Max
5.932 -3.006 -1.257  0.991 25.560

oefficients:
              Estimate Std. Error t value Pr(>|t|)
Intercept)  8.7075090  2.2526075   3.866  0.00046 ***
istance.OD -0.0010173  0.0003446  -2.952  0.00560 **
eserves.O   0.0002645  0.0001502   1.760  0.08709 .
--
ignif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

esidual standard error: 6.189 on 35 degrees of freedom
ultiple R-squared:  0.239,     Adjusted R-squared:  0.1956
-statistic: 5.497 on 2 and 35 DF,  p-value: 0.008391
```

Figure 3.2.1.4 – Summary of DR(3), China

As expected, imports and consumption stayed non-significant, leaving us with (3) as the only one with some degree of significance on all coefficients. Unlike the models we made with the complete dataset, none of the parameters' coefficients increased in significance. The intercept, notably, is only significant on the models without total imports, meaning a higher intercept compensates for the lack of having total imports as a guide for scaling the import volumes. When applied to 2019 data for the models' final estimates, a high increase in total import will cause larger errors for models (3) and (4) as the intercept will stay the same not being able to compensate. While the models will not produce estimates with the same degree of confidence, they will still be nice to compare with the other models with more significant coefficients. Thus we will continue the process as before, by validating the models mathematically and visually.



```
       MAPE     RMSE      MAE
1 0.7664494 9.116876 5.154748
2 0.7701649 9.278984 5.266774
3 1.7972765 9.414651 4.852793
4 3.1208845 9.260376 4.493832
```

Figure 3.2.1.6 - Validation of models, China

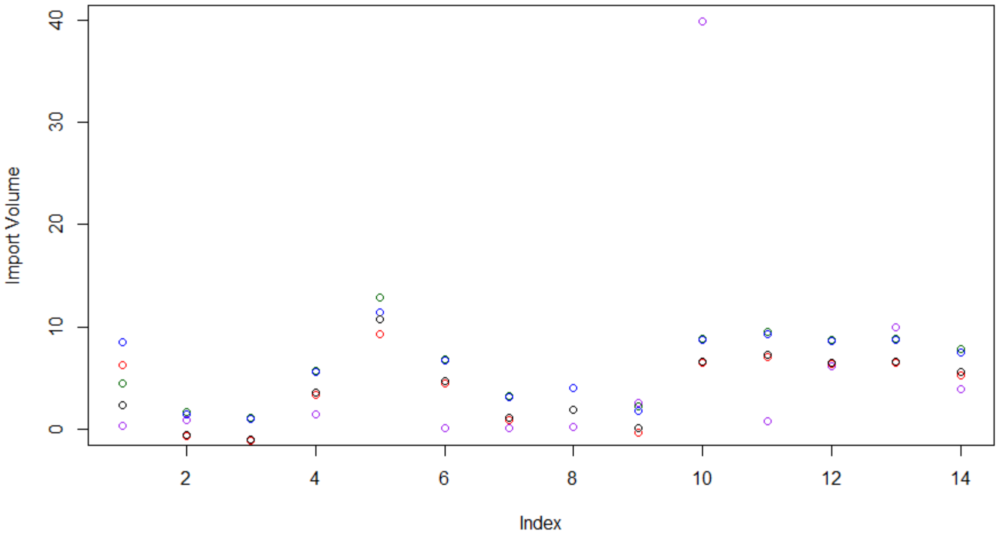
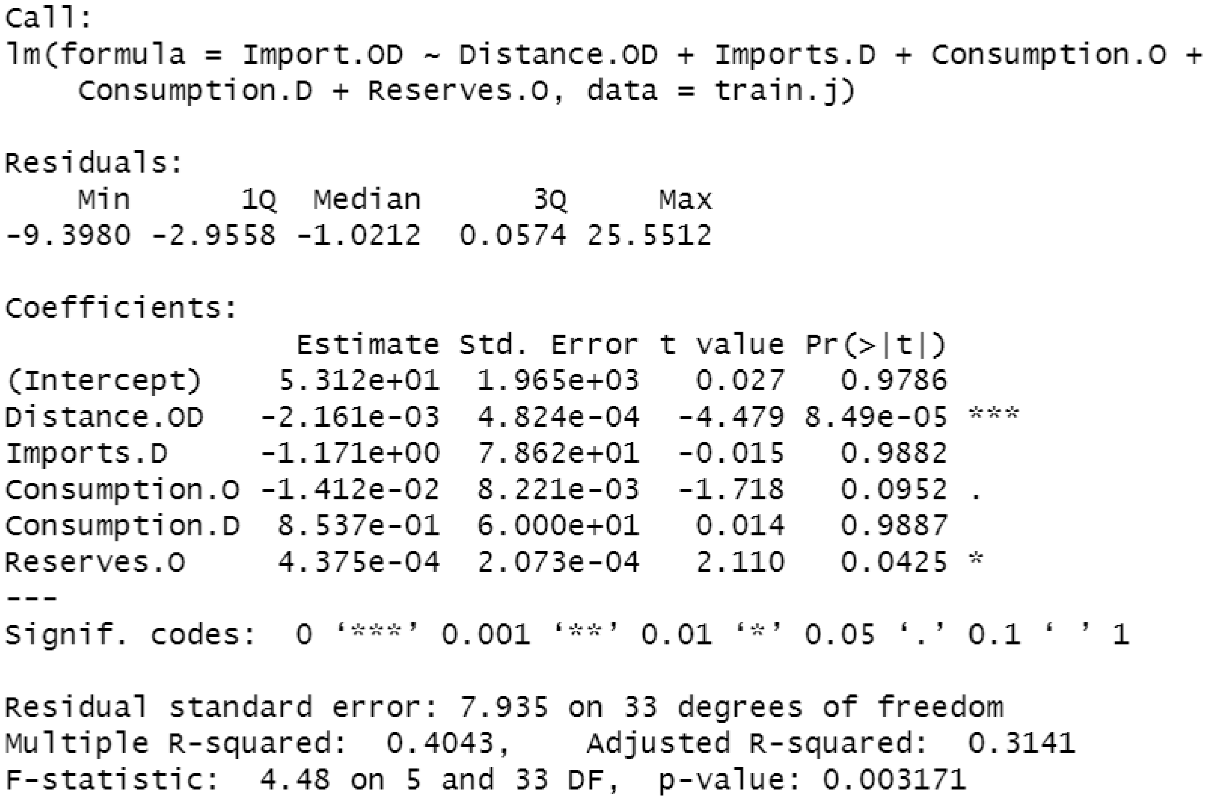


Figure 3.2.1.7 - Scatterplot of actual values and predictions, China

This plot is set up the same way as the one used in the main analysis, with the actual amounts in purple, prediction (1) in green, (2) in blue, (3) in red, and (4) in black. Similarly to the results from the analysis on the complete dataset, Australia keeps being an outlier, and the major issue with our models, who preform decently otherwise. From the mathematical validations the first two models perform significantly better in MAPE, while all four perform similarly in the RMSE and MAE. Model (4) performs worst by a significant margin in MAPE. While the models had issues with their significance, having such major outliers in a more limited dataset can arguably be the cause, possibly giving results in line with the models of the complete set when used to predict the imports of Norway and Russia.

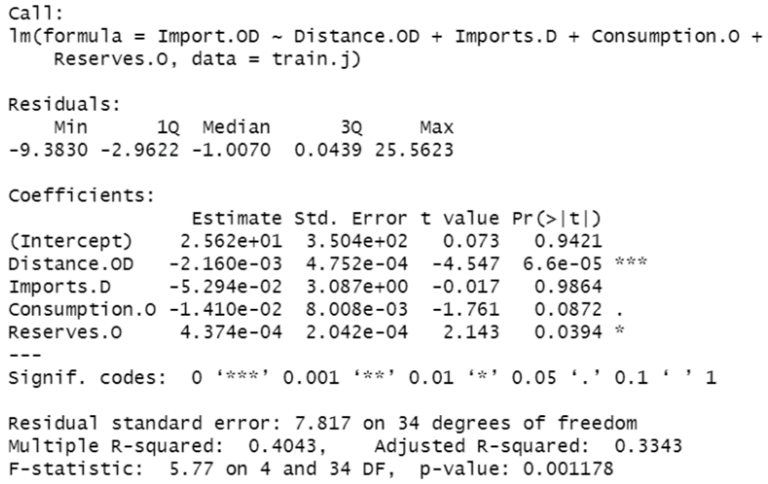
3.2.2 Japan



```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Consumption.D + Reserves.O, data = train.j)

Residuals:
    Min      1Q  Median      3Q     Max
-9.3980 -2.9558 -1.0212  0.0574 25.5512

