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Research on the economic viability of Mega container ship

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RESEARCH ON THE ECONOMIC VIABILITY OF MEGA CONTAINER SHIPS

By

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views and are not necessarily endorsed by the University.

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(Date): 30th June 2020

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ABSTRACT

Title of dissertation: **RESEARCH ON THE ECONOMIC VIABILITY OF MEGA CONTAINERSHIPS**

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The size of container ships has been gradually increasing for the last few decades, which is probably the most significant development of liner shipping and it should be analyzed from another perspective in light of recent events. This dissertation is a study of the economic viability of mega container ships under the new market condition.

This paper will first analyze the evolution of container ships and the influencing factors for increasing ship size, which involves driving factors and limiting factors. Secondly, the paper established the calculation model for container ship cost and compared the unit cost of ships of different size. Then, the paper focused on the economic implication of sulfur cap on container ships, analysis and recommendations would be given to find the optimal solution for different ship size.

The paper found that 23,000 TEU ship is still economically viable for Europe-Asian trade, incurring less daily unit cost than smaller ships. And shipping lines who operate mega ships are advised to stick to VLSFO during the pandemic to comply with sulfur cap, which is the most economical solution for now and near future.

KEYWORDS: Mega container ships, Economies of scale, Sulfur cap, Unit cost

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LIST OF ABBREVIATIONS

UN	United Nations
IMO	International Maritime Organization
M&A	Merger and Acquisition
OPEX	Operating Cost
TEU	Twenty Feet Equivalent Unit
OECD	Organization for Economic Co-operation and Development
UNCTAD	United Nations Conference on Trade and Development
VLCS	Very Large Containership
ULCS	Ultra Large Containership
LNG	Liquefied Natural Gas
LIBOR	London Interbank Offered Rate
VLSFO	Very Low Sulfur Fuel Oil
HSFO	High Sulfur Fuel Oil

Chapter 1 Introduction

1.1 Research Background

Over the past few years, the world shipping industry had witnessed significant increase in containership size, most of which happened on Asia-Europe trade route. Major shipping lines are becoming much bigger through merger and acquisitions, giving them sufficient financial power to order bigger vessels with cutting-edge technology so as to exploit the economies of scale which were clearly defined and analyzed by maritime scholars.

Back in 2011, the biggest containership in operation has the capacity of roughly 14,000 TEU, which were owned by China Shipping. 9 years has passed, the biggest containership now is the M/V “MSC Gülsün” which can carry at most 2,3356 TEU. However, this record is not going to last long, because HMM is expected to deploy 12 2,4000 TEU ships on Asia-Europe route in April in conjunction with the beginning of its membership in THE alliance. Apart from HMM and MSC, Hapag-Lloyd, CMA CGM, COSCO, Evergreen and ONE also have plans to build 2,3000+ TEU ships. However, Maersk, the largest shipping line, promised to refrain from ordering new ships in the next two years and its CEO questioned the cost advantage of these 2,3000 TEU ships under current market condition, because nowadays shipping line cannot fully load the ship to exploit economies of scale and only a few ports could accommodate these “giants”.

Addition to these problems, shipping lines have to comply to the global Sulfur cap coming into effect this year. Various options are chosen by different companies, each indicates different reasoning and benefit. Thus, it is quite important to analyze the economic viability of 2,3000+ TEU ship under current market condition which contains several new features did not covered by previous studies.

1.2 Research Purpose

The main purpose of this dissertation is to establish a model to analyze the economic viability of mega containerships and the influencing factors for it, base on which the suggestions would be given so as to facilitate the liner company decision-making. This study could also improve the operational excellence, cost saving as well as the regulation compliance of the shipping lines.

1. To identify the economic benefits or disadvantages of mega containerships

2. To provide guidance for containership cost analysis and saving

3. To identify the influencing factors of the mega containership economic viability

4. To comply with global Sulfur cap in an economical way

1.3 Research Methodology

The methods adopted by this paper include qualitative analysis and quantitative analysis. The former refers to the analysis of the influencing factors for ever increasing container ship sizes while the latter is about constructing Microsoft Excel model for calculating the cost of mega-ships under new conditions. Data used for these analyses will be collected from primary sources (such as UN, IMO, shipping lines and manufacturers) and secondary sources (research papers, journal articles and market report).

Chapter 2 Literature Review

2.1 The Economies of Scale of Liner Shipping

There are plenty of researches on the economic viability of mega containerships by Scholars and shipping lines. This paper adopts the definition gave by International Transport Forum who deems ships with a capacity of at least 18,000TEUs as mega-ships (Merk, 2018).

Wang Xuefeng (2006) assessed the economies of scale existing in the container shipping sector by setting minimizing shipping cost and inventory cost as two separate objective and constructing a two-objective model. Li Jing (2005) discussed the economies of scale from two perspectives, i.e. container ship and liner shipping company. He argued that economy of scale is the basic motive for increasing the size of container ships. Shipping alliance and M&A in the market represents the exploitation of economies of scale on the company level. Guo Yonghong (2000) examined the economies of scale of container shipping by constructing mathematical model for container transport cost. Yan Jiaming (2012) found that mega-ships tend to be more profitable than smaller ones and can better exploit the economies of scale when the economy is growing rapidly. William Murray (2016) analyzed the cost structure of container ship and found that as vessel capacity increases, the construction cost per TEU clearly decreases. It is also pointed out that marginal decrease in cost savings as ship size increases.

Kevin Cullinane and Mahim Khanna (2000) constructed mathematical model to quantify the economies of scale in large container vessels, found that the voyage time and the voyage are the two causal factors which have the most significant effect on costs. The paper argued that deploying mega-ship can only offer short term advantage, because it does not take long for its competitors to following this strategy. Additionally, the research on the economic viability of mega container ships was done by adopting a non-zero two-person game with two specific strategies based on different service network configurations for different ship sizes, which concluded that mega-ships are competitive in all scenarios on Asia-Europe trade routes while it is only profitable in Asia-North America market provided the freight rates and feeder cost are low（Akio Imai et al., 2006）. Chen Feier (2008) analyzed the economic viability of mega containerships in different service networks by building the ship cost model and routing model. She concluded that mega-ships remain competitive in Asia-Europe trade, but it can only be economically viable in Asia-North America trade provided the feeder costs are low.

2.2 The Influencing Factors and Implications of Mega Ships

Weng Yubo (2018) examined the main influencing factors of economic value for megaships, which are cargo volume, fleet capacity, vessel price, freight rate, OPEX and financing method. He also found that Megaship's profitability is more sensitive to changes of freight rates, fuel price, loading rate, port charges and interest rate, comparing with smaller ships. Wu Honggao (2012) found there are many technical aspects which limit the growth of container ship sizes. Mega-ships have low maneuverability, with longer time for turning circles and stopping distance, which means it is more difficult to operate than smaller ones. This increase the job difficulty and pressure for crew who are required to be extra cautious when navigating in restricted waters, for mega-ships are more likely to have accident.

Rodrigue (2020) studied the evolution of the container ship which were divided into several stages and Olaf Merk (2018) examined the pressure that mega-ships brought to the port facilities and infrastructure. Mega-ships have also generated industry consolidation and more intense co-operation via alliance which lead to a concentration of regional port systems. The study also argued that increase of ship size on one trade route has cascading effects across all trade routes, squeezing out the smaller ships. Rahul Kapoor (2016) argued that the cost savings achieved by deploying bigger ships might be partially offset by the additional cost incurred by port and terminals. Though Shipping lines obtained sea transport cost savings for themselves (and cargo owners) by deploying bigger ships, they generated higher costs in other parts of the supply chain. The scale economy from mega-ships only work for the total supply chain of terminals can increase productivity in line with increase in ship size. Jost Bergmann (2014) examined the limitations of ship capacity growth, which are imposed by port facilities and infrastructures, such as quay length, crane outreach as well as turing basin diameter. Sherif Helmy and Ahmed Shrabia (2016) studied the pros, cons and the implications of mega container ships. Mega vessels help to bring down the coast of container shipping but also raising concerns among vessel operators, insurers. They predicted that further increase in ship size could result in negative impacts and even crisis.

Jong Sil Baik (2017) found that mega-ships require adaptations of port infrastructure, container handling equipment and create larger peaks in container traffic in ports, with wide ranging impacts. Martin Stopford (2002) pointed out that tanker size reached its peak in 1970s and then went down due to change of commercial environment, this process could be repeated by container ships. He argued that shipper could not enjoy the savings achieved by bigger ships if there are diseconomies in other parts of the whole transport system. International Transport Forum (2015) recognized the cascading effect that would take place after ship upsizes and herd effect which tends to result in oversupply of ships in the market. The report found that a significant proportion of the cost reduction were achieved by ship upsizing up to 5,000 TEU, beyond which the reduction becomes much smaller.

Nam Kyu Park and Sang Cheol Suh (2019) examined the size of port facilities which are able to accommodate mega container ships, and found that larger ships wait for longer in port than smaller ships due to port restrictions. Guan Changqian, Ahalom Shmuel and Yu Jun (2017) used multiple regression model to analyze the relationship between ship size and port time, and found that one per cent growth in vessel size would raise port time by 2.9 per cent. McKinsey (2018) predicted that 50,000 TEU ship will be put into operation in 2066 and created two scenarios in 2066 for container trade. The study also provided several suggestions to prepare for the uncertain future of container shipping. Xiang, Zhu and Jin (2014) studied the driving factors and limiting factors for the development of mega container ships, and predicted that container ship size will continue to growth after some technological breakthrough.

2.3 The Analysis of Global Sulfur Cap

The global sulfur cap coming into effect this year changed liner shipping market significantly, the economic implications for which have to be examined if we want to value the economic viability of mega containerships under current market conditions. Simme Veldman, Cees Glansdrop and Robert Kok (2011) included the ship design parameters and exhaust emissions into the model for calculating ship cost, and concluded that economies of scale continue to exist for ships up to 25,000 TEU. Qian Qiang and Liu Jia (2016) estimated the additional cost caused by scrubber and its payback period and discuss whether it is economically competitive to install the scrubber on chemical tankers. Zhang Tongxu (2019) studied the countermeasures for shipping companies and examined the cost of each of them, based on which recommendations was given for relevant parties.

