An Analytical Study of the Break-Even Bunker Price in the East-West Intercontinental Container Shipping Market

Bachelor Thesis by

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Abstract

Slow steaming is the current way of doing business in the container shipping market. In times that margins are getting smaller and smaller and overcapacity in the industry is structural, cutting costs is more important than ever before. This research investigates the costs and benefits faced by container carriers at an annual individual service level as a result of vessel speed adjustments. By means of a first difference analysis, bunker prices needed to offset cost increases resulting from consecutively vessel speed decreases by one knot are calculated. This first differential break-even bunker price analysis is a function of operating, capital, time and emission costs on the one hand and fuel consumption on the other hand. Break-even bunker prices found in this research vary between $762 and -$74 for different services and different speed levels implying the high cost savings potential at higher speeds. In this research, for several major east-west container shipping services the break-even IFO380 bunker price is computed at various speed levels. It appears that the current optimal speeds lie between 15 and 17 knots given current bunker prices in major bunker ports. This research complements existing research by completely focussing on the speed decision faced by carriers and accounting for the environmental aspect in term of CO_2 emission cost. The results from this research serve as a basis for strategic decision making on individual service level from a carrier perspective in terms of vessel speed and vessel deployment decisions.

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Introduction

The container shipping industry has experienced a tremendous growth since the introduction of the container half a century ago. With the introduction of newly build megaships and the increasing exploitation of economies of scale the container shipping industry was flourishing. Shipping lines mainly focussed on delivery speed of their clients' products and the enhancement of service reliability. Even increasing fuel prices were not able to stop this trend of everlasting demand growth of container transportation and margins (Meyer, Stahlbock, & Voß, 2012). However, the latest economic crisis put this phenomenon to an abrupt hold. Global trade, as well as revenues in the container transport segment, severely dropped and a massive amount of pre-crisis ordered shipping capacity became operational. This resulted in a huge wedge between supply and demand for container transport (Meyer, Stahlbock, & Voß, 2012). The Economist (2012) described the post-crisis situation as *"it never rains but it pours for the shipping industry"* referring to the big troubles the industry is facing since the great recession began in 2009.

In order to absorb some of this excess fleet capacity the existing container vessel fleet was utilized at a slower speed, which is nowadays commonly referred to as the practice of 'slow steaming'. Slow steaming means sailing below the design speed of a ship. Slow steaming has a huge reducing effect on the fuel consumption of a ship and it allows the shipping line to get more ships in operation by lowering the effective supplied capacity (Maloni, Paul, & Gligor, 2013). In a period where oil prices were sky rocketing, up to $145 per barrel in 2008 (Trading Economics, 2016), fuel costs represented over 50% of a carrier's operating costs (Rex, 2015). Notteboom & Vernimmen (2009) have shown the high potential of fuel costs savings for container carriers. The savings potential could lead up to 82%[1] by sailing at 14 knots instead of 26 knots when assuming a 12.000 TEU[2] container vessel on a specific route.

Not surprisingly, all shipping lines active at east-west trade lanes are currently implementing slow steaming as a common practise. With a wide speed margin to play with, vessel speeds are varying between 11,7 knots to 24,7 knots depending on the service direction and route (Americanshipper, 2013). Slow steaming is the best way to battle crashing freight rates due to the glut of capacity by using larger and more fuel-efficient container ships (ShipandBunker, 2015).

As such, it is easy to relate a high bunkering price to a large potential of fuel costs savings for the carriers. Even when the bunker prices are low, for example below $200/t, fuel savings can still be significant. However, in order to maintain a weekly frequency, slow steaming requires the deployment of additional vessels, which in turn generates additional costs (Cariou, 2010).

Besides reduced fuel consumptions and the absorption of excess fleet capacity, also lower greenhouse gasses (ghg) emissions (e.g. CO_2) and increased liner flexibility are mentioned as advantages of lower vessel speeds (Maloni, Paul, & Gligor, 2013). It is the question however, to what extend is bunker pricing the most important influential

[1] Assuming end-July 2006 bunker prices
[2] TEU = Twenty Foot Equivalent (20ft container)

factor for considering the implementation of slow steaming? In other words, if the bunker prices are at bottom prices, will shipping lines still be implementing slow steaming? It may be economically more efficient in case of bottoming bunker prices, for a container carrier to speed up resulting in a higher scheduling performance and reduced transit times (ShipandBunker, 2015).