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    5.312e+01  1.965e+03   0.027   0.9786
Distance.OD   -2.161e-03  4.824e-04  -4.479 8.49e-05 ***
Imports.D     -1.171e+00  7.862e+01  -0.015   0.9882
Consumption.O -1.412e-02  8.221e-03  -1.718   0.0952 .
Consumption.D  8.537e-01  6.000e+01   0.014   0.9887
Reserves.O     4.375e-04  2.073e-04   2.110   0.0425 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7.935 on 33 degrees of freedom
Multiple R-squared:  0.4043,    Adjusted R-squared:  0.3141
F-statistic:  4.48 on 5 and 33 DF,  p-value: 0.003171
```

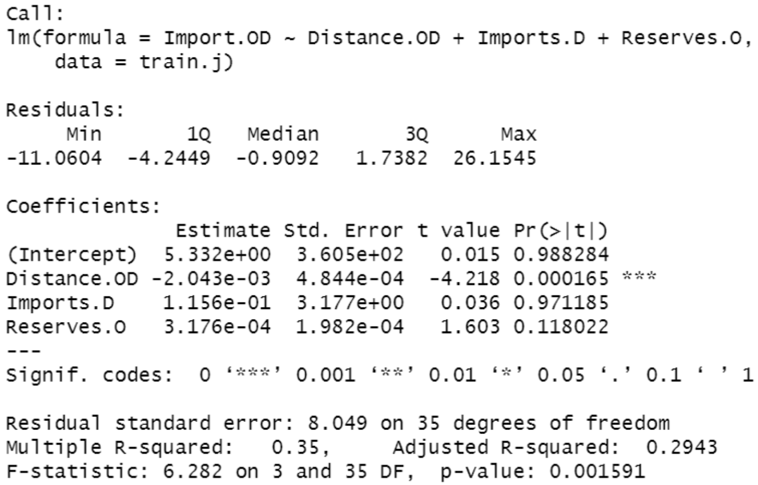
Figure 3.2.2.1 - Summary of Japanese subset - all

As expected, the same issue arises as with the Chinese data. Due to the nature of the dataset, imports and domestic consumption will not be significant parameters. Compared to the Chinese dataset, the initial Japanese model shows higher significance in both reserves and the exporting country’s consumption. As such, the models created should provide more accurate estimates than the Chinese models.



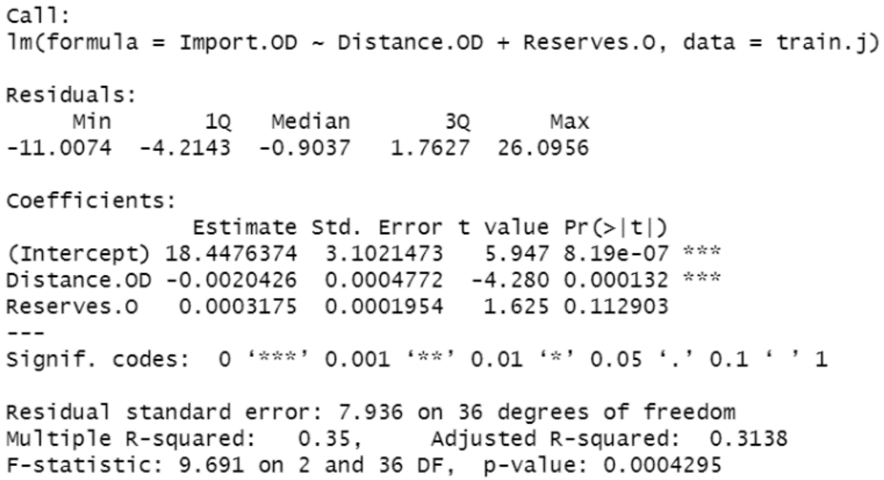
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Reserves.O, data = train.j)

Residuals:
    Min      1Q  Median      3Q     Max
-9.3830 -2.9622 -1.0070  0.0439 25.5623

Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)     2.562e+01  3.504e+02   0.073   0.9421
Distance.OD    -2.160e-03  4.752e-04  -4.547  6.6e-05 ***
Imports.D      -5.294e-02  3.087e+00  -0.017   0.9864
Consumption.O -1.410e-02  8.008e-03  -1.761   0.0872 .
Reserves.O      4.374e-04  2.042e-04   2.143   0.0394 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7.817 on 34 degrees of freedom
Multiple R-squared:  0.4043,    Adjusted R-squared:  0.3343
F-statistic:  5.77 on 4 and 34 DF,  p-value: 0.001178
```

Figure 3.2.2.2 – Summary of DICoR(1), Japan



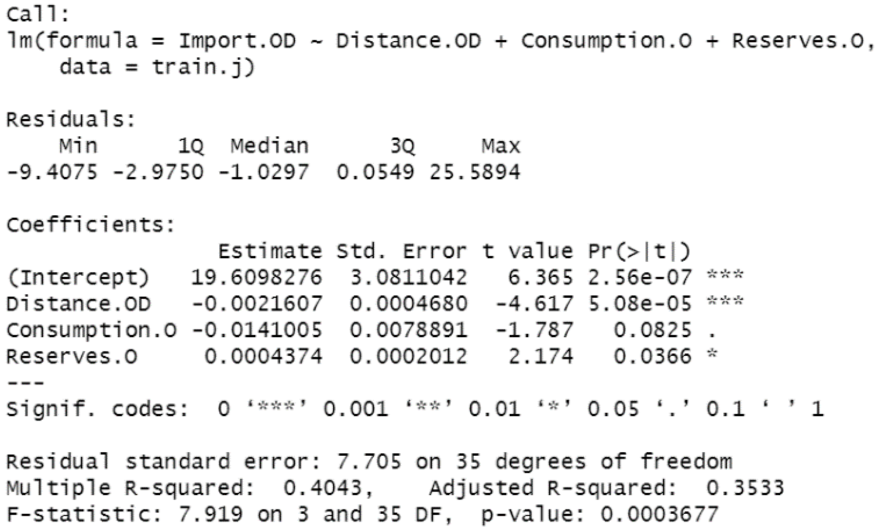
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Reserves.O,
    data = train.j)

Residuals:
     Min       1Q   Median       3Q      Max
-11.0604  -4.2449  -0.9092   1.7382  26.1545

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  5.332e+00  3.605e+02   0.015 0.988284
Distance.OD -2.043e-03  4.844e-04  -4.218 0.000165 ***
Imports.D    1.156e-01  3.177e+00   0.036 0.971185
Reserves.O   3.176e-04  1.982e-04   1.603 0.118022
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8.049 on 35 degrees of freedom
Multiple R-squared:    0.35,     Adjusted R-squared:  0.2943
F-statistic: 6.282 on 3 and 35 DF,  p-value: 0.001591
```

Figure 3.2.2.3 – Summary of DIR(2), Japan



```
Call:
lm(formula = Import.OD ~ Distance.OD + Reserves.O, data = train.j)

Residuals:
     Min       1Q   Median       3Q      Max
-11.0074  -4.2143  -0.9037   1.7627  26.0956

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 18.4476374  3.1021473   5.947 8.19e-07 ***
Distance.OD -0.0020426  0.0004772  -4.280 0.000132 ***
Reserves.O   0.0003175  0.0001954   1.625 0.112903
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7.936 on 36 degrees of freedom
Multiple R-squared:    0.35,     Adjusted R-squared:  0.3138
F-statistic: 9.691 on 2 and 36 DF,  p-value: 0.0004295
```

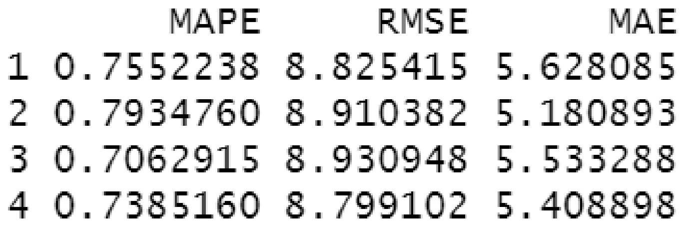
Figure 3.2.2.4 – Summary of DR(3), Japan



```
Call:
lm(formula = Import.OD ~ Distance.OD + Consumption.O + Reserves.O,
    data = train.j)

Residuals:
    Min      1Q  Median      3Q     Max
-9.4075 -2.9750 -1.0297  0.0549 25.5894

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)   19.6098276  3.0811042   6.365 2.56e-07 ***
Distance.OD   -0.0021607  0.0004680  -4.617 5.08e-05 ***
Consumption.O -0.0141005  0.0078891  -1.787   0.0825 .
Reserves.O     0.0004374  0.0002012   2.174   0.0366 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 7.705 on 35 degrees of freedom
Multiple R-squared:  0.4043,    Adjusted R-squared:  0.3533
F-statistic: 7.919 on 3 and 35 DF,  p-value: 0.0003677
```

Figure 3.2.2.5 – Summary of DCoR(4), Japan

Worth noting, models (2) and (3) caused a drop in significance for reserves and similarly to the Chinese models, model (3) and (4) the intercept gained statistical significance as total imports was excluded from the model as they fulfill mostly the same purpose due to the limited variations present. This will bring the same issue as with the Chinese data, but is likely to be less impactful as Japanese imports have been more stable across the years. We also see that model (4) is the only model with significance in all coefficients. We will follow the same steps as before and perform some validations of the models.