Though there plenty of researches and studies on mega containership, revisions and adjustments need to be made based on market changes which could nullify the previous conclusions.

1. Global Sulfur cap is expected to incur significant cost on shipping lines, which is impossible for previous studies to foresee. The cost for complying with this new regulation needs to be taken into consideration when analyzing the economic viability of mega containerships. Thus, the paper will incorporate the cost analysis of sulfur cap in chapter 5.

2. The optimal ship size has been calculated repeatedly for the past decades, most of the results were already proved wrong. Several papers concluded that the ideal ship size or the biggest size for profitable containerships is around 20,000 TEUs or even lower. However, the current market has seen ships much bigger than that and could reasonably expect that even bigger ship will be built soon. And some in the industry are questioning the economic viability of the latest type of mega container ships. Consequently, the theory of scale economy in the shipping sector and the analysis for mega containerships need to be revised and the understanding of which needs to be deepened.

Chapter 3. The Influencing Factors for Increasing Ship Size

3.1 The Evolution of Container Ships

The evolution of containerships is divided into several stages to better reflect its features and characteristics developed with new technologies and commercial environment.

Containerization started in 1950s, leading to large scale deployment of container ships, the first generation of which were either converted from bulkers or tankers. The famous "idea-X" was a converted tanker made during the second world war, many shipowners followed this strategy, because the massive production of vessels carrying supplies for allies during the war created overcapacity in bulk transport market, and the conversion was less costly than building containerships which were totally unfamiliar for the shipowners then. These "forerunner" in container shipping industry could carry around 700 TEU of containers and was equipped with cranes, for many terminals at that time did not have the capacity and facility for handling containers. Malcolm Mclean, the father of containerization, realized that containership's economic potential can only be fully utilized if the port could find a way to handle containers efficiently. He himself invested much in finding the most cost-effective way for loading and discharging containers. As the terminal operators invested increasing amount of money in container handling facilities, the first full cellular containership was introduced in 1968, which was more specialized, efficient and also faster than those converted tankers, could carry 1,100 TEU and shipboard cranes have to give way to more carrying capacity to better utilized the ship's economic benefit. Several years later, major container shipping routes became operative, such as trans-pacific routes, trans-Atlantic routes, Asian-Europe route, Asia-Oceania route and Asian-Africa route.

Container ship, like other ship types, were getting bigger after its invention. As the initiator of containerization, United States was the home to many liner companies of great renown, who were operating in the west coast and east coast of America. Thus, Panama Canal became the strategic position for liner company, through which many container ships were passing. Due to the physical limit of the canal, container ships size also reached a limit, whose draft, beam were limited by the depth of water and width of the canal. Consequently, the ship that reached the size limit of Panama Canal was defined as Panamax, with a capacity of roughly 4,000 TEU.

In late 1980s and 1990s, with the development of international commodity trade, the capacity of Panamax could no longer satisfy the increasing demand. Post-Panamax (4,000-8,000 TEU) was subsequently introduced, these ships could not go through the Panama Canal until the canal expansion project which was finished in 2016. The formation of shipping alliance in 1995 further facilitated the deployment of bigger ships. In 2005, ships with the capacity of at least 8,000 TEU became the major ship type for deep sea trade. Based on the new canal parameters, Neo-Panamax was designed and built, with the capacity of 13,000 TEU. These ships imposed new pressure for the terminal operators who had to upgrade its facilities every time the container ship upsized.

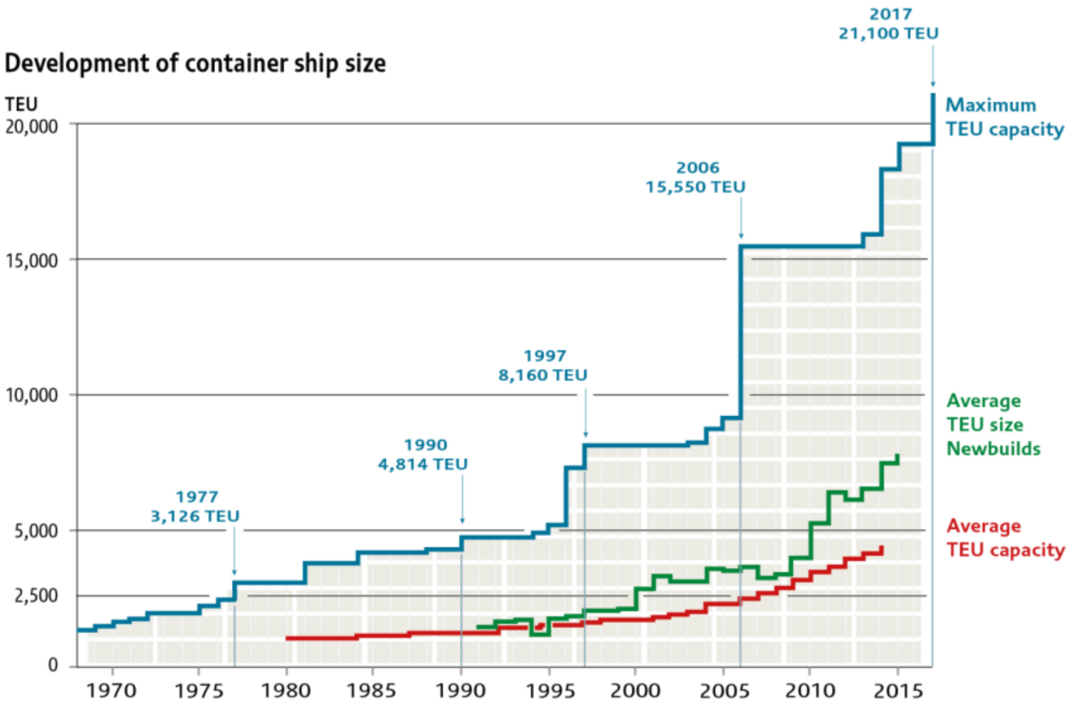

Figure 1. Development of container ship size. From “The Impact of Mega-Ships, 2015”, by International Transport Forum, OECD, 2015, p.18. Copyright 2015 by International Transport Forum, OECD.

As Figure 1 shows, the growth of container ship size has accelerated since 2000, doubling its size within just a few years. The Very Large Containership (VLCS), which can carry around 14,000 TEU, was deployed. 6 years from that, a 18,000 TEU ships was deployed and was defined as Ultra Large Containership (ULCS), based on which the containerships were still getting bigger. In order to adapt to this change, Suez Canal was also expanded in 2016. After 2017, increasing number of container ships carrying more than 20,000 TEU were deployed, indicating a further expansion of containership size. However, naval architects are still considering bigger containerships, for example, the Malacca Max, which theoretically could carry 30,000 TEU (Rodrigue, 2020).

3.2 The Driving Factors

Many factors contributed to the investment of bigger container ships, this paper will focus on the most important of which, i.e., international commodity trade growth, market consolidation, scale economies. It needs to be stressed that the following factors are to some extent interrelated, for instance, the scale economies of liner shipping give rise to the formation of shipping alliance, M&A and building of megaships (Li, 2005).

3.2.1 World Commodity Trade Growth

Trade can affect the growth of vessel size, for example, size of crude oil carrier had increased to 440,000 dwt until 1970s when the trade changed and oil traders who controlled the transport became more interested in flexibility than size, thus the size of tanker decreased (Stopford, 2002).

Growth of global commodity trade facilitates the development of mega containerships. Maritime transport demand is derived from global commodity trade, which means the former will grow as the latter grows. Since the beginning of containerization in 1950s, the world has witnessed the wide spread of the idea of free trade which gradually got adopted as policies in many countries, tariff barrier was reduced worldwide as a result. In addition, the collapse of the Soviet Union and socialist countries in eastern Europe enabled new players to join the global economic and trade system. The rise of Asian economies (such as Japan, South Korea, Taiwan) and the reform and opening up of China had created huge demand of raw materials and unprecedented amount of export of manufactures to all parts of the world. It needs to be stressed that the development of container shipping technology which could partly displayed by increasingly bigger ships also have a positive effect for trade growth.

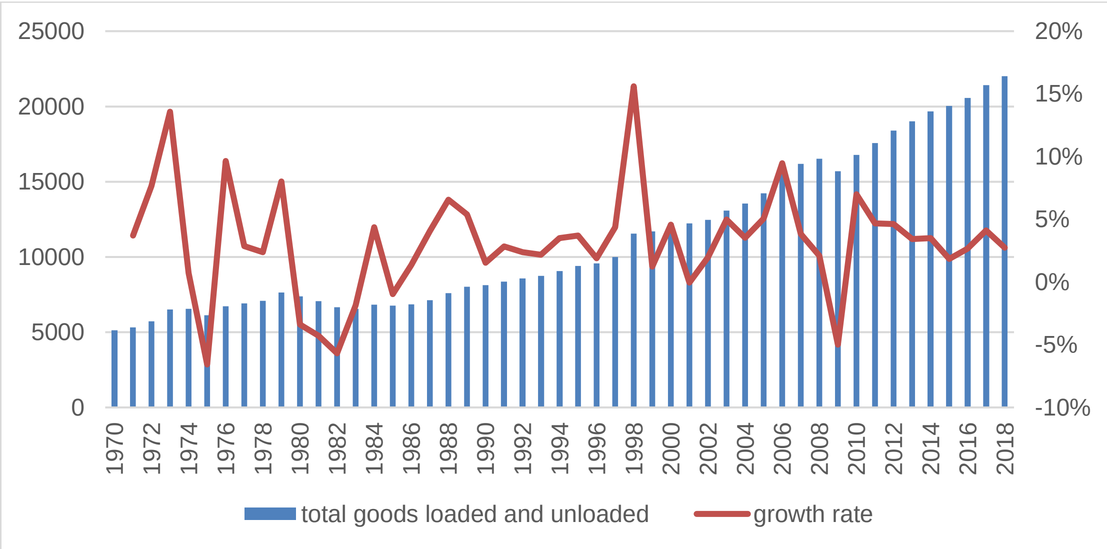

Figure 2. World seaborne trade volume (loaded and unloaded). Compiled from the database of United Nations Conference on Trade and Development (UNCTAD).