Therefore it is necessary to define the bunker price level that is needed to justify a certain speed reduction in terms of costs and benefits. In other words, what is the break-even bunkering price for each speed reduction making steaming slower economically justified? Comparing these figures with current bunker prices gives implications about what strategies container carriers should pursue in order to make the most profits.

This research considers the intercontinental east-west liner services of the big five[3] container carriers, together accounting for 48,7% of the market share in international containers shipping. Service data is gathered addressing the service characteristics of all Europe-Asia, Europe-USA and Asia-USA routes offered by these five shipping lines. This research will focus on answering the following research question:

What is the break-even bunker price for east-west intercontinental liner services from the container carriers' perspective on individual service level?

The latter part of the research question implies that the break-even bunker prices will be calculated on a specified liner service. This way, only relevant costs for a specific service on an annual basis are taken into account, rather than the cost of the carriers as a whole.

In order to answer this research question, this research is divided in five sections. Section one will address background information about the container shipping industry investigated in this research using a short market analysis. Section two considers background information about the theory and practical applicability of slow steaming using scientific literature and several articles. All relevant pro's and con's of slow steaming are addressed together with environmental legislation concerning emissions. Also the way the shipping lines pass on fuel costs to the customer is explained. In section three, the methodology section, a conceptual model will be constructed for the calculation of the break-even bunker price. Afterwards the dataset and its sources are briefly elaborated. Finally, the conceptual variables are operationalized into measurable factors and relevant assumptions are discussed. Section four is the data analysis section, which discusses the results of the implemented model on the used dataset using all variables and formulas explained in the methodology section. Section five, the conclusion, will discuss the implications of this research and the limitations of the used data and the created model. Also recommendations for future research will be given.

[3] Shipping lines and market shares: Maersk (14,9%), MSC (13,1%) , CMA CGM (8,7%), COSCO (7,5%) , Evergeen (4,5%). Source: http://www.alphaliner.com/top100/

1. Market Analysis

Section one gives an introduction to the container liner shipping market and its key characteristics, primarily focussed on shipping lines. Secondly, the market will be analysed based on its most important actors and most important service routes in terms of trade volume.

1.1 A Mature Market Focussed on a Low Cost Strategy

In order for shipping lines to be competitive they have to be able to handle increasing cargo throughput and they have to provide the demanded service at low rates (Hesse & Rodrique, 2004). Due to low rates and overcapacity, international container shipping can be described as a very mature industry that is hardly profitable. Since the container transport services on major trade routes are viewed to be relatively homogenous, it is difficult for a carrier to create sources of long-term competitive advantages. Most firm specific competitive advantages considering improved customer services and schedule reliability are already being fully exploited (Brooks, 1993). Container shipping is a market segment that is nowadays characterized by a globally integrated supply chain creating a link between global sourcing and regional distribution. In response to this integration, major players in the distribution business are trying to control as many parts of the logistic chain as possible. (Hesse & Rodrique, 2004). This explains the high level of horizontal and vertical linkages via mergers, takeovers or strategic alliances (Slack, MacCalla, & Comtois, 2002). All of this is done to create cost reductions by means of co-operation. Many analysts say it is "*consolidating or quitting"*. SeaIntel, a maritime industry analyst, stated that almost half of the forty biggest shipping lines has merged, has been taken over or has disappeared in the last twenty years (Eldering, 2016). Besides consolidating and exploiting economies of scale by deploying larger vessels, another very promising cost saving strategy has emerged. With fuel costs exceeding 50% of a vessel's operational costs, exploiting the exponential relation between vessel speed and fuel consumption yields high cost savings potential. Peaking bunker prices combined with vessel overcapacity and declines in demand for container transportation, makes slow steaming a great strategy to stay profitable (Notteboom & Vernimmen, 2009; ShipandBunker, 2014).