```
       MAPE     RMSE      MAE
1 0.7552238 8.825415 5.628085
2 0.7934760 8.910382 5.180893
3 0.7062915 8.930948 5.533288
4 0.7385160 8.799102 5.408898
```

Figure 3.2.2.6 - Validation of models, Japan

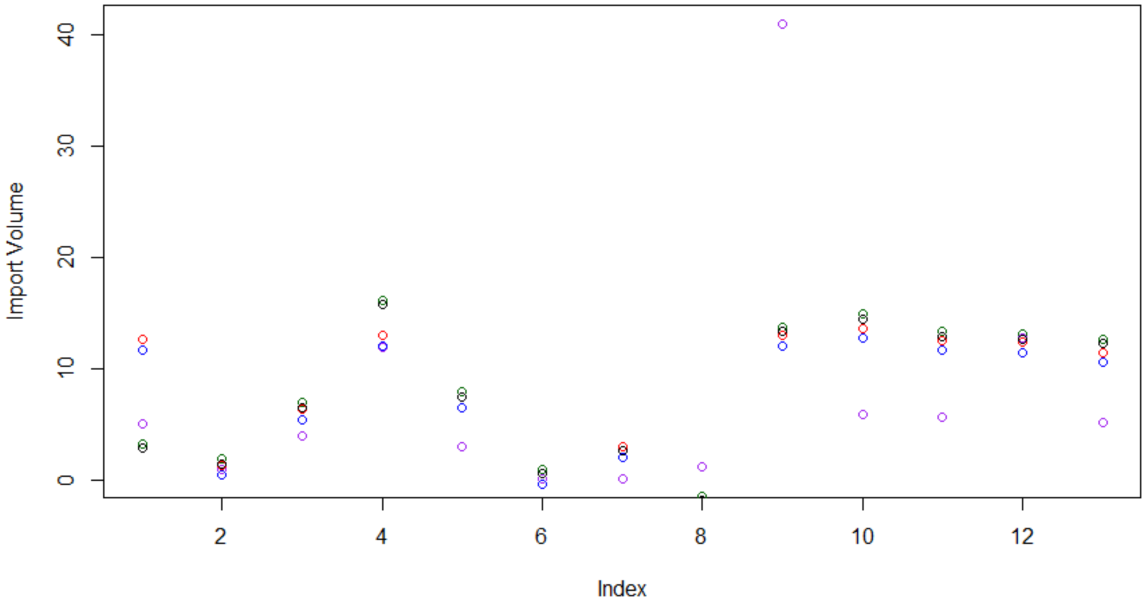
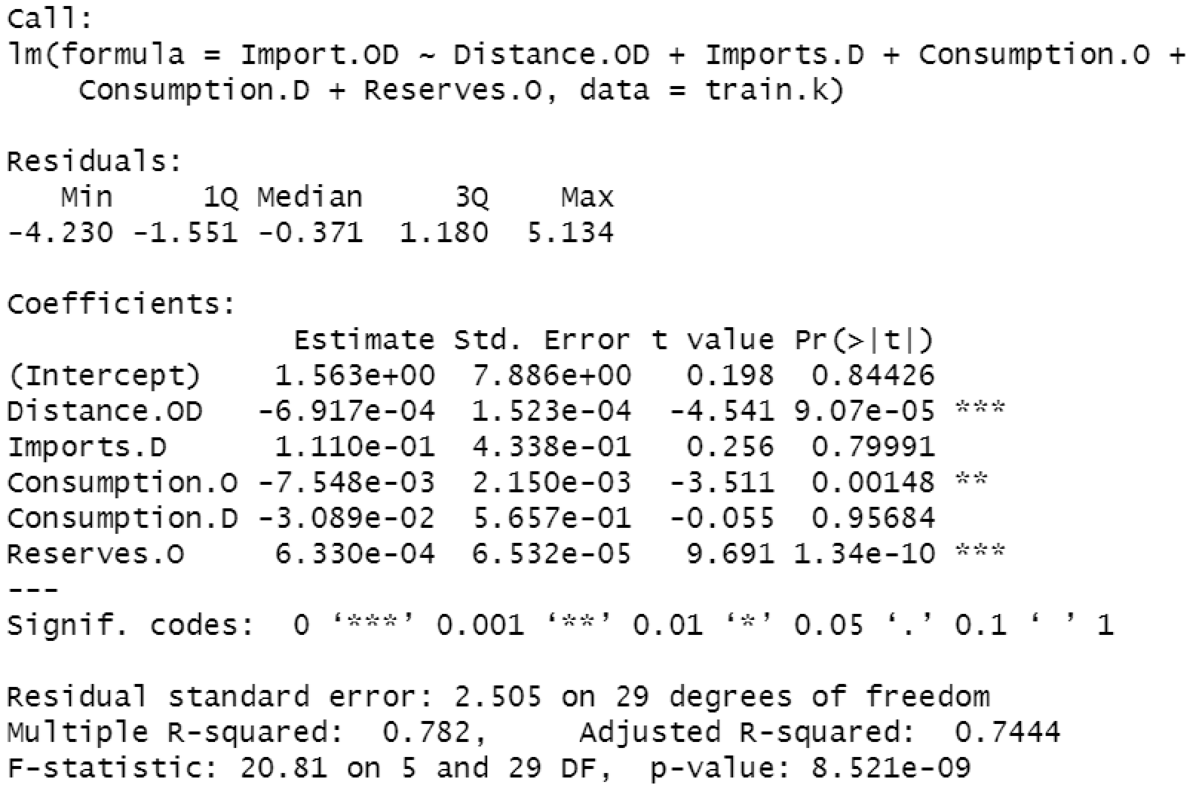


Figure 3.2.2.7 - Scatterplot of actual values and predictions, Japan

The mathematical analysis of the models shows very similar performances in all categories, with (3) and (4) performing marginally better. In accordance with the two previous models the Australian trade remains a major outlier, while the rest are more reasonable. The main trend seems to be a slight overestimation from the actual values. This may be caused by the models skewing upwards due to the Australian numbers. Overall, the Japanese models perform similarly to the Chinese models.

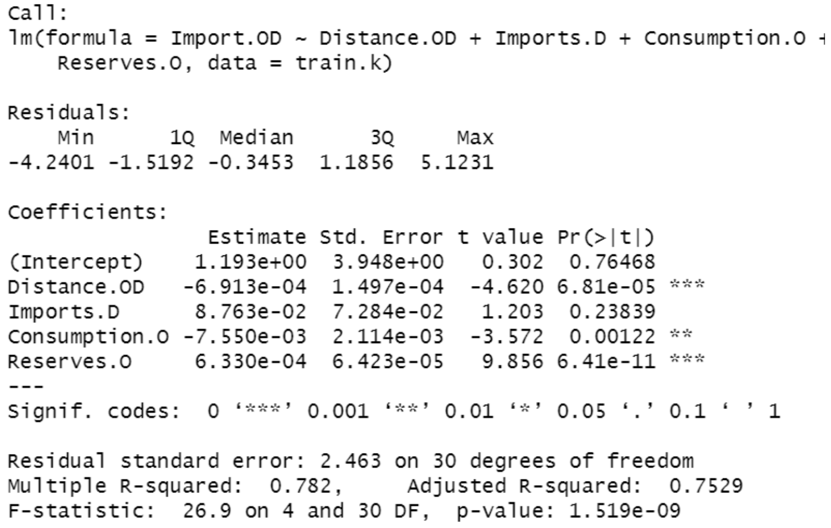
3.2.3 Korea



```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O + 
    Consumption.D + Reserves.O, data = train.k)

Residuals:
   Min     1Q Median     3Q    Max 
-4.230 -1.551 -0.371  1.180  5.134 

Coefficients:
                 Estimate Std. Error t value Pr(>|t|)    
(Intercept)    1.563e+00  7.886e+00   0.198  0.84426    
Distance.OD   -6.917e-04  1.523e-04  -4.541 9.07e-05 ***
Imports.D      1.110e-01  4.338e-01   0.256  0.79991    
Consumption.O -7.548e-03  2.150e-03  -3.511  0.00148 ** 
Consumption.D -3.089e-02  5.657e-01  -0.055  0.95684    
Reserves.O     6.330e-04  6.532e-05   9.691 1.34e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.505 on 29 degrees of freedom
Multiple R-squared:  0.782,	Adjusted R-squared:  0.7444 
F-statistic: 20.81 on 5 and 29 DF,  p-value: 8.521e-09
```

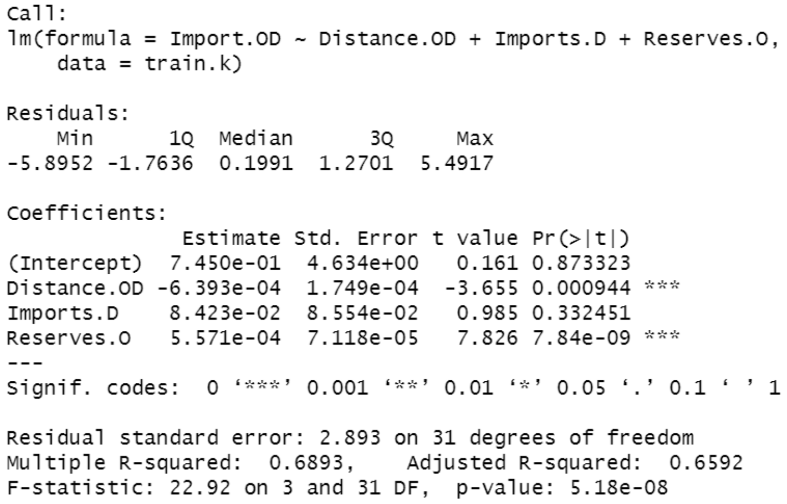
Figure 3.2.3.1 - Summary of Korean subset - all

For the complete model we see similar improvement compared to the Japanese model as the Japanese model had to the Chinese. Reserves and exporter’s consumption both increased in significance, while the coefficients for total imports and domestic consumption stays insignificant. Due to aforementioned reasons we still wish to include total imports for some models in case of large increases in import volume for 2019. Domestic consumption can be disregarded as total domestic imports does a better job at scaling up the individual import numbers when necessary.



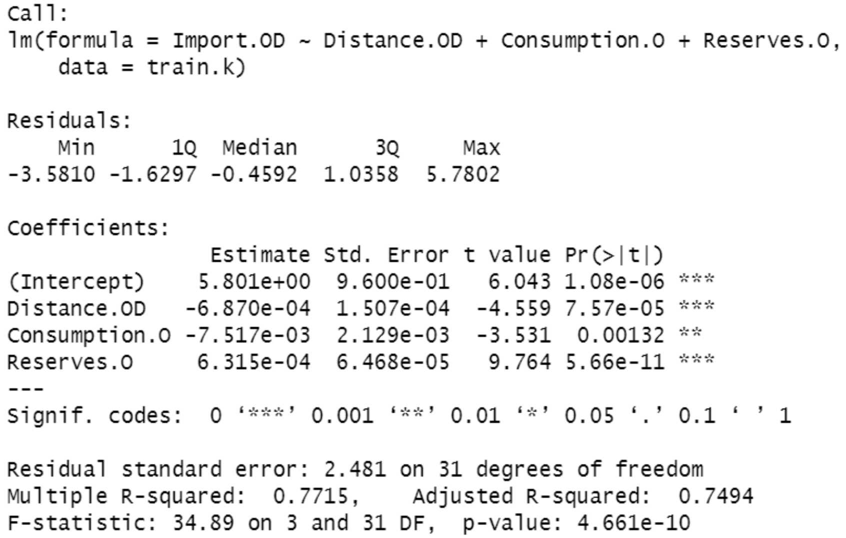
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Consumption.O +
    Reserves.O, data = train.k)

Residuals:
    Min      1Q  Median      3Q     Max 
-4.2401 -1.5192 -0.3453  1.1856  5.1231 

Coefficients:
                Estimate Std. Error t value Pr(>|t|)    
(Intercept)    1.193e+00  3.948e+00   0.302  0.76468    
Distance.OD   -6.913e-04  1.497e-04  -4.620 6.81e-05 ***
Imports.D      8.763e-02  7.284e-02   1.203  0.23839    
Consumption.O -7.550e-03  2.114e-03  -3.572  0.00122 ** 
Reserves.O     6.330e-04  6.423e-05   9.856 6.41e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.463 on 30 degrees of freedom
Multiple R-squared:  0.782,	Adjusted R-squared:  0.7529 
F-statistic:  26.9 on 4 and 30 DF,  p-value: 1.519e-09
```