3.2.2 The Shipping Market Consolidation

The liner shipping market has been consolidated through merger & acquisition over the past few decades, especially the decade after the financial crisis. According to Alphaliner, top 10 liner companies in 2008 accounted for 26.6% of global container fleet capacity, this figure rose to 83% in 2020, further demonstrating the level of consolidation in liner shipping market. The depressed market created by weak demand and large amount of new deliveries increased the intensity of competition. Liner service is highly standardized and shipping line found it extremely hard to differentiate their service, thus lowering freight rate somehow became the one of the few options to remain competitive in the market, which put downward pressure on earnings. Another option is merger & acquisition which lead to further horizontal integration, for liner companies could enhance market control and competitiveness through resource integration and resource optimization. Generally speaking, bigger company has more recourses which put them in a better financial position to invest in mega-ships (Helmy & Shrabia, 2016).

The formation of shipping alliances also contributed to the consolidation of the market. Shipping alliance is a flexible form of co-operation, enable shipping lines to further benefit from economies of scale through employment of mega ships (Imai et al., 2006). Currently, there are three alliances in the industry: 2M alliance (Maersk, Mediterranean Shipping Company), Ocean alliance (COSCO shipping company, CMA CGM, Evergreen) and THE alliance (ONE, Hyundai, Hapag-Lloyd, YangMing), all of which provide the 81.3% of the liner shipping capacity. Number of shipping alliances has halved since 2001. Alliance members could gain better access to shippers through slot sharing agreement, which could help them attract more cargo and increase vessel utilization, leading to the investment of bigger ships.

3.2.3 The Scale Economy

The economy of scale existed in the shopping industry is arguably the most important driving factor for the development of mega containerships. the shipping scale economy means that average vessel fixed cost, unit shipbuilding cost and unit operating cost would reduce as ship size increases (Wang, 2006). The deployment of bigger ships enables shipping lines to save more unit cost which put them in a better position in the short term than their competitors who do not possess vessels of equivalent size. Thus, when one company decides to increase ship size, its competitors may follow suit (Cullinane & Khanna, 2000).

3.2.4 Technological Improvement

The technological advancement facilitates the development of megaships which were theoretically impossible in the last century. Many technological problems had to be overcome, for example, the construction of mega container ships requires thicker steel plates, making it extra difficult for wielding operation and it may lead to technological problem which endangers the safety of the ship at sea during bad weather. This was solved by the development of new materials which are resistant to corrosion, low temperature (Xiang et al., 2014). It is also reasonable to expect that the "fourth industrial revolution", which will create new materials technology, could create further upsize the mega container ship. However, the time for the fourth industrial revolution is hard to predict.

3.3 The Limiting Factors

Many limiting factors slowed down or limited the growth of containership size by making the deployment of bigger vessel less economical, some of which have troubled the industry since the beginning of containerization.

3.3.1 Port Constraints

The economic value of container ships cannot be utilized if the destination port does not have the capability to accommodate the ship. The physical constraints of ports are related to draft, beam, length and so on. Bigger ships have low maneuverability, with longer time for turning circles and stopping distance, and quay length could seriously restrict the movement of such ship (Wu, 2012). Ship beam is also a concern, which has to be compatible with the crane outreach and seaways in order for it to be properly served. Draft also must be considered, “the depth of sea channel should be adequate to safely accommodate ships with the deepest draft” (Park & Suh, 2019, p.7), many ports around the world are using dredging facilities to deepen their draft, so the ULCVs whose draft normally is 14.5 m-16 m could avoid running aground (Bergmann, 2014).

Port operational constraints need to be taken into consideration, the first of which is handling capacity. Mega container ships can create huge cargo flow for destination port, so ports are required to handle it efficiently, otherwise ship would spend too much time in port which creates significant diseconomies, because ships are only generating profits during sea voyage rather than staying in port. In another word, economies of scale that are gained at sea are lost at the port (Guan et al., 2017), for larger the ship, longer the time spent in port. Other port facilities, such as container yard and warehouses, together with IT system and inland transport are also relevant to the port operational excellence. If the local infrastructure could not transport the cargo discharged from ship to the hinterland, the scale economies of mega ships still could not be fully utilized. Thus, the development of mega ships has to be compatible with port's development, which will lead to the building of bigger port and terminals, bigger cranes, higher terminal productivity. This could result in longer handling peak time and bigger peak volume (Jong, 2017).

3.3.2 Vessel Utilization Rate

One of the assumptions for the calculation of the scale economies in liner shipping is that the vessel's carrying capacity is highly utilized (around 80%-90%). However, this assumption is hard to be met, especially during low seasons. The delivery of large number of mega ships worsen the problem of overcapacity, making it even harder to fully load the ship. The unbalanced trade also affects vessel's utilization, for instance, analysis of commodity flow for Europe-far east trade and fleet capacity, shows overdemand for westbound trade and oversupply of capacity for eastbound trade (Weng, 2018), same thing happens to trans-pacific trade. However, "trade flows will become more balanced across trade lanes as incomes converge between East Asia and developed economies, and the emerging economies in South Asia and Africa catch up" (McKinsey, 2018, p.32).

The cost advantages of container ships diminishing as utilization reduced (Kapoor, 2016), consequently, unutilized capacity ultimately leads to lower profitability, even making bigger vessel lesser economic than smaller ones. When the utilization rate is lower than 79%, a panama is more economic than a 6,000 TEU ship (Guo, 2000). "Weak trade growth and the sustained delivery of mega container ships in an overly supplied market exerted further pressure on fundamental market balance, resulting in lower freight rates in general" (UNCTAD, 2019, p.41). Consequently, the weaken market and possibly low return of mega ships might discourage shipping lines from ordering such ships.

3.3.3 Vessel's Flexibility

The increasing size of container ship limits its choice of shipping routes, for instance, mega ships are often deployed on the Europe-Asian route and call at several hub ports, the long distance and large cargo volume of this route justifies such arrangement. Since only a few hub ports could accommodate these mega container ships, feeder service is of vital importance, which of cause incur extra cost. Chen (2008) found that the competitiveness of mega ships declines as the feeder cost rises. Consequently, as container ships further upsizes which outpaces the upgrade of port facilities, the demand for feeder service would increase, possibly leading to uneconomical operation of mega ships.

In addition, the deployment of bigger ship has cascading effect (International Transport Forum & OECD, 2015). The newly built ship with bigger capacity would replace smaller ships on certain trade routes, and those ships which were being replaced will substitute vessels with even smaller capacity on other routes. Ultimately, the average capacity of vessels on all trade routes would rise. Under this scenario, many mega ships will be transferred (cascaded) to other trade routes which could not compare with Europe-Asia route in terms of distance and cargo volume, so these ships would suffer from reduced ton-mile and loses its cost advantage which could have been achieved on Europe-Far east trade. Consequently, mega ships have low flexibility and can only rely on a few routes at current stage, which limits the growth of container ship size.

3.3.4 Weakened Global Economy

When the ship is getting bigger, its utilization rate, and subsequently profitability, are becoming more sensitive to economic fluctuation (Yan, 2012). In 2019, under the impact of protectionism and unilateralism, the world economic growth continued to decline. United Nations Conference on Trade and Development (UNCTAD) estimated that the world GDP growth in 2019 declined to roughly 2.3% from 3% of previous year, which indicates a further drop comparing with 3.1% growth in 2017. The world economic growth from 1994 to 2008 averaged at 3.3%, higher than the figure of last 3 years. China’s growth has been slowing down continuously over the past few years, dropped to only 6.1% in 2019 which is partly contributed to the trade tension. However, China is still among the world's leading economies, contributing 28% to world economic growth in 2019, making it the largest contributor to world economic growth for 14 consecutive years.

The outbreak of coronavirus also seriously damaged the global economy. China was hit by the virus first, forcing it to lockdown the city of Wuhan, the strategic transport center of China. It is estimated that the Chinese GDP growth in 2020 would drop below 6% because of the virus. According to World Health Organization, up to March 12th, the virus has spread to 114 countries in the world, 118,000 people was infected. Italy was the second country to lockdown cities and many countries were also limiting international flights as well as other forms of transport. The world economy is hurting by the virus, which would have a negative effect on shipping and container ship development.

Chapter 4 The Economic Analysis of Mega Container Ships

4.1 The Assumption

In order to build a calculation model, several assumptions must be made. Firstly, the vessel in question can attract enough cargo, which means the vessel could achieve 90% utility for westbound service and 50% for eastbound service. Secondly, only fuel cost, port dues and cargo handling cost will be included for voyage cost analysis. Thirdly, the vessel will be financed 100% by bank loan, loan period is 5 years and the installment will be paid quarterly. Fourthly, the vessel in question would be operational for 350 days per year. Fifthly, annual operating cost equals to 3.5% of vessel newbuilding price.

4.2 The Capital Cost

The cost of capital is the cost for buying the ship, which is composed of depreciation and interest of loan.

Shipping lines tend to apply for loan from banks in order to finance the investment of new vessels and pay interest, because ordering new ship is extremely expensive that it is not economical or feasible for shipping lines to pay for it with their own capital. Tax is indeed a part of the capital cost, which can be reasonably reduced or even avoided, consequently, it will not be included in our discussion for simplicity. The daily capital cost can be formulated as follows,

$$CC = (OL \times (IR + MG) + P/L) / OD \qquad (4\text{-}1)$$

Where;

CC - Capital Cost

OL - Outstanding Loan

IR- LIBOR

MG - Margin

P - Principal

L - Loan Period

OD - Operating Days

4.3 The Operating Cost

Operating costs refer to the maintenance expenses needed to keep the ship seaworthy. Shipping lines need to hire crew to operate the ship, which incurs costs. In this paper, Crew wages is a general term, referring to crew wages, navigation allowance, food allowance and bonus, etc.