1.2 The Importance of East-West Services in a Consolidated Market

Since the start of the containerization in the 1960's, liner shipping has mainly been involved in carrying containers. As such, the terms liner shipping and container shipping are both used to express the same industry. The east-west international container shipping route is the biggest trade corridor in the global container shipping industry. Table 1 shows the total number of TEU transported and the number of services offered at this east-west corridor[4]. Around 36% of all liner services offered worldwide are offered at this trade corridor accounting for almost 80% of the containerized cargo transported. This implicates that the east-west trade corridor is the most important corridor in the global freight industry. The container shipping market is very consolidated of nature. Around 77,4% of the fleet capacity[5] is in hands of the fifteen biggest shipping lines. Almost 50% of the market is in hands of the biggest five shipping lines.

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[4] The far east – middle east route is ignored

[5] Measured in TEU and incorporating existing fleet and the vessels in the orderbook

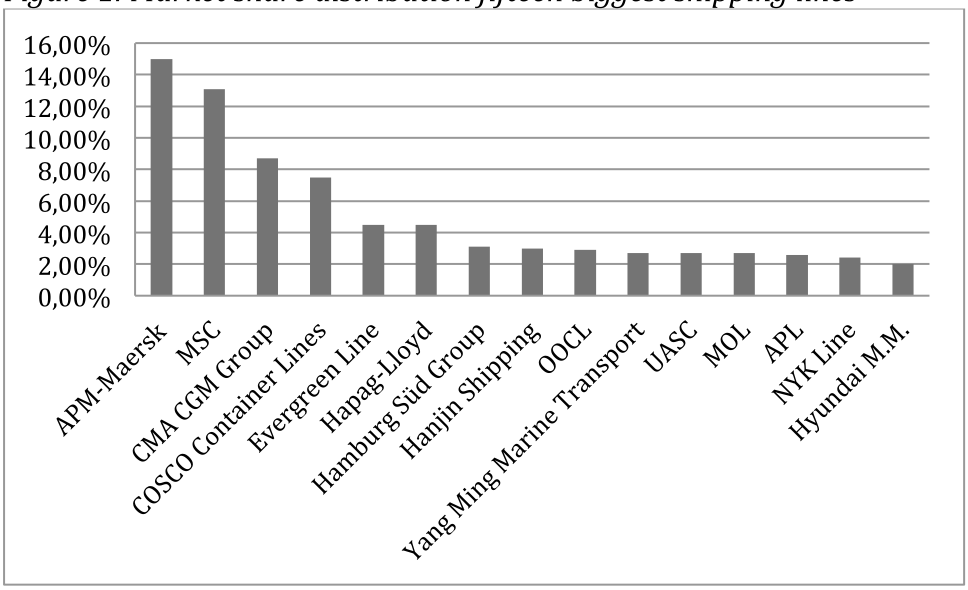
Table 1: Number of services offered and number of TEU transported along the east-west trade corridor.

Route	Services	Total TEU Shipped in 2013
Far East- North America	73	23.125.000
North Europe - Far East	28	13.706.000
Far East - Mediterranean	31	6.739.000
North Europe - North America	23	4.710.000
Mediterranean - North Europe	21	n/a
Total number of services/TEU	490	61.334.279
% East-West Service	36%	79%

Source: (WSC, 2013)

For the fifteen biggest shipping lines, individual market shares are displayed in figure 1. The container shipping industry is facing a period of further consolidation among top carriers. Carriers see consolidation on the horizon and want to make sure they have the size needed to stay competitive at a time when scale increasingly matters. A second driver is that there is no short-term relief of overcapacity that is pushing down freight rates (JOC, 2015). To place this into perspective, Maersk and MSC are both part of the '2M-alliance' (JOC, 2015) and CMA CGM, COSCO, Evergreen and OOCL have formed the 'Ocean Alliance' in April this year (CMA CGM, 2016). While other alliances exist too, it can be seen that the amount of vessels available and the number of services offered by the big five are very horizontally integrated. This can be seen, for example, by the large amount of vessels owned by Maersk that are deployed at the MSC service network (MSC, 2016).

Figure 1: Market share distribution fifteen biggest shipping lines



Source: (Alphaliner, 2016)

Carriers all operate in a saturated market and all act in a way to obtain the most market share. Squeezing out smaller competitors triggers waves of price wars causing carriers to price at their marginal cost. This is for most of them the right decision, however, for others it is irrational due to ineffective pricing methods. The industry suffers if everyone does it (Glave, Joerss, & Saxon, 2014). Shipping lines are deeply conservative and change comes slowly. The industry is highly cyclical and imbalances in supply and demand are systematic. Main challenges to stay profitable are pursuing more efficient operations, enhancing network design and the improvement of commercial activities. All of these include more efficient bunker management, procurement, better asset utilization and more flexible pricing strategies. On the longer term, vessel network design is increasingly important, which is mainly dependent on vessel size and distance. The only way to stay ahead of competition is to launch comprehensive transformations addressing technical and organizational issues (Glave, Joerss, & Saxon, 2014).