Figure 3.2.3.2 – Summary of DICoR(1), Korea



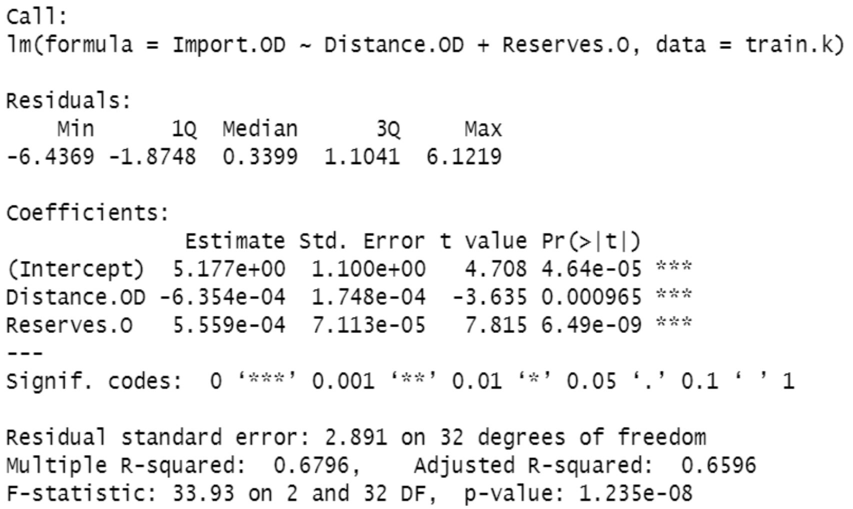
```
Call:
lm(formula = Import.OD ~ Distance.OD + Imports.D + Reserves.O, 
    data = train.k)

Residuals:
    Min      1Q  Median      3Q     Max 
-5.8952 -1.7636  0.1991  1.2701  5.4917 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.450e-01  4.634e+00   0.161 0.873323    
Distance.OD -6.393e-04  1.749e-04  -3.655 0.000944 ***
Imports.D    8.423e-02  8.554e-02   0.985 0.332451    
Reserves.O   5.571e-04  7.118e-05   7.826 7.84e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.893 on 31 degrees of freedom
Multiple R-squared:  0.6893,	Adjusted R-squared:  0.6592 
F-statistic: 22.92 on 3 and 31 DF,  p-value: 5.18e-08
```

Figure 3.2.3.3 – Summary of DIR(2), Korea



```
Call:
lm(formula = Import.OD ~ Distance.OD + Consumption.O + Reserves.O, 
    data = train.k)

Residuals:
    Min      1Q  Median      3Q     Max 
-3.5810 -1.6297 -0.4592  1.0358  5.7802 

Coefficients:
                Estimate Std. Error t value Pr(>|t|)    
(Intercept)    5.801e+00  9.600e-01   6.043 1.08e-06 ***
Distance.OD   -6.870e-04  1.507e-04  -4.559 7.57e-05 ***
Consumption.O -7.517e-03  2.129e-03  -3.531  0.00132 ** 
Reserves.O     6.315e-04  6.468e-05   9.764 5.66e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.481 on 31 degrees of freedom
Multiple R-squared:  0.7715,	Adjusted R-squared:  0.7494 
F-statistic: 34.89 on 3 and 31 DF,  p-value: 4.661e-10
```

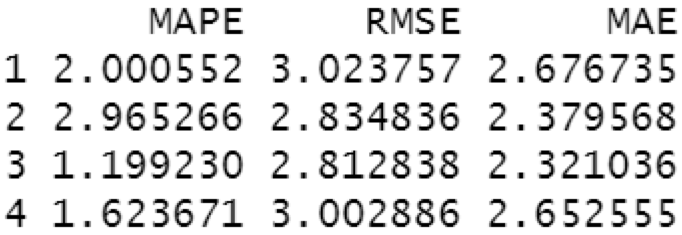
Figure 3.2.3.4 – Summary of DR(3), Korea



```
Call:
lm(formula = Import.OD ~ Distance.OD + Reserves.O, data = train.k)

Residuals:
    Min      1Q  Median      3Q     Max 
-6.4369 -1.8748  0.3399  1.1041  6.1219 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  5.177e+00  1.100e+00   4.708 4.64e-05 ***
Distance.OD -6.354e-04  1.748e-04  -3.635 0.000965 ***
Reserves.O   5.559e-04  7.113e-05   7.815 6.49e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.891 on 32 degrees of freedom
Multiple R-squared:  0.6796,	Adjusted R-squared:  0.6596 
F-statistic: 33.93 on 2 and 32 DF,  p-value: 1.235e-08
```

Figure 3.2.3.5 – Summary of DCoR(4), Korea

With regards to significance, the Korean models have the highest number of significant coefficients in the models. While the overall patterns are very similar to the other countries' models, the actual significance levels of the coefficients are higher across the board. The one exception to this still remains total imports that, while inaccurate, continues functioning as a sort of safeguard in case of big swings in total import volume from the timespan covered by the training dataset compared to the test set.



```
      MAPE     RMSE      MAE
1 2.000552 3.023757 2.676735
2 2.965266 2.834836 2.379568
3 1.199230 2.812838 2.321036
4 1.623671 3.002886 2.652555
```

Figure 3.2.3.6 - Validation of models, Korea

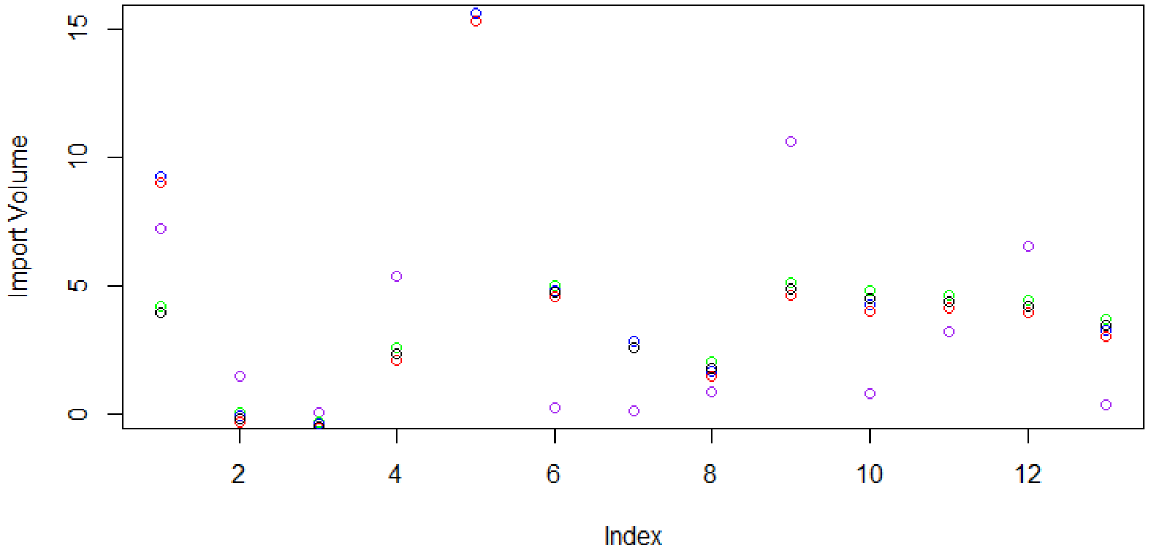


Figure 3.2.3.7 - Scatterplot of actual values and predictions, Korea

Despite the models' higher degrees of significance, the MAPE is higher across the board compared to the Japanese. While the RMSE and MAE are significantly lower, this is likely caused by South Korea importing far lower volumes of LNG from Australia, more in line with their relative reserves. The models still struggle with accuracies, and generally overestimates lower volumes and underestimates higher volumes.