Maritime industry is known to be a very risky industry, many risks have to be taken into account when operating ships. Great fluctuation of freight rate creates significant commercial risk, but risk related to sea voyage can be more significant. For instances, ship might collide with other ships and may hit the rock during voyage. Shipping lines need to protect themselves from those risks and potential financial loss cause by it, consequently, they buy insurance and pay premium which is classified as operational cost.

Repair & maintenance of ships are required by classification society, insurance company and other parties for save voyage, which has to be done periodically. These activities incur additional costs for shipping lines, which is classified as operational cost.

Stores cost refers to the cost of materials used and consumed by the ship, such as equipment, spare parts, accessories, the most important of which is lubricant for main engine as well as auxiliary engine. As vessel getting older, cost of stores tends to increase, for example, the amount of spare parts required is expected to rise.

Administration cost refers to the shore-based staff wages, office rent, and administrative expenses incurred by the management personnel of the shipping company, which shall be calculated as part of operating costof vessels. Unlike tramp shipping where several staffs could operate a vessel, liner shipping requires huge amount of shore-based staff to support daily operation of even a few ships. Because every container ship is dealing with thousands of shippers who have numerous containers to ship per voyage, while tramp shipping normally only carries the cargo of only one shipper. This feature of liner shipping makes administration cost quite important.

The operating cost of the vessel tends to be kept secret by shipping lines as important commercial intelligence, so the actual data for which is hard to come by. However, it is reasonable to estimate that the annual sum of R & M, insurance, administration and store cost equals to 3.5% of the price of the ship, which is quite close to the actual data (Guo, 2000). With the rapid development of vessel technology, container ships need lesser crew nowadays, for instance, a 13,500 TEU vessel owned by Maersk only has 13 seafarers. Thus, crew cost will account for a small proportion of total operating cost in the future, which can be negligible (Wang, 2006). In this paper, we would assume that total annual operating cost equals to 3.5% of vessel price. The daily operating cost can be formulated as follows,

$$OC = (3.5\ \% \times VV) / OD \qquad (4\text{-}2)$$

Where;

OC - Daily Operating Cost

VV - Vessel Value

OD - Operating Days

4.4. The voyage cost

Voyage cost refers to the expenses incurred by the voyage of the ship.

Fuel cost, the most important part of voyage cost, refers to the sum of all fuel expenses consumed by a ship during its navigation, berthing and loading and unloading operations. The fluctuation of fuel price often heavily influences the profitability of the entire shipping line, reflecting how important fuel cost is. Port and canal charges is the sum of all expenses incurred in the port of call for its facilities and service provided, such as tonnage dues, berthing fees, dock fees, tug fees, mooring and unmooring fees, etc. The port dues of different port of call can vary significantly, which has to be taken into consideration of ship’s economic analysis. Cargo handling charges refer to the sum of all expenses incurred in the operation related to cargo handling. Canal charges is the expense incurred when passing through the Panama Canal or Suez Canal which is quite complicated to calculate. Other voyage charges are also included. The daily voyage cost can be formulated as follows,

$$VC = FC + PD + CHC \qquad (4\text{-}3)$$

Where;

VC - Daily Voyage Cost

FC - Daily Fuel Cost

PD - Daily Port Due

CHC -Daily Cargo Handling Cost

And for container ships, the daily fuel cost can be formulated as follows,

$$FC = OC \times FP \qquad (4\text{-}4)$$

Where,

OC - Daily Fuel Oil Consumption

FP - Fuel Oil Price

Fuel consumption is a function of vessel size and speed (Veldman et al., 2011). Thus, we assume that vessel's capacity and speed is related to its daily fuel consumption, and the formula for which can be formulated as follows,

$$OC = \beta + CA \times X_1 + S \times X_2 \qquad (4\text{-}5)$$

Where,

OC - Daily Fuel Oil Consumption

β - Intercept

CA - Vessel Capacity

S - Vessel Speed

X_1 - X Variable 1

X_2 - X Variable 2

Multiple liner regression would be used to calculate those variables and intercept. 106 sets of data were obtained from the database of Clarkson Research, which contains the design capacity, the service speed and the daily fuel consumption (VLSFO) of the vessel. 106 sets of data were imported into EXCEL before OC calculation formula was established in it, after that the value of intercept and X variables was given.

The results of multiple liner regression analysis are shown in Table 1, the value of β is -150.946, the values of X variable 1 and 2 are 0.004097 and 13.44745 respectively. We can also tell from Table 1 that prob is extremely close to 0, which is less than 5%, meaning that those values are acceptable.

Table 1
The results of multiple liner regression analysis in EXCEL

SUMMARY OUTPUT								
Regression Statistics								
Multiple F	0.927818							
R Square	0.860847							
Adjusted I	0.858145							
Standard E	31.98477							
Observati	106							
ANOVA								
	df	SS	MS	F	gnificance F			
Regressio	2	651864.5	325932.3	318.5964	7.76E-45			
Residul	103	105371.6	1023.026					
Total	105	757236.2						
	Coefficient	andard Err	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	lpper 95.0%
Intercept	-150.946	12.6287	-11.9526	0.00	-175.992	-125.9	-175.992	-125.9
X Variable	0.004097	0.000708	5.787014	0.00	0.002693	0.005501	0.002693	0.005501
X Variable	13.44745	0.537952	24.9975	0.00	12.38055	14.51435	12.38055	14.51435

Therefore, the daily fuel consumption can be formulated as follows,

$$OC = -150.946 + 0.004097 \times CA + 13.44745 \times S \qquad (4\text{-}6)$$

And for container ships, the daily port due can be formulated as follows,

$$PD = \sum PDP / VT \qquad (4\text{-}7)$$

Where,

PDP - Port Due of Every Port of Call

VT - Voyage Time

And for container ships, the daily container handling cost can be formulated as follows,

$$CHC = \sum CP / VT \qquad (4\text{-}8)$$

Where,

CP - Container Handling Cost of Every Port of Call

VT - Voyage Time

Consequently, the total daily unit cost of container ship can be formulated as follows,

$$TC = (CC + OC + VC) / CA \qquad (4\text{-}9)$$

Where,

TC - Total Daily Cost

CC - Daily Capital Cost

OC - Daily Operating Cost

VC - Daily Voyage Cost

CA - Ship Capacity

4.5 Comparison of Cost between Different Ship Sizes at Fixed Route

Comparison is better made when some factors are fixed. In this research, we choose AEU3 of COSCO shipping lines as the fixed route. The vessel would start the voyage in the port of Tianjin, then sail to Dalian, to Shanghai, Ningbo, Singapore, Piraeus, Rotterdam, Hamburg and Antwerp, then sail back to Rotterdam, Shanghai and finally Tianjin.

3 vessels are selected for this cost analysis, the first of which is CSCL STAR, a Container Ship built in 2011 and currently sailing under the flag of Hong Kong, with a capacity of 14,000 TEU. This vessel is owned by COSCO shipping lines, currently operating on the route of AEU3. The second vessel is COSCO Shipping Sagittarius, a Container Ship built in 2018 and currently sailing under the flag of Hong Kong, which is can carry up to 20,119 TEU, also operating on the route of AEU3. The third vessel was ordered by COSCO in March 2020. It expected to be delivered in the first quarter of 2023 and we assume it will

be deployed on the route of AEU3 for the benefit of our research.

Table 2

Basic Parameters for Capital Cost Analysis of Container Ships

Vessel Capacity	**14,000 TEU**	**20,000 TEU**	**23,000 TEU**
Newbuilding Price	$116,800,000	$139,500,000	$ 155,700,000
LIBOR	2%	2%	2%
Margin	2%	2%	2%
Loan Percent	100%	100%	100%
Loan Period	5 years	5 years	5 years
Interest Period	3 months	3 months	3 months

Note: Own elaborations based on industry data and estimates.

As Table 2 shows, all 3 vessels will be 100% financed from bank who offers a margin of 2% on top of the 2% of LIBOR. The principal and interest will be paid quarterly within 5 years. Additionally, these vessel prices are quoted based on current market conditions, because the CSCL STAR was built in 2011, which actually costed more than building a 23,000 TEU vessel in 2019, and thus the economies of scale would be overestimated when the smaller vessel is more expensive than the bigger one.

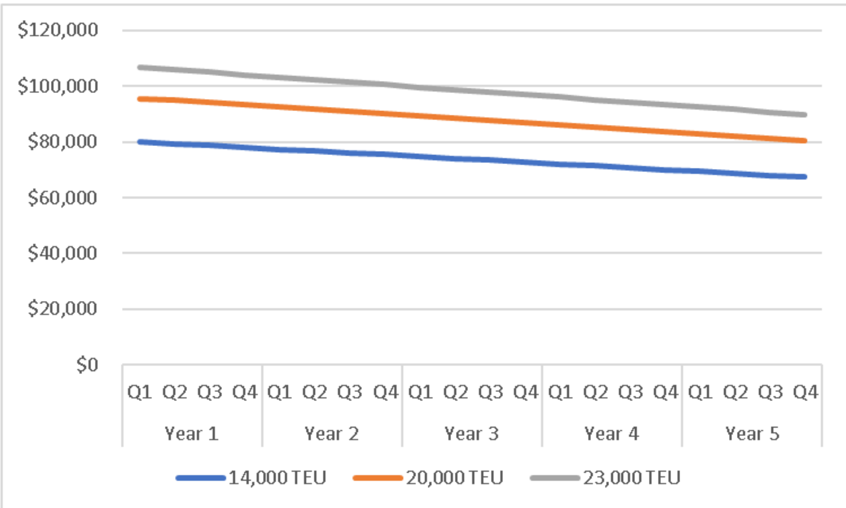

Figure 3. Daily capital cost of container ships.

Note: Own elaborations based on industry data and estimates.

Figure 3 shows the daily capital cost (operating days) of 3 container ships, from which we can tell that daily capital cost will be decreasing throughout the loan period because of the continuous repayments of principal and interest, and container ships with bigger size tend to incur higher capital cost than smaller ships, which is caused by the high newbuilding price of the mega ships in current market situation. The daily capital cost of 23,000 TEU ship is roughly 12% higher than that of the 20,000 TEU ship, and 33% higher than that of 14,000 TEU ship.