Supply and demand imbalances are not expected to disappear anytime soon and careful management of capacity deployment by individual carriers is of utmost importance (BIMCO, 2016). Despite higher forecasted GDP growth rates for 2016, the shipping industry can expect a period of an uncertainty and a lower level of support form one of the most important economic drivers in container shipping, namely China. Disappointing European demand figures and a record of new capacity entering the market in 2015 keep market conditions challenging for the upcoming years (WMN, 2016).

2. Theoretical Background

This section consists of four sections. The first section considers academic work on the topic of slow steaming since its emergence in 2008 in the form of a literary review. The second section elaborates on the effect of slow steaming since it was firstly implemented in 2008. Also the advantages and disadvantages primarily focussed on shipping lines are discussed. Section three and four address environmental and the most important surcharge that carriers use to pass on fuel costs to its customers.

2.1 Literary review

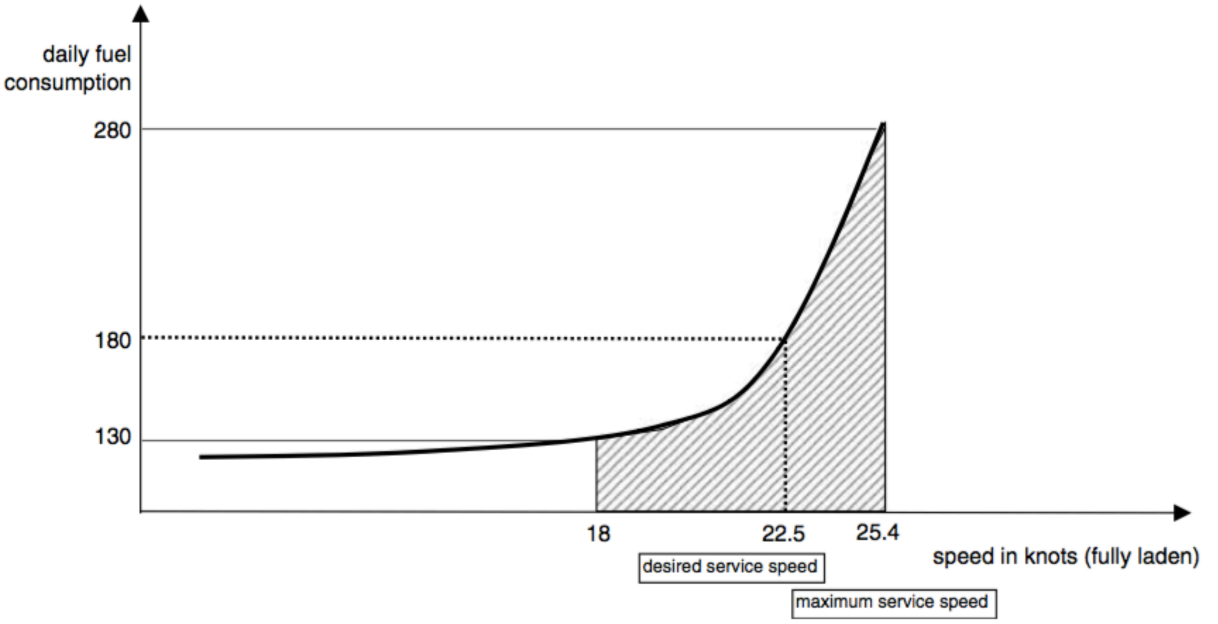
The decrease of commercial shipping speed is a phenomenon that has found its introduction less than ten years ago. Whereas economies of scale is already a widely investigated subject for decades, the amount of scientific research addressing the costs and benefits of slow steaming has made a big leap the last decade. Some early pre-crisis researchers already emphasized the potential of becoming a very important cost-saving method for the container carriers. However, during the pre-crisis era, business was mainly focussed on speeding up and offering high frequency an tight sailing schedules to satisfy its customers. After the first implementation of slow steaming in 2008, academic literature addressing this topic started growing and growing. This growing list of academic literature will be discussed in this section.