3.3 Sensitivity analysis for demand changes for exporter and importer

As we have discussed earlier in the paper, there are several indicators for the demand for natural gas to increase, particularly in countries with a high amount of coal in their energy mixes. Additionally, LNG is in a prime position to become a major fuel source in the shipping industry, which will create a large demand for LNG in nations with busy ports. All the primary focuses of our current analysis are countries with a high focus on shipping, while China's energy consumption is heavily filled by coal. China's coal consumption has detrimentally affected the air quality in several of its major cities, and together with the steadily increasing focus on climate change, China has major incentives to move away from the usage of coal. (BBC, 2021)

Natural gas is the cleanest fossil fuel, with the lowest local pollutants. (Bloomberg NEF, 2017) Since its easier and readily available to adopt another fossil fuel source as a replacement for coal and oil, natural gas is the quickest way to cut down on pollution without sacrificing energy security. While better performing batteries are developed to shore up renewable energy's intermittency issues, gas is likely to become the fuel that bridges the gap until then. In other words, the global demand for natural gas is likely to increase in the next years and needs to be accounted for in our analysis. To achieve this, we need to create a new data frame with altered values. To adjust the demand for LNG in China, Japan, and Korea, we have to adjust the value of the importer's total import, signified by I in the models. To give a more accurate estimate, we also need to alter the exporters' consumptions.

Instead of using simple percentage changes in the original values, we decided to make very simple forecasts for the relevant parameters. We achieved this by taking the available data for past imports of LNG for the importers, and past consumption for the exporters. After gathering this data, we converted each country's data into time series. With the time series constructed, we can utilize the **forecast** package in R. Since the available data for LNG imports just covers a relatively small timeframe, we decided to make our forecasts with ARIMA models suggested automatically by R with the **auto.arima**()-function, forecasting 5 years forward. Since we expect the demand to rise, we picked out the data from the mean and upper levels, i.e. from the middle line and up in the graphs and tables below.

3.3.1 Forecasting import demand

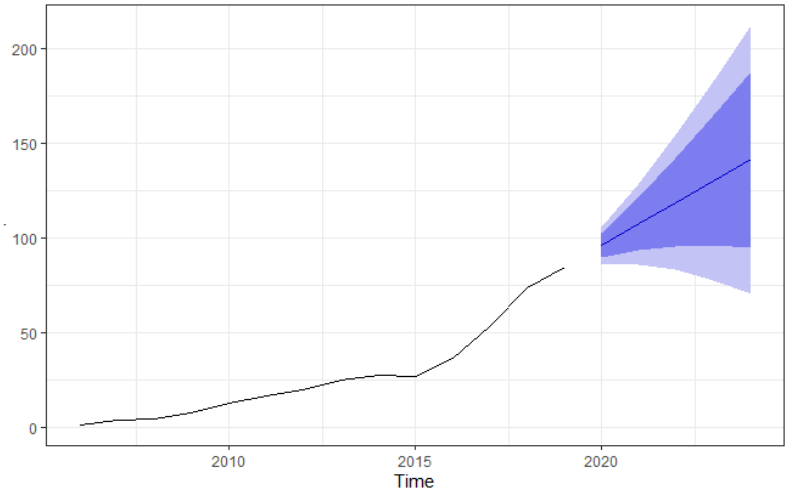


Figure 3.3.1.1 - Forecast China, imports

The Chinese import volumes have been sharply increasing since 2015, and that is very much reflected in the forecasts generated. The mean levels of the forecast are projecting a 50% increase in import volumes over the next five years. Due to the reasons explained earlier in the thesis, we are expecting a strong demand increase for LNG in the global market, and will be using the mean, the upper estimates within 80% confidence, and the upper estimates within 95% confidence estimated by the model as our guideline for the demand increase.

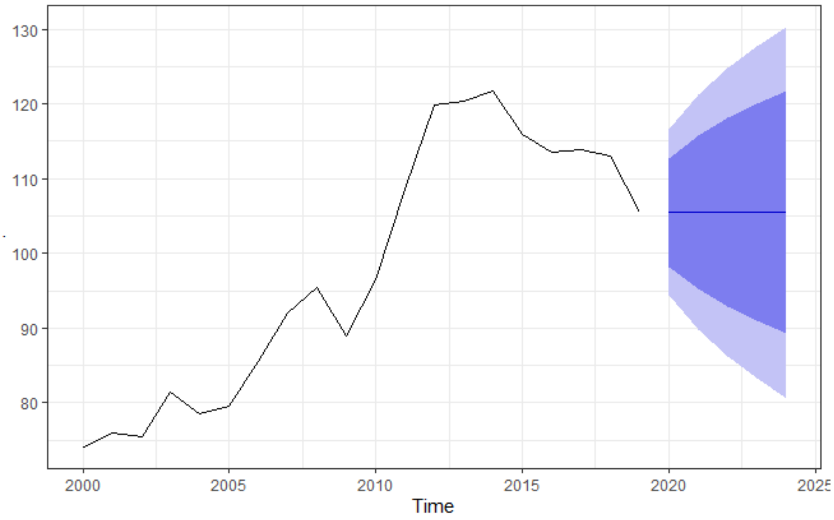


Figure 3.3.1.2 - Forecast Japan, imports

Unlike the development of the Chinese LNG imports, Japan's have been fluctuating far more in the past decade. While having a sharp increase between 2010 and 2012, they have been on a slight downward trend since 2014. This results in a far more conservative forecast, with a completely level mean projection. Nevertheless, due to our previous justifications for a global demand increase for LNG, we will still be using the forecast's upper projections for our analysis of demand change. Unlike China's projections of up to above 100% increase in imports over five years, the Japanese projections reaches a max at just south of 30%.

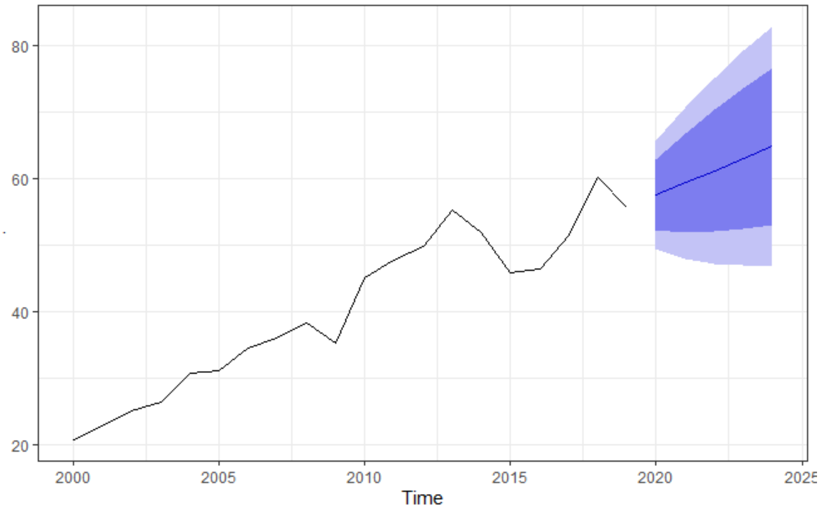


Figure 3.3.1.3 - Forecast South Korea, imports

South Korea’s imports the last two decades have had a steady increase, similarly to China, with some minor fluctuations. The forecast itself shows a steady increase in import volume, though not as sharp, with a mean projection of between 15% and 20% increase. Similarly to China and Japan, the thesis operates under and assumption of a solid increase in demand over the coming years and will continue operating with the higher end of the estimates, using the mean projection as the floor of our estimates.

3.3.2 Forecasting exporter’s domestic consumption

Alongside the demand forecasts for the importing countries, an estimation of domestic demand for the exporting countries, Norway and Russia was made. Since both countries are net exporters and will be supplying their own demand, total consumption will be used.

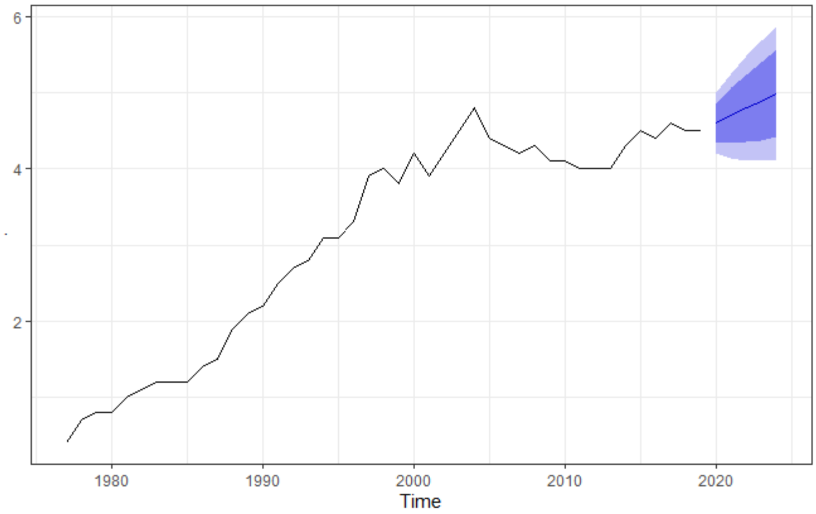


Figure 3.3.2.1 - Forecast Norway, consumption

Since these forecasts are for natural gas consumption and not LNG imports, there is more available data to base them on. This should hopefully increase the accuracy of the forecasts. While Norway is a big producer of natural gas, they consume very little of it themselves, and the numbers are relatively small. Given the previous assumptions of increased global demand for natural gas, especially in the shipping industry, the upper projections will still be used as LNG will have increased usage in ports and Norway should see more shipping traffic with a more active Northern Sea Route.