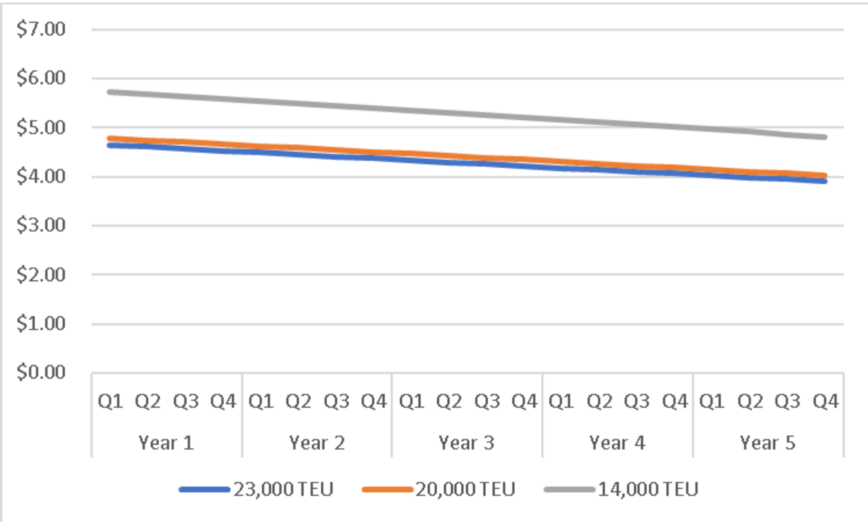

Figure 4. Daily capital cost per TEU of container ships.
Note: Own elaborations based on industry data and estimates.

However, if we look at it from the per-TEU perspective, the result can be quite the opposite. Figure 4 shows that, though the numbers are also declining over the loan period, the 23,000 TEU ship enjoys the lowest daily capital cost per TEU, 3% lower than that of 20,000 TEU ship and 19% lower than that of 14,000 TEU ship. This result demonstrates the economies of scale existing in container ship’s capital cost.

Table 3

Basic Parameters for Operating Cost Analysis of Container Ships

Vessel Capacity	14,000 TEU	20,000 TEU	23,000 TEU
Annual OPEX	$4,088,000	$4,882,500	$ 5,449,500
Annual OPEX per TEU	$ 292	$ 244	$ 237
Daily OPEX	$ 11,680	$ 13,950	$ 15,570
Annual Increase of OPEX	2%	2%	2%
Operating Days	350	350	350

Note: Own elaborations based on industry data and estimates.

As Table 2 demonstrated, the annual vessel operating cost (estimated to be 3.5% of the newbuilding price) is going to rise because the aging of the vessel, and we estimated the increase would be around 2% per annum. The daily operating cost is calculated based on 350 days (operating days). Though 23,000 TEU ship is leading in annual operating cost, in terms of annual operating unit cost, it is the lowest.

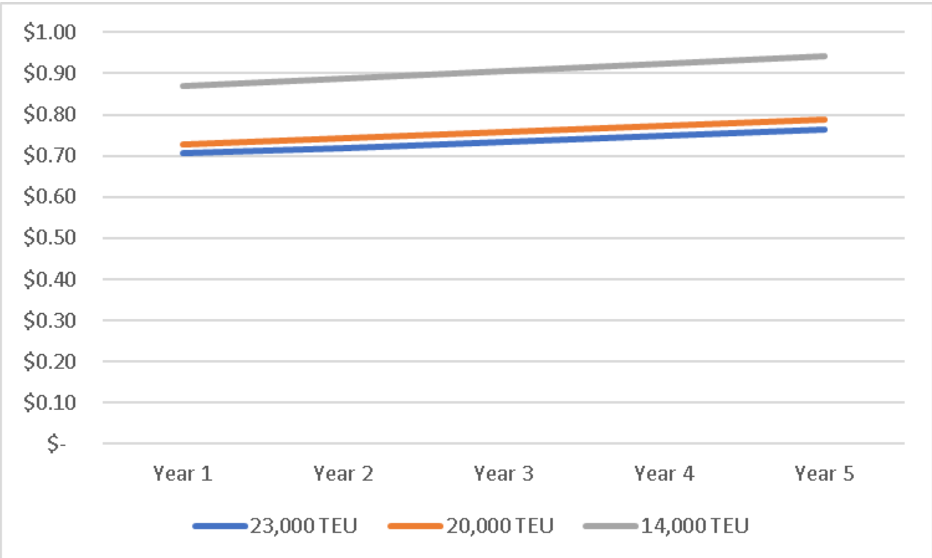

Figure 5. Daily operating cost per TEU of container ships.

Note: Own elaborations based on industry data and estimates.

Same case for daily unit operating cost, as is shown in Figure 5, 23,000 TEU ship is 3% lower than 20,000 TEU ship and 19% lower than 14,000 TEU ship. It also clearly reflects the economies of scale in vessel’s operating cost.

Table 4
Basic Parameters for Voyage Cost Analysis of Container Ships

Vessel Capacity	**14,000 TEU**	**20,000 TEU**	**23,000 TEU**
Operating Days	350	350	350
Service Speed	13 knots	13 knots	13 knots
Daily Fuel Oil Consumption	81 ton	106 ton	118 ton
Fuel Oil Price per Ton	$ 525	$ 525	$ 525
Total Fuel Cost per day	$ 54,351	$ 55,650	$ 61,950
Voyage Distance	26,919 nm	26,919 nm	26,919 nm
Sea Voyage Time	86 days	86 days	86 days
Number of Port of Call	13	13	13
Port Time	19 days	19 days	19 days
Total Voyage Time	105 days	105 days	105 days
Pot Due	$ 1,621,807	$ 1,943,151	$ 2,377,687
West bound cargo (90% utility)	12,667 TEU	18,107 TEU	20,700 TEU
East bound cargo (50% utility)	7037 TEU	10,060 TEU	11,500 TEU
Container Handling Cost	$ 16,923,985	$ 24,193,098	$27,657,500

Note: Own elaborations based on industry data and estimates.

As Table 3 shows, we assume that all 3 vessels will be operating at 13 knots, for 350 days per year. Bunker prices were quoted on April 7th, 2020 when the price was dropping drastically because of the oil price war between Russia and Saudi Arabia after failing to reach a deal.

Every vessel on the route of AEU3 will sail about 26,919 nautical miles, calling at 13 ports per voyage which lasts for about 85 days. Port due includes the tonnage Due, pilotage due (in & out), tugs (in & out), berthage, quarantine charge, convoy fee and agency fee. Vessel utility for westbound trade and eastbound trade is differently adjusted according to the imbalance of containerized trade. we can learn from table 3 that, vessel size is positively related to bunker consumption, port due and cargo handling cost.

Table 5

Voyage Cost Comparison between different ship sizes

Vessel Capacity	**14,000 TEU**	**20,000 TEU**	**23,000 TEU**
Daily Voyage Cost	$218,684	$303,907	$347,242
Daily Unit Voyage Cost	$15.62	$15.20	$15.10

Note: Own elaborations based on industry data and estimates.

The daily voyage cost shown in Table 5 is calculated based on operating days (350 days). Though 23,000 TEU ship has the highest daily voyage cost, it achieves lowest cost on a per-TEU basis, showing further economies of scale to be exploited in container shipping sector.

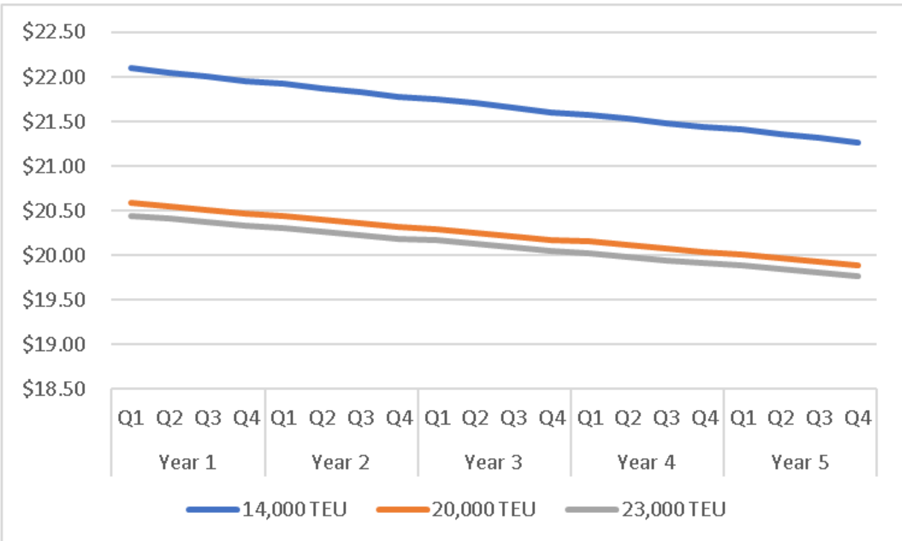

Figure 6. Daily total cost per TEU of container ships.

Note: Own elaborations based on industry data and estimates.

According to Figure 6, 23,000 TEU ship enjoys the lowest daily total unit cost which is 1% lower than that of 20,000 TEU ship and 8% lower than that of 14,000 TEU ship. This result demonstrates that there is still economy of scale for vessel with capacity bigger than 20,000 TEU, though the cost reduction is quite small. It also justifies COSCO shipping's decision to build more 23,000 TEU ships and deploy them on Europe-Asian trade route such as AEU3.

However, the principle of diminishing marginal returns dictates that there is a limit of scale economies, that at some point this reduction in marginal cost may be so small that it is negligible (Murray, 2016). And we can tell that 23,000 TEU ship achieves only 1% cost reduction comparing with 20,000 TEU ship. There is no guarantee that container ship with bigger capacity than 23,000 TEU could still achieve cost reduction under the current technical and market conditions.

Many factors could influence the profitability of containerships, consequently it is more reasonable to set up different scenarios to better reflect the economic viability of the vessels in question, which will be covered in the following chapter.