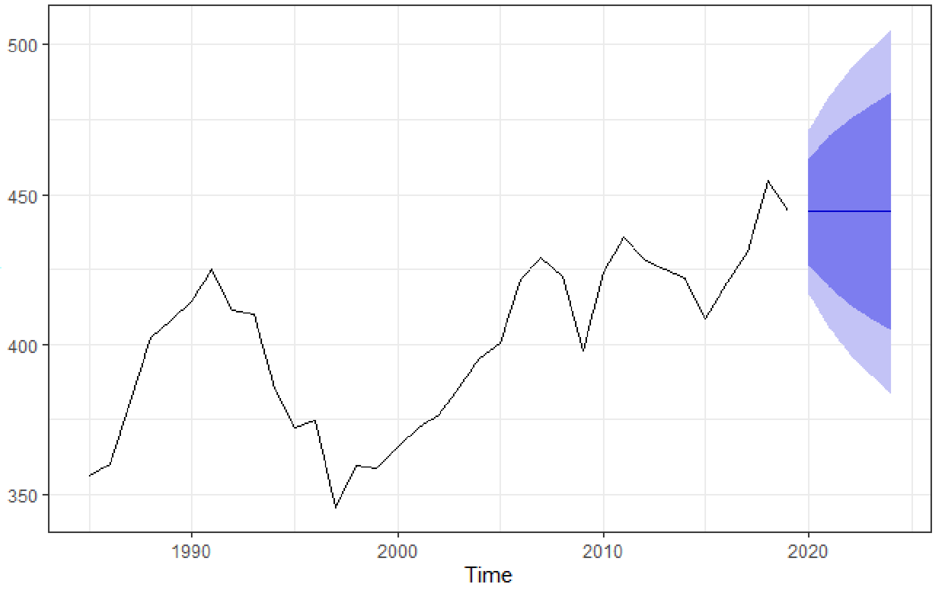


Figure 3.3.2.2 - Forecast Russia consumption

Russia’s consumption is similar to Japan’s imports. While it has increased overall, there have been frequent fluctuations, and the forecast’s mean predicts no increases or decreases in consumption. Following the same logic as the importers and Norway, the assumption of increased LNG usage still stands and the higher projections will be used.

After generating the consumption data for the two countries, it was paired together with the corresponding forecasts (mean, upper 80%, upper 95%) of demand in China, Japan, and South Korea in a single data frame. Since this analysis is mainly based on import demand, the DICoR(1) and DIR(2) models were applied to the new data. Both the models constructed for the complete set and the models for each country were applied, overall eight in total for the appropriate data. Effectively, the DICoR(1) model will show demand and supply changes, by way of less willingness to export, while the DIR(2) model will show just demand increase.

4. Results and preliminary discussion

4.1 Complete Dataset

The following tables show the import estimates for each country's imports from both Norway and Russia, using the models developed with the combined dataset for all countries. Each model is named by the parameter coefficients included in the model. D signals distance between the countries, I signify importer's total imports, Co is exporter's consumption, and R signifies exporter's Natural Gas Reserves. In other words the DICoR(1) model uses all parameters, while the DR(3) model only uses distance and reserves. All estimates are in billion cubic meters.

Projected Norwegian Exports by Model

	DICoR(1)	*DIR(2)*	*DR(3)*	*DCoR(4)*
China	4.3555	3.9939	3.3380	3.7382
Japan	7.0414	6.6711	4.5695	5.0235
Korea	2.9145	2.4765	3.7885	4.2084

Table 4.1.1 – Norwegian estimates, complete dataset

Projected Russian Exports by Model

	DICoR(1)	*DIR(2)*	*DR(3)*	*DCoR(4)*
China	18.2990	18.5026	17.7749	17.5834
Japan	20.6883	20.8944	18.7295	18.5796
Korea	17.0032	17.1249	18.3610	18.1950

Table 4.1.2 - Russian estimates, complete dataset

The biggest issues here are with models 3 and 4. While they give a look into the differences between the expected imports from Norway and Russia for each respective country, they are not helpful in comparing the different imports from a single exporter. This is caused by the models only differentiating from each other based on distance when predicting import volumes. While models with just these combinations of parameters can be helpful when calculated from the isolated importer sets, they only tell us the difference in distance from the exporter to the importers when compared. Therefore, the most accurate estimates of these models should be from the first two models, DICoR and DIR. The difference between the models, the exporters consumption of natural gas, is well demonstrated by Norway estimates, with its low domestic usage of gas, having overall higher export numbers when that is accounted for. This is a logical outcome as Norway will be able to export a larger portion of their reserves since they do not rely on its consumption domestically.

4.2 Datasets subset by importer

In the following tables we have the results from the models crafted with separate datasets for each importing country:

Projected Norwegian Exports by Model

	DICoR(1)	*DIR(2)*	*DR(3)*	*DCoR(4)*
China	4.9526	4.6395	2.4536	2.7603
Japan	8.7370	6.7541	7.6797	8.3130
Korea	2.7399	2.3404	2.1111	2.4996

Table 4.2.1 - Norwegian estimates, country subsets

Projected Russian Exports by Model

	DICoR(1)	*DIR(2)*	*DR(3)*	*DCoR(4)*
China	14.8695	14.8739	12.7704	12.7607
Japan	19.7476	19.2203	20.1424	19.3256
Korea	23.1987	23.1339	22.8595	22.9130

Table 4.2.2 - Russian estimates, country subsets

Since these models are developed individually from each other, the DR(3) and DCoR(4) models should be more open for comparison between importers. However, as noted during the preliminary analysis, these two models that are not using total imports (I) as a parameter struggles scaling up their projected imports for China, as it had a larger increase in volume for

2019 than Japan and South Korea. This issue, while especially pronounced, was not unique to these models with China, when compared to the other results as the total imports was not considered significant in any model, thereby leaving none of the models equipped to deal with a large increase in total import volume.

Overall, these individual models should be considered less accurate than the models based on the combined dataset, due to lower significance in models developed. Worth noting is the South Korean projections for imports from Russia far exceeding the estimates from the complete dataset analysis. This may be due to South Korea not importing abnormally large volumes from Australia, unlike China and Japan, providing a stronger correlation between import and reserves, thereby increasing the Russian estimates significantly.

4.3 Comparison with actual values

With our estimates calculated we can now compare with the actual values of LNG trade between the countries for the last year. While Russia had some documented trade with each importer in 2019, Norway did not have sufficiently high exports to Japan and Korea to be documented in the latest annual report from BP. However, Norway's exports to these countries in 2018 was documented in the previous report, and for the purposes of this analysis, these numbers will be used in replacement. According to the preliminary evaluation of the results, the estimates of the DICoR(1) model developed with the complete dataset will be used as the representatives for the estimates.

DESTINATION	ORIGIN	IMPORT OD	DICOR(1)
CHINA	Norway	0.0941	4.3555
CHINA	Russia	3.4489	18.2990
JAPAN	Norway	0.0861	7.0414
JAPAN	Russia	8.7181	20.6883
KOREA	Norway	0.0877	2.9145
KOREA	Russia	3.0791	17.0032

Table 4.3.1 - Estimates and actual values

This comparison indicates a large increase in trade potential between these nations when the LNG trade along the Northern Sea Route has been properly established. Overall, the model estimates a massive increase in trade volume, in particular between from Russia to China and South Korea, and between Norway and Japan. As the prices are converging, price levels in Asia should be at similar levels as in Europe leaving no extra incentive to intensify trade to Asia beyond what is estimated from a logistics standpoint. (Enerdata, 2018)

It is important to note that the estimates given are based on total volume for a year, and the Northern Sea Route is not operational year-round. So for these estimates to be realized, the trades must take place while the route is traversable. Without considering external factors and depending on seasonal demand, the actual yearly trade volumes for most of these relationships will likely be reduced by 50-70%, meaning the Japanese volume from Russia can be deemed representative.

External factors like Chinese investments in Sabetta, can end up pushing the trade volumes towards the full year estimates. (Staalesen, 2016) Due to the Russian and Chinese collaborations, the import prices of Russian LNG to China will presumedly be below market price, and China is likely to take advantage of such a case.

Additionally, much of Russia's petroleum reservoirs are geographically hard to export without the use of the sea route, as pipelines are costly at such distances. Russia also has incentives to establish strong trade relationships with the Asian markets, due to geopolitical conflict with the West, increasing the possibility for them to make price concessions in order to establish themselves. (Astrasheuskaya, 2019) Norway's gas industry is less likely to make such concessions due to strong political relations with their main trade partners in Europe, and Russia focusing on other markets increases the demand for Norwegian petroleum in the region. This could allow Norway and Russia to focus on separate markets without stepping on each other's toes which would be mutually beneficial for both countries. If this is the case, the Norwegian export levels are unlikely to see a big increase, while Russia will look more towards Asia both due to geography and geopolitics pushing their numbers upwards.

Increases in supply from Norway and Russia will likely cause reductions in supply from the Middle East, as the distances are similar. Russia and Qatar both have massive reserves and are very similar from the perspective of this analysis, so an increase for one of them is likely to balance out by a reduction for the other. Lastly, seeing as some supply will be moving out of Europe and into Asia, there will likely be a small shift in prices, increasing the prices in Europe while reducing them in Asia.

4.3.1 Results of sensitivity to demand for exporter and importer

When estimating with demand increases, we got three sets of tables containing estimates per importer. The sets consists of four models each: Both applicable versions of DICoR(1) and DIR(2) for each country. The tables produced estimates for both Norway and Russia for each model, resulting in a total of 8 estimates per projected value of demand. C, J, and K at the end of model names indicates that the model was developed using Chinese, Japanese, and Korean datasets, respectively.