Chapter.5 Global Sulfur Cap and its Implications on Mega Ships

5.1 The Introduction of Sulfur Cap

As the most important mode of transportation in international trade, Maritime transport causes serious air pollution. Consequently, the international maritime organization (IMO) has issued relevant policies to reduce the exhaust emissions from ships.

Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL), first adopted in 1997, aims to limit harmful air pollutants in ship exhaust - including sulfur oxides and nitrogen oxides - and to ban the deliberate discharge of ozone-depleting substances (ODS). It also regulates the burning and emission of volatile organic compounds (VOC) from ships. In mid-2005, annex VI of the MARPOL convention came into force.

At its 53rd session, the commission for Marine Environmental Protection (MEPC) decided to amend the convention's shortcomings in order to further limit the ship emission because of technological advances and accumulated regulatory experience. Thus, at its 58th session, the MEPC adopted the amendment of the annex VI of the MARPOL convention. The main changes in the amendments are more limits on global emissions of sulfur oxides and nitrogen oxides and the introduction of emission control zones (ECAs), which would significantly reduce emissions of air pollutants in selected sea areas.

According to the amendment, all ships sailing outside the emission control zone will reduce the sulfur content of their fuel oil from 4.5 % to 3.5 % from the beginning of 2012 and must use Marine fuel oil with a sulfur content of no more than 0.50 % from 2020. The standard for sulfur content of the fuel oil in the emission control zone, which took effect in 2015, is 0.10 %, and ECA includes the North Sea, the Baltic Sea, the coasts of the US and

Canada, the US Caribbean and Hawaii. At the MEPC's 70th and 71st meetings (in October 2016 and July 2017, respectively), all parties confirmed that the implementation of 0.50% limit would not be delayed, which means it would take effect as scheduled.

5.2 The Countermeasure Available for Liners

The first countermeasure for liner companies is switching to compliant fuel or very low sulfur fuel oil (VLSFO) with only 0.5% of sulfur content, which is perhaps the simplest measure of all and was chosen by majority of shipping lines.

One serious problem with the VLSFO solution is that there are many ways to produce it, which means there are many types of VLSFO. It brought a lot of trouble to shipping companies, different types of VLSFO are incompatible with each other, sediments created as the result of incompatibility may cause damage to vessel's main engine. Thus, if a container ship first refuels in the port of Rotterdam and then in Singapore, the fuel it received at both ports must be of the same type, otherwise compatibility problem will arise.

Another problem is the availability of VLSFO. Many in the industry have voiced their concern about insufficient market supply of compliant fuel, which lead to the creation of the fuel oil non-availability report (FONAR), allowing shipowners to avoid being penalized by the port authorities unless they cannot prove that their vessel could not obtain compliant fuel despite best efforts. The third major problem is the price of VLSFO, which is normally higher than high sulfur fuel oil. Shipping lines have to bear this additional cost, or they could transfer part of the cost to shipper though fuel surcharge.

The second countermeasure is installing scrubbers, which could remove sulfur dioxide and other harmful chemicals from vessel’s emission, allowing vessel to continue using high sulfur fuel oil which is cheaper than VLSFO. However, the installation of scrubber would take months, during which the vessel could not be operational and make profit. There are three types of scrubber, close-loop scrubber, open-loop scrubber and hybrid-loop scrubber. Vessel installed with open-loop scrubber would discharge waste water with sulfur content into the sea, while the close-loop scrubber would store the waste water on the ship until it could discharge environmentally friendly. The hybrid-loop scrubber is basically the combination of both, allowing the vessel to switch to open-loop mode or close-loop mode.

Since the open-loop solution is polluting the ocean instead of the air, many countries have banned the usage of open-loop scrubber in their territorial waters, such as Singapore, Malaysia, India, Panama and Norway, etc. Therefore, scrubber solution has some regulatory risks, because it is unknown whether IMO will implement stricter environmental regulation which possibly would put more restrictions on vessel installed with scrubber. Since scrubber allows vessel to continue burning high sulfur fuel oil, one should also consider the narrowing price gap between high sulfur fuel oil and VLSFO as well as the possibility of insufficient supply of high sulfur fuel oil when the industry gradually switches to the production of compliant fuel.

The third countermeasure is switching to LNG which is widely regarded as the cleanest fossil fuel in the world. It not only solves the problem caused by this emission reduction regulation, but also cope with the possible further stringent regulation in the future. Using LNG as fuel for ships can reduce emissions of nitrogen oxides and sulfur oxides by 90 %to 95 % compared with using high sulfur fuel oil. As a unique fuel, LNG has many characteristics, it is odorless, colorless, non-corrosive and non-toxic.

The first problem shipping companies face when using LNG fuel is that its supporting facilities are very expensive. If a ship wants to use LNG fuel, it must install LNG engines, LNG storage tanks and other supporting facilities. Therefore, LNG fuel is often used in new shipbuilding. According to DNV GL, the capital expenditure for these facilities is between $3 million and $30 million.

The second problem is the limited number of LNG refueling facilities. Currently, LNG refueling facilities are concentrated in northern Europe, Western Europe, the US gulf coast and the US east coast, thus the unbalanced distribution of refueling facilities is a huge obstacle to the application of LNG fuel.

The third problem is that the installation of LNG supporting facilities will reduce the capacity of ships for carrying cargo. The density of LNG is less than half that of the ship's heavy oil, the capacity of the LNG bunker is much larger than that of the fuel tank, and the LNG engine and storage tank will take up part of the hull space, which will reduce the space for the ship to carry the cargo.

5.3 The Cost of Complying with Sulfur Cap

Firstly, we need to consider the cost of buying compliant fuel, the VLSFO, since IMO no longer allows vessel to use high sulfur fuel oil (HSFO) unless equipped with scrubber. We can see from Figure 7 that there is a price gap between these two kinds of fuel oil, which averaged at $175 per ton from November 22nd, 2019 to April 17th, 2020. The price gap reached its peak on January 3rd, 2020, since last November, which is at $302 per ton. It dropped to a record low on April 17th ,2020, at merely $52 per ton. This can be largely contributed to the coronavirus pandemic which forces governments across the globe to put cities under lockdown in order to contain the spread. Lockdown leads to decline of economic activities and subsequently lower demand for manufacturing products as well as raw materials, including oil, and thus fuel oil witnesses a drop in price.

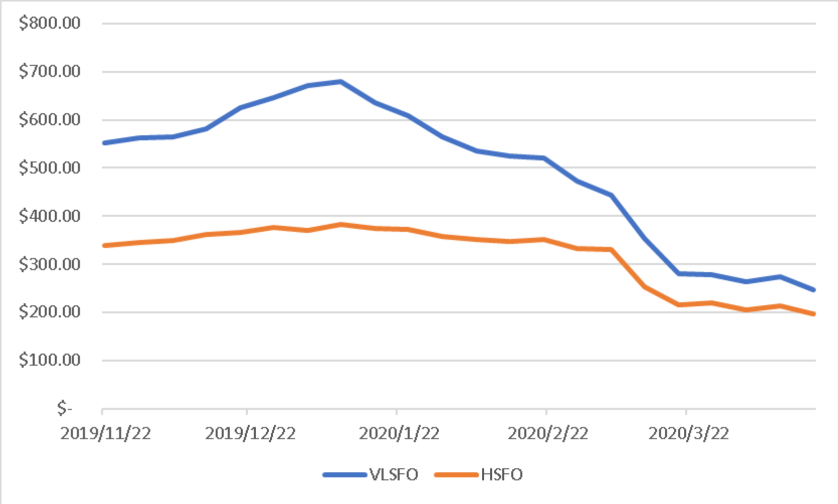

Figure 7. Price of VLSFO and HSFO per ton. From Clarkson database.

As for the cost for scrubber solution, the total cost can be divided into installation cost, HSFO cost and maintenance cost. Qian Qiang and Liu Jia (2016) estimated that the annual maintenance cost of scrubber is roughly 1% of its installation cost, it could be formulated as follows,

$$MC = 1\% \times IC \qquad (5\text{-}1)$$

Where,

MC - Scrubber Annual Maintenance Cost

IC - Scrubber Installation Cost

Since the difference between the consumption of HSFO and VLSFO is quite small, we assume that the vessel's HSFO consumption equals to that of VLSFO. Scrubber operations tend to cause malfunctions, so we assume that 10 days will be deducted from operating days for additional repairs. Zhang (2019) established the formula for the scrubber installation cost under the assumption that "the total power of a ship is proportional to the price of the scrubber system, and the main engines run on 70% load at maximum, the auxiliary engines runs on 85% load at maximum" (p.52). The formula is given as follows,

$$IC = (0.0565 \times (PM \times 70\% + PA \times 85\%) + 1.615) \times 106 \qquad (5\text{-}2)$$

Where,

IC - Scrubber Installation Cost

PM - The Main Engines Powers of the Ship (Mw)

PA - The Auxiliary Engines Powers of the Ship (Mw)

Table 6 shows the scrubber installation cost of container ships, 23,000 TEU ship incurs the highest installation cost, 7% higher than that of 14,000 TEU ship and 25% higher than that of 20,000 TEU. In terms of installation cost per TEU, 14,000 TEU has the highest figure, followed by 23,000 TEU. It should be noted that the 20,000 TEU enjoys the lowest figure in both total cost and unit cost for scrubber installation, thus we can clearly tell from Table 6 that, the economies of scale in this case do not extend to the vessel exceeding the capacity of 20,000 TEU.

Table 6

Scrubber Installation Cost Comparison between different ship sizes

Vessel Capacity	**14,000 TEU**	**20,000 TEU**	**23,000 TEU**
Marin Engine	72.24 Mw	55 Mw	76 Mw
Auxiliary Engine	10 Mw	8 Mw	14 Mw
Installation Cost	$ 4,928,330	$ 4,188,329	$ 5,252,131
Installation Cost per TEU	$ 352.02	$ 209.42	$ 228.35

Note: Own elaborations based on data from Clarkson Research.

We divide the cost for LNG solution into engine installation cost and fuel cost, for LNG would become unusable without LNG power engine. We can see from Figure 7 that the price of LNG changed dramatically, which averaged at $ 10.36 from the period from April of 2007 to March of 2020. LNG price rose to a peak before the collapse of 2008, after the financial crisis, it rose to another peak and kept fluctuating until 2014 when the market experienced a huge drop. It resumed fluctuation from 2016 to 2018, after which the price decreased significantly until a small rise in mid-2019. Then, the coronavirus hit major economies in the world, and the oil price witnessed a huge drop, stimulating the consumption of fuel oil rather than LNG fuel or other clean fuel. Consequently, the price of LNG has been declining since December 0f 2019. We would quote the latest available price for our analysis.

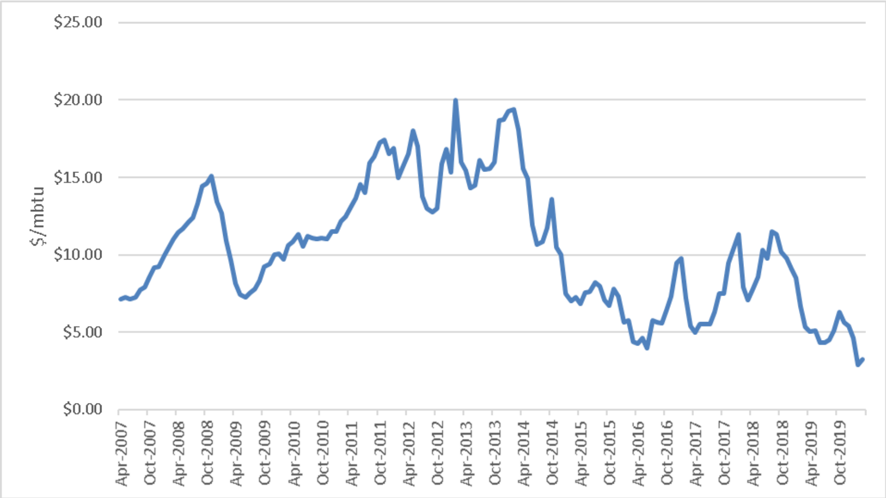

Figure 8. LNG Spot Price, Delivered Asia. From Clarkson database.

According to industry estimates, 48.2 mbtu of LNG equals to 1 ton of LNG and we assume the consumption of VLSFO equals to that of LNG. Therefore, the daily LNG fuel consumption can be formulated as follows,

$$LC = (-150.946 + 0.004097 \times CA + 13.44745 \times S) \times 48.2 \qquad (5\text{-}3)$$

Where,

LC - Daily LNG Consumption

CA - Vessel Capacity

S - Vessel Speed

And for LNG powered container ships, the daily fuel cost can be formulated as follows,

$$FC = LC \times LP \qquad (5\text{-}4)$$

Where,

FC - Daily Fuel Cost

LC - Daily LNG Consumption

LP – LNG Price

Zhang (2019) estimated that the construction cost of LNG power ship is roughly 30% higher than that of average ship. Thus, the LNG power engine installation cost can be formulated as follows,

$$LI = 30\% \times VV \qquad (5\text{-}5)$$

Where,

LI - LNG Power Engine Installation Cost

VV - Vessel Value

Table 7
LNG solution Cost Comparison between different ship sizes

Vessel Capacity	**14,000 TEU**	**20,000 TEU**	**23,000 TEU**
Vessel Value	$116,800,000	$139,500,000	$155,700,000
LNG Engine Installation Cost	$26,280,000	$31,387,500	$35,032,500
LNG Engine Installation Cost per TEU	$1,877	$1,569	$1,523
Daily fuel oil Consumption	81 ton	106 ton	118 ton
Daily LNG Consumption	3904 mbtu	5109 mbtu	5688 mbtu
LNG Price	$2.9	$2.9	$2.9
Daily LNG Fuel Cost	$11,322	$14,817	$16,494

Note: Own elaborations based on data from Clarkson Research.

As shown in Table 7, LNG engine installation cost and LNG fuel cost are positively related to the size of the vessel, which means the bigger ship would incur higher installation cost and LNG fuel cost. However, 23,000 TEU ship has the lowest installation cost in per-TEU basis, which is 3% lower than that of 20,000 TEU ship and 23% lower than that of 14,000 TEU ship. After converting ton to mbtu, we can tell that those vessel's daily LNG fuel cost is lower than that of VLSFO.

5.4 The Economic Implication of Sulfur Cap on Mega Ships

After looking into the cost for each solution, we shall incorporate these analyses into the calculation model for container ship cost. The analysis in chapter 4 is actually based on compliant fuel solution, so we shall calculate the vessel's cost based on the other two solutions and compare the results, from which we can derive the conclusions and suggestions.

Table 8

Three Scenarios of fuel prices

Scenario	VLSFO Price per ton	HSFO Price per ton	LNG Price per mbtu
1 (High Price Gap)	$671	$369	$4.63
2 (Low Price Gap)	$247	$196	$2
3 (Medium Price Gap)	$525	$347	$2.9

Note: Own elaborations based on data from Clarkson Research.

As shown in Table 8, three scenarios will be established to better analysis the economic implication of sulfur cap, which are based on fuel prices. Scenario 1 reflects a situation when the price gap between VLSFO and HSFO is high ($301). Scenario 2 reflects the situation when the price gap is low ($51) and scenario 3 shows medium price gap ($178). Scenario 1 happened in January of 2020, the beginning of the implementation of sulfur cap, which lead to overdemand of VLSFO as refineries struggled to increase capacity and change production. Scenario 2 happened in April of 2020, as the coronavirus continued to severely hit the global economy, reducing demand and subsequently the price for fuel oil. Scenario 3 happened in February of 2020, when the coronavirus just began to affect the major economies other than China, fuel oil price dropped to a certain extent because of which.

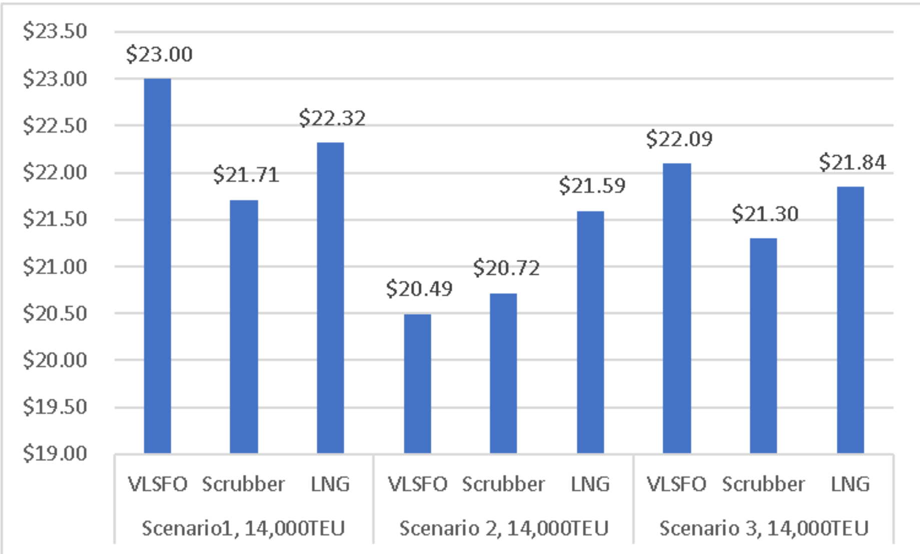

Figure 9. Daily total cost per TEU of different solutions under different scenarios for 14,000 TEU ship. Note: Own elaborations based on industry data and estimates.

As figure 9 shows, scrubber has cost advantage under scenario 1 and 2, which means it is economical to install scrubbers on 14,000 TEU ships when there is a substantial price gap between VLSFO and HSFO. VLSFO becomes more economical when the price gap is small and LNG solution is too expensive for 14,000 TEU ships. Under scenario 2, VLSFO achieves the lowest unit cost of all solutions under all 3 scenarios.

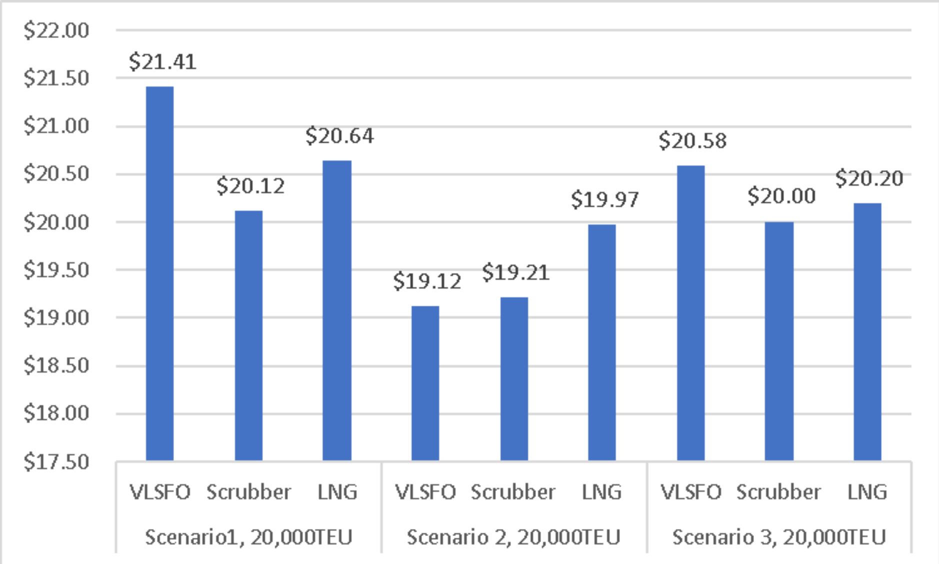

Figure 10. Daily total cost per TEU of different solutions under different scenarios for 20,000 TEU ship. Note: Own elaborations based on industry data and estimates.

As it is demonstrated in Figure 10, scrubber enjoys lower cost advantage comparing with other solutions under scenario 1 and 2, same case for 14,000 TEU container ships. VLSFO is more economical when the price gap is small, but the cost advantage is quite small comparing with scrubber. Under scenario 2, VLSFO achieves the lowest unit cost of all solutions under all 3 scenarios.