Chinese Estimates with demand changes

Total Imports	Norway DIRC	Russia DIRC	Norway DICoRC	Russia DICoRC	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
102.35	5.92	16.16	6.24	15.92	5.19	19.70	5.51	19.11
121.37	7.32	17.55	7.63	17.27	6.48	20.99	6.76	20.31
142.08	8.83	19.06	9.15	18.75	7.89	22.40	8.13	21.62
164.22	10.45	20.68	10.77	20.35	9.39	23.90	9.59	23.05
187.63	12.16	22.40	12.49	22.04	10.98	25.49	11.13	24.56

Table 4.3.1.1 - Chinese estimates, sensitivity analysis

Japanese Estimates with demand changes

Total Imports	Norway DIRJ	Russia DIRJ	Norway DICoRJ	Russia DICoRJ	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
112.77	7.59	20.06	8.35	18.78	7.17	21.39	7.52	20.82
115.78	7.94	20.41	8.18	18.51	7.37	21.59	7.71	20.96
118.09	8.21	20.68	8.06	18.31	7.53	21.75	7.86	21.06
120.03	8.43	20.90	7.95	18.14	7.66	21.88	7.99	21.15
121.75	8.63	21.10	7.86	17.99	7.78	22.00	8.10	21.23

Table 4.3.1.2 - Japanese estimates, sensitivity analysis

Korean Estimates with demand changes

Total Imports	Norway DIRK	Russia DIRK	Norway DICoRK	Russia DICoRK	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
62.71	2.94	23.73	3.36	23.51	2.96	17.61	3.38	17.13
66.74	3.28	24.07	3.71	23.80	3.23	17.88	3.64	17.33
70.25	3.57	24.37	4.02	24.07	3.47	18.12	3.87	17.51
73.51	3.85	24.64	4.30	24.32	3.69	18.34	4.09	17.69
76.59	4.11	24.90	4.57	24.56	3.90	18.55	4.29	17.86

Table 4.3.1.3 - Korean estimates, sensitivity analysis

These results show the supply effect of both importers and exporters following their upper.80 forecasts for import demand and domestic consumption. These estimates follow the same patterns as previously established, with a steady increase alongside increases import demand, with one notable exception. For the DICoRJ(1) model, both Norway's and Russia's forecasted increases in domestic consumption has a larger effect on the estimate overall, ultimately causing the import estimates to decrease from these countries as the import demand for Japan increases. Otherwise, we see the previously noted balance between the models, where Norway's exports increases when domestic consumption is included, while the opposite is true for Russia.

While these estimates are created with a multitude of different models, the preliminary analysis of the models alongside the evaluations of the final estimates have established that the DICoR(1) model created with all datasets should be the most accurate for both Norway and Russia. Therefore, the main focus of the sensitivity analysis for demand should be on the estimates provided by said model. Similarly to the results of the initial model, the actual volumes would likely be significantly lower due to the limited window the route is operational, and the degree of this reduction depends on trade agreements and seasonal demand changes.

5. Shortcomings of the analysis

5.1 Lack of available data

The main issue during this analysis, has been a lack of data. While total imports, consumption, production, etc. have generally been readily available, neither monthly/quarterly data – to better adjust for seasonality – and yearly breakdowns of LNG trade volume between specific actors were available in big quantities. The best source for LNG trade data that was available for free online was BP's annual report, and while it did include historical data for the separate countries' yearly totals of natural gas figures, it only had trade breakdowns for a single year. Furthermore, after a new annual report has been released, the previous reports are now longer easily available from BP's web resources. While the pdfs of the actual reports were easily obtained for the previous years, the excel files containing the datasets with all the breakdowns were not, and only three previous editions' full datasets were ultimately procured. This led to a lack of data to conduct proper analysis on which was especially troublesome during the analysis of the individual countries and turned out way less accurate than intended.

Given more extensive data, the individual country analysis should turn out more accurate than an overall model. Amongst other things, it would have opened up for autoregression, which would help remedy the issues the model ran into with Australia, which by all included parameters exported way above expectations to China and Japan. However, an autoregressive model would bring similar problems as using total exports – which we deliberately avoided – making the model unsuitable for predicting the true potential of a route, or a newly established one. One potential solution could be simply excluding the biggest outliers, mainly Australia with regard to China and Japan. This would be a more acceptable decision to make if the analysis was not already suffering from a limited dataset. With seasonal data the model could also adjust better for the route not being open all year long, with breakdowns based on actual import data instead to decide the yearly import totals from each exporter.

5.2 Distance inflexibility

When creating the datasets for the models, the LNG trade breakdowns only provided numbers for countries as a whole. For large countries like China, Australia, and especially Russia, –

given its important role in the overall analysis – this distance can potentially be very unrepresentative for the actual trade taking place. While the selection of certain ports were based on qualitative assessments, they were not the only options and choosing differently could have a large impact on the final results. If the analysis was to be repeated, with more extensive data available, the models and calculations could instead be based on LNG plant to port, with their corresponding capacity and distances, avoiding grouping up all data for geographically massive countries into a single distance. Another way this could have been remedied for the estimation of Norway's and Russia's total imports, is to use two different distances, one for the usage of the Northern Sea Route and one for the traditional route through the Suez Canal, averaging them out based on the portion of the year the route is open.

5.3 Training set and test set split

Another possibility which could have remedied some of the issues, especially with the individual country models, is the way the test and training data was split. For this analysis, the dataset was split based on year instead of using a random. This was particularly challenging for the Chinese model, as the difference in imports was much larger in 2019. The other side of this issue is that with such a limited dataset, the model could have changed drastically based on how the random sampling ended up, even with stipulation of i.e. 75% of the each country's datapoints ending up in the training set and 25% into the test set.

5.4 Ethical concerns

While not a direct concern with the analysis itself, ethical factors, particularly in relation to climate change could impact the actual outcome of LNG trade along the Northern Sea Route. The Arctic is a very precarious region and the environmental effects of the ice melting can have huge consequences for both global temperatures and local fauna. While shipping through the shorter distances of the NSR reduces the overall emissions of voyages between Northern Europe and East Asia, the adverse effect in disrupting the ice coverage can nullify or exceed the effects of said emission reductions. On the other hand, the melting of Arctic ice might be considered unavoidable, and thus reduction of emissions by utilizing the opportunity given may be argued to be the morally correct choice.

6. Conclusions

The thesis has attempted to show how the effect of distance on LNG imports, and particularly how the increased utilization of the Northern Sea Route would effect LNG trade. The main aim of the paper is to gauge how much LNG two large natural gas producers, Norway and Russia, should realistically export to three large importers, China, Japan, and South Korea, when the distance between them is shortened as the Arctic ice melts away. In addition to distance, the analysis determined that the exporter's reserves, their domestic consumption, as well the importer's total LNG demand were the best predictors for imports.

DESTINATION	ORIGIN	IMPORT OD	DICOR(1)
CHINA	Norway	0.0941	4.3555
CHINA	Russia	3.4489	18.2990
JAPAN	Norway	0.0861	7.0414
JAPAN	Russia	8.7181	20.6883
KOREA	Norway	0.0877	2.9145
KOREA	Russia	3.0791	17.0032

Table 4.3.1 - Estimates and actual values

In addition to the results of the model itself, the estimates will need to be adjusted for how much of the year the Northern Sea Route is traversable and other political factors that could impact the supply patterns. Depending on the vessels traversing the route, and the climate change trajectory, this number can be reduced by up to 75% assuming an open market.

	PC3		*PC6*		*OW*	
RCP4.5	Avg	σ	Avg	σ	Avg	σ
2011-2030	111	*18*	98	*26*	81	*27*
RCP6.0	Avg	σ	Avg	σ	Avg	σ
2011-2030	110	*18*	99	*24*	85	*26*
RCP8.5	Avg	σ	Avg	σ	Avg	σ
2011-2030	118	*11*	109	*20*	97	*26*

Table 6.1 - Projected annual accessibility, NSR (Stephenson et al., 2013)

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8. Appendix

8.1 – Data and Literature

Complete regional estimates for accessibility in the Northern Sea Route (Stephenson et al., 2013)

Region	*Current Navigation Season*	*Standard Deviation*	*Mid-century season increase*	*Late-century season increase*
Kara Sea	>120 days	0-10 days	+9	+10
Chukchi Sea	>120 days	0-10 days	+9	+10
Laptev Sea	95-100 days	~25-40 days	+7	+12
East Siberian	~95-120 days	~25-40 days	+7	+12
Vilkitsky Strait	95-105 days	~40 days	+4	+5
New Siberian Islands	~70-80 days	~40-45 days	+4	+5

Region	*Current Navigation Season*	*Standard Deviation*	*Mid-century season increase*	*Late-century season increase*
Chukchi	~110-120 days	~0-17 days	+15	+19
Kara Sea	~100-120 days	~3-20 days	+15	+19
Laptev Sea	~75-90 days	~35-43 days	+9	+21
Vilkitsky Strait	~85-90 days	~45-50 days	+10	+13

New Siberian Islands	~45-60 days	~40-50 days	+9	+21

Region	*Current Navigation Season*	*Standard Deviation*	*Mid-century season increase*	*Late-century season increase*
Kara Sea	~90-120 days	unspecified	+20	+28
Chukchi	~110-120	unspecified	+20	+28
Laptev Sea	~35-65	40	+12	+30
New Siberian Islands	~35-100	40	+12	+30
Vilkitsky Strait	unspecified	40-48	+15	+24

8.2 Methodology

Forecast levels for mean and upper levels of forecasts

Projections for China’s LNG demand

Mean	Upper.80	Upper.95
96.1	102.34	105.65
107.4	121.37	128.76
118.7	142.07	154.45
130.0	164.22	182.33
141.3	187.63	212.16

Projections for Japan’s LNG demand

Mean	Upper.80	Upper.95
105.5	112.76	116.61
105.5	115.77	121.21
105.5	118.08	124.74
105.5	120.03	127.72
105.5	121.74	130.35

Projections for Korea’s LNG demand

Mean	Upper.80	Upper.95
57.44	62.72	65.50
59.28	66.74	70.68
61.12	70.25	75.09
62.96	73.51	79.09
64.81	76.59	82.83

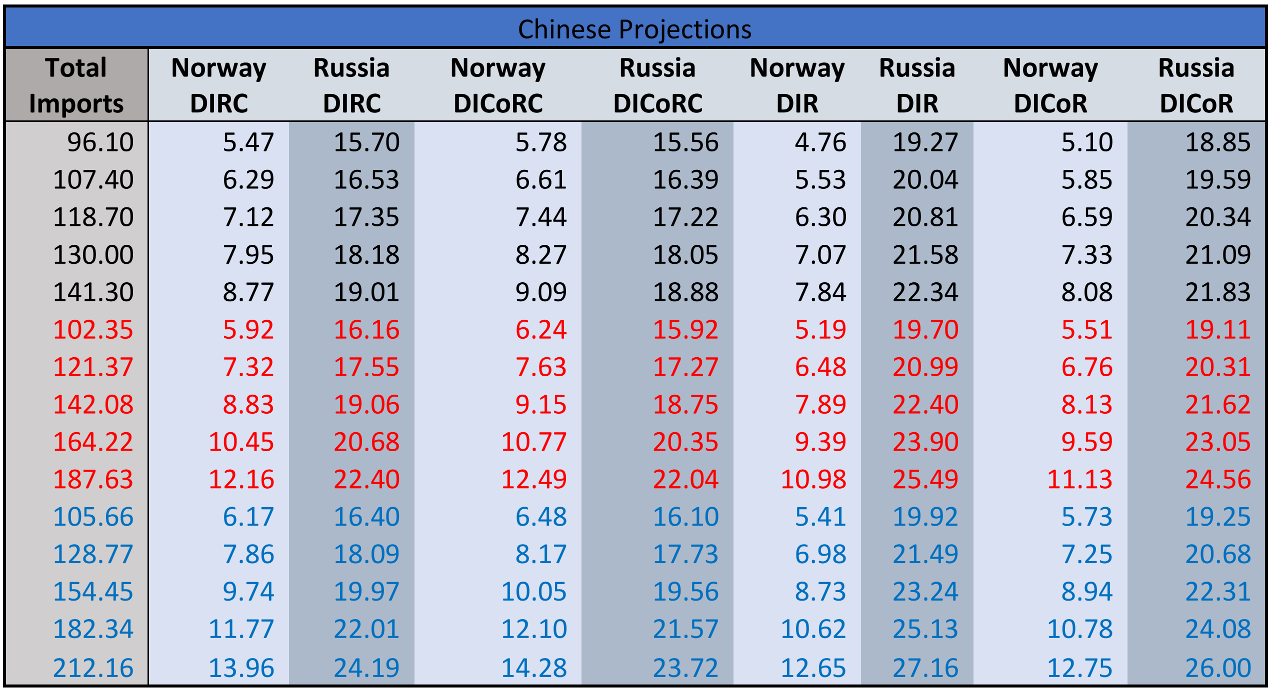
Projection for Norway’s domestic natural gas consumption

Mean	**Upper.80**	**Upper.95**
4.59	4.85	4.99
4.69	5.05	5.25
4.79	5.24	5.47
4.89	5.40	5.67
4.98	5.56	5.86

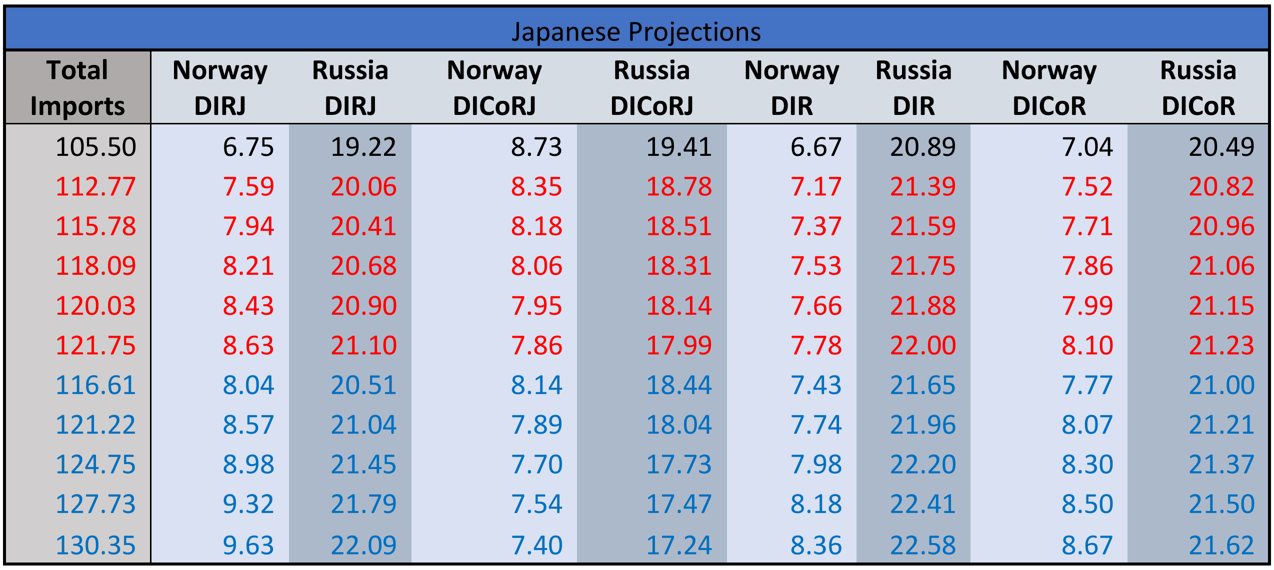
Projections for Russia’s domestic natural gas consumption

Mean	**Upper.80**	**Upper.95**
444.3	462.10	471.52
444.3	469.48	482.80
444.3	475.14	491.46
444.3	479.91	498.76
444.3	484.11	505.18

Complete sensitivity analysis for mean and upper levels of forecast



Chinese Projections								
Total Imports	Norway DIRC	Russia DIRC	Norway DICoRC	Russia DICoRC	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
96.10	5.47	15.70	5.78	15.56	4.76	19.27	5.10	18.85
107.40	6.29	16.53	6.61	16.39	5.53	20.04	5.85	19.59
118.70	7.12	17.35	7.44	17.22	6.30	20.81	6.59	20.34
130.00	7.95	18.18	8.27	18.05	7.07	21.58	7.33	21.09
141.30	8.77	19.01	9.09	18.88	7.84	22.34	8.08	21.83
102.35	5.92	16.16	6.24	15.92	5.19	19.70	5.51	19.11
121.37	7.32	17.55	7.63	17.27	6.48	20.99	6.76	20.31
142.08	8.83	19.06	9.15	18.75	7.89	22.40	8.13	21.62
164.22	10.45	20.68	10.77	20.35	9.39	23.90	9.59	23.05
187.63	12.16	22.40	12.49	22.04	10.98	25.49	11.13	24.56
105.66	6.17	16.40	6.48	16.10	5.41	19.92	5.73	19.25
128.77	7.86	18.09	8.17	17.73	6.98	21.49	7.25	20.68
154.45	9.74	19.97	10.05	19.56	8.73	23.24	8.94	22.31
182.34	11.77	22.01	12.10	21.57	10.62	25.13	10.78	24.08
212.16	13.96	24.19	14.28	23.72	12.65	27.16	12.75	26.00



Japanese Projections								
Total Imports	Norway DIRJ	Russia DIRJ	Norway DICoRJ	Russia DICoRJ	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
105.50	6.75	19.22	8.73	19.41	6.67	20.89	7.04	20.49
112.77	7.59	20.06	8.35	18.78	7.17	21.39	7.52	20.82
115.78	7.94	20.41	8.18	18.51	7.37	21.59	7.71	20.96
118.09	8.21	20.68	8.06	18.31	7.53	21.75	7.86	21.06
120.03	8.43	20.90	7.95	18.14	7.66	21.88	7.99	21.15
121.75	8.63	21.10	7.86	17.99	7.78	22.00	8.10	21.23
116.61	8.04	20.51	8.14	18.44	7.43	21.65	7.77	21.00
121.22	8.57	21.04	7.89	18.04	7.74	21.96	8.07	21.21
124.75	8.98	21.45	7.70	17.73	7.98	22.20	8.30	21.37
127.73	9.32	21.79	7.54	17.47	8.18	22.41	8.50	21.50
130.35	9.63	22.09	7.40	17.24	8.36	22.58	8.67	21.62

Korean Projections								
Total Imports	Norway DIRK	Russia DIRK	Norway DICoRK	Russia DICoRK	Norway DIR	Russia DIR	Norway DICoR	Russia DICoR
57.44	2.49	23.29	2.90	23.18	2.60	17.25	3.03	16.93
59.28	2.65	23.44	3.06	23.34	2.73	17.37	3.15	17.05
61.13	2.80	23.60	3.22	23.50	2.85	17.50	3.27	17.17
62.97	2.96	23.75	3.38	23.66	2.98	17.62	3.40	17.29
64.81	3.11	23.91	3.54	23.83	3.10	17.75	3.52	17.41
62.71	2.94	23.73	3.36	23.51	2.96	17.61	3.38	17.13
66.74	3.28	24.07	3.71	23.80	3.23	17.88	3.64	17.33
70.25	3.57	24.37	4.02	24.07	3.47	18.12	3.87	17.51
73.51	3.85	24.64	4.30	24.32	3.69	18.34	4.09	17.69
76.59	4.11	24.90	4.57	24.56	3.90	18.55	4.29	17.86
65.50	3.17	23.97	3.60	23.68	3.15	17.80	3.56	17.23
70.68	3.61	24.40	4.05	24.05	3.50	18.15	3.90	17.48
75.09	3.98	24.77	4.44	24.37	3.80	18.45	4.19	17.70
79.09	4.32	25.11	4.79	24.67	4.07	18.72	4.45	17.90
82.83	4.63	25.43	5.11	24.95	4.33	18.97	4.70	18.09