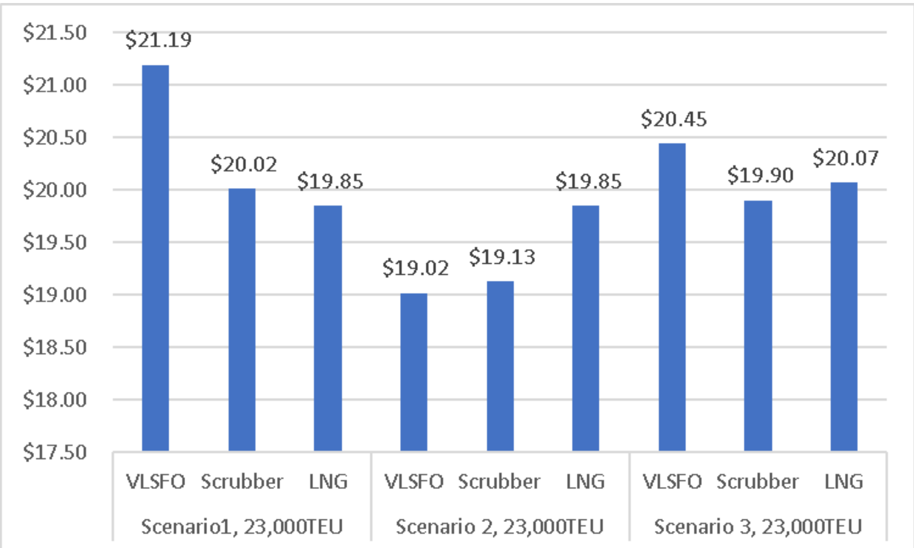

Figure 11. Daily total cost per TEU of different solutions under different scenarios for 23,000 TEU ship. Note: Own elaborations based on industry data and estimates.

Figure 11 shows that LNG is more economic in scenario 1 and scrubber should be chosen in scenario 2. Same with 14,000 TEU ship and 20,000 TEU ship, VLSFO is not only cheaper than scrubber and LNG in scenario 2, but also cheaper than other solutions of all 3 scenarios.

After incorporating the cost for complying with sulfur cap, the result we obtained in chapter 4 is still valid: 23,000 TEU ship incurs less daily unit cost, comparing with 20,000 TEU ship and 14,000 TEU ship. For instance, under scenario 1, for VLSFO solution: the daily unit cost of 14,000 TEU ship is $23; the daily unit cost of 20,000TEU ship is $21.41; the daily unit cost of 23,000 TEU ship is $21.19.

Table 9

Solution Selection under Three Scenarios

Scenario	**14,000 TEU**	**20,000 TEU**	**23,000TEU**
1 (High Price Gap)	Scrubber	Scrubber	LNG
2 (Low Price Gap)	VLSFO	VLSFO	VLSFO
3 (Medium Price Gap)	Scrubber	Scrubber	Scrubber

Note: Own elaborations based on data from Clarkson Research.

According to Table 9, scrubber is more often selected under all scenarios for all 3 ship types, showing great potential saving for this solution to comply with sulfur cap. LNG is only more economical for 23,000 TEU under scenario 1 when price gap is high, meaning LNG solution is only suitable for mega ships during times of high fuel oil price. VLSFO solution is only chosen when the price gap is small, because the cost saving achieved by installing scrubber and burning HSFO is small.

Chapter 6 Conclusion and Recommendations

6.1 Conclusion

Different from many previous studies, this paper found that there is still economy of scale to be exploited for container ships beyond the size of 20,000 TEU, justifying major shipping line’ s decision to build 23,000 TEU ships and deploy those ships on Europe-Asia trade routes. This result is still solid after we incorporate the cost for complying with sulfur cap. However, the delivery of these mega ships should be postponed in light of the current situation. As for the countermeasures for sulfur cap, scrubber is more economical when the price gap between VLSFO and HSFO is high, switching to VLSFO is less costly when the price gap is low, LNG solution is only suitable for 23,000 TEU ships when the fuel oil price is high. However, this research is based on many assumptions and estimates, which should be analyzed deeper and more accurately.

6.2 Recommendations

The recommendations of this paper shall be based on latest event, the coronavirus, which greatly changed the bigger picture. Since the outbreak of this global pandemic, the shipping market has witnessed a continuous drop in fuel oil price and maritime transport demand, because of the shut-down of economies across the globe to contain the spread of the virus. Some experts warned that the virus will not be gone until summer and it may come back in winter. According to the estimates of Clarkson Research, the world economic growth in 2020 will be reduced by 3% and seaborne trade growth will be around 2% or even -0.3%, way lower than the estimates made before the virus. Under this circumstance, shipping lines profit will be significantly reduced which has been shown by their quarter report.

Therefore, scenario 2 is more likely to come true which means the price gap between VLSFO and HSFO will remain small and VLSFO solution would be more economical.

Considering the shipping line's profitability will be reduced, it is harder for them to spend extra money on installing scrubbers or LNG engines, because the top priority for now is to survive through this difficult time. This has been partly demonstrated by data of Clarkson Research, which shows a decline of number of vessels waiting to be installed with scrubbers, some contracts were even canceled. Besides, the regulatory risk of the scrubber solution cannot be underestimated, since many countries and regions have banned the open loop scrubber, closed loop or hybrid scrubber may possibly be deemed un-environmentally friendly in the future when IMO decides to implement stricter regulation. Thus, we recommend that shipping lines should stick to VLSFO solution at least in this year.

References

Bergmann, J. (2014, April 8). Future development of ultra large container ships. [PowerPoint slides]. Retrieved from https://www.innovasjonnorge.no/globalassets/arrangementer/9-jost-bergmann.pdf

Chen, F., & Zhang, R. (2008). Economic viability of mega-size containership in different service network. *Journal of Shanghai Jiaotong University (Science)*, 13(2), 221-225. doi:10.1007/s12204-008-0221-6.

Cullinane, K., & Khanna, M. (2000). Economies of scale in large containerships: optimal size and geographical implications. *Journal of Transport Geography*, 8, 181-195.

Guan C., Yahalom, S., & Yu, J. (2017). Port congestion and economies of scale: *The large container ship factor*. Paper presented at the Annual Conference of the International Association of Maritime Economists. Conference. 27–30 June. Kyoto, Japan.

Guo, Y. (2000). *The economic analysis of the enlargement of container ship* [Master’s thesis, Dalian Maritime University].

Helmy, S., & Shrabia, A. (2016). Mega container ships, pros, cons and its implication recession. *Journal of Shipping and Ocean Engineering*, 6, 284-290. doi:10.17265/2159-5879/2016.05.004.

Imai, A., Nishimura, E., Papadimitriou, S., & Liu, M. (2006). The economic viability of container mega-ships. *Transportation Research Part E: Logistics and Transportation Review*, 42 (1), 21-41. doi:10.1016/j.tre.2004.07.002.

International Transport Forum, OECD. (2015). *The impact of mega ships*. Retrieved from https://www.itf-oecd.org/sites/default/files/docs/15cspa_mega-ships.pdf

Jong, S. (2017). The study on Impacts of mega container ships on ports. *Pan-Pacific Journal of Supply Chain Management*: Applications and Practices, 1, 22-40.

Kapoor, R. (2016, May 12). *Diminishing economies of scale from megaships*. [PowerPoint slides]. Retrieved from https://www.marinemoney.com/system/files/media/mm/pdf/2016/1150%20Rahul%20Kapoor.pdf

Li, J. (2005). *Study on economies of scale of container liner transport industry* [Master’s thesis, Shanghai Maritime University].

McKinsey. (2018). *Brave new world? Container transport in 2043*. Retrieved from https://www.mckinsey.com/~/media/mckinsey/industries/travel%20transport%20and%20logistics/our%20insights/brave%20new%20world%20container%20transport%20in%202043/brave-new-world-container-transport-in-2043.ashx

Merk, O. (2018), *Container ship size and port relocation*, Discussion Paper, International Transport Forum.

Murray, W. (2016). *Economies of Scale in Container Ship Costs*. United States Merchant Marine Academy

Park, N., & Suh, C. (2019). Tendency toward Mega Containerships and the Constraints of Container Terminals. *Journal of Marine Science and Engineering*, 7, 131-144.

Qian, Q, & Liu, J. (2016). Economic study on chemical tankers equipped with exhaust gas scrubber.

Naval Architecture and Ocean Engineering, 32 (4), 23-26.

Rodrigue, J. (2020). *The Geography of Transport System*. New York: Routledge.

Stopford, M. (2002). *Is the drive for ever bigger containerships irresistible*. Proceedings of the Lloyds List Shipping Forecasting Conference, 26 April.

UNCTAD. (2019). *The Review of Maritime Transport 2019*. Retrieved from https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf

Veldman, S., Glansdorp, C., & Kok, R. (2011). Economies of size of large containerships based on internal and external costs. *Int. J. of Decision Sciences*, 3, 384 - 400. doi:10.1504/IJDSRM.2011.046160.

Wang, X. (2006). *Study on the operational economics of large containership under the hub-port condition* [Doctor's thesis, Shanghai Jiao Tong University].

Weng, Y. (2018). The technological economics and sensitivity analysis of mega containerships. *China Ship Survey*, (10), 86-91.

Wu, H. (2012). Discussion on economic efficiency and safety of ever-larger container ships. *Navigation of China*, 35(02), 114-118.

Xiang, J., Zhu, X., & Jin, Y. (2014). Analysis of promotion and restriction factors in the process of ship size growth. *Journal of Shanghai Ship and Shipping Research Institute*, 37(1), 19-24.

Yan, J. (2012). *Study on large container vessel's economics viability and countermeasure research based on the economic recession* [Master's thesis, Shanghai Jiao Tong University].

Zhang, T. (2019). *Comparative analysis of SOx emission control technologies for container ships* [Master's thesis, World Maritime University]. https://commons.wmu.se/all_dissertations/