Notteboom (2006) was one of the first emphasizing the great benefits that could be obtained from slowing down vessel speed. Since fuel costs typically represent half of the total operating costs of modern container vessels, the non-linear relation between speed and fuel consumption had shown the magnitude of its savings possibilities. The example of this relation used by Notteboom (2006) is shown in figure 2. However, in order to compensate for the extra costs resulting from increased transit times, shipping lines need to estimate its value of time and that of its customers. This involves many factors and was considered as a factor which requires to be studied more intensively.

Notteboom and Vernimmen (2009) related skyrocketing bunker prices, new environmental legislation and declining revenues with the possibilities for network redesign. Adjusting vessel speed, vessel size and the number of vessels per loop creates large saving potentials. Bunker costs alone are reduced by approximately 30% when lowering vessel speed from 24 to 20 knots for 9500 TEU vessels. This research was very clear in comparing the savings potential that liner service network redesign has on the cost structure on individual service level. In this paper a break-even bunker price is calculated by comparing annual service costs of a specific service for a speed decrease from 23 knots to 20 knots. It appeared that a bunker price between \$125 and \$150 was already justified to speed 20 knots instead of 23 knots. One problem identified is the fact that shipping lines are reacting quite late to increasing bunker costs due to inertia, transit time concerns and fleet management issues. Therefore the urgent need for further research on the full impact of fuel costs on wide liner service networks is emphasized.

Corbett et al (2009) investigated the effectiveness and costs of speed reductions on emissions from international container shipping. It is found that speed reductions of 50% can lead up to 70% emissions reductions. This research was an important contribution since container shipping emits relatively large amounts of emissions compared to the size of the industry. However, the cost-effectiveness is found to vary with different profit-maximizing characteristics among different routes.

Figure 2: Daily fuel consumption at different service speeds



Note: Data for CSCL Oceania, 8,468 TEU, 93,000 bhp (data provided by Sea Span)
Source: Notteboom (2006)

Psaraftis et al (2009) also showed that speed reduction has a reducing effect on emissions. They also elaborate that the effectiveness of this reduction is dependent on the possibility of reducing port time as well, emphasizing the roll of ports within the intermodal supply chain. A speed reduction of 20% is associated with an emission and fuel cost reduction of 36.38% and a 15% speed reduction must be combined with a 37% reduction in port time (to maintain an equal voyage time). The latter is very challenging, however the use of extra vessels on the route to maintain service schedule is not considered.

Psaraftis and Kontovas (2010) examined models that have been developed to capture the trade-off between maritime logistics effects and policies to reduce the environmental effects of shipping. They stated that both in-transit inventory and non-operational ship costs increase when vessel speed is reduced. Their final results showed that slow steaming could be more expensive than full steaming given the fact that the daily charter rate is very high and/or when the cargo value is very high, resulting in higher in-transit inventory costs.

Cariou (2010) researched slow steaming as a cost-effective and sustainable way for reducing CO_2 emissions in shipping. In the short term slow steaming appears to be a very effective way of reducing emissions. However, if bunker prices go down combined with increased freight and inventory costs, the dilemma of sailing at a higher speed will sooner or later rise again. Slow steaming is claimed to be only sustainable in the long term when future bunker prices remain high and he proposes the need for tax levies or cap-and-trade systems to ensure this. Cariou (2010) calculated a break-even bunker price that varies between \$259/t[6] and \$568/t depending on the route selected. The break-even price accounted for the cost of additional vessel deployment and shipper inventory costs as a measure of time.

Meyer et al (2012) took a closer look to what extent slow steaming is profitable and how profit optimizing speeds can be calculated. They demonstrated that the optimal speed mainly depends on freight rates and fuel prices and estimated an optimal speed of 20,09 knots for a 8000 TEU vessel given their assumptions. Slow steaming is very unlikely to hold if the demand for shipping exceeds the supply of vessel capacity. The impact of exogenous variables like weather conditions and wave resistance are claimed to have significant influence on a vessel's fuel consumption. Nonetheless, these factors are often ignored in other studies. Meyer et al (2012) point at the technical issues regarding to sub-optimal engine usage resulting in shortened engine life spans creating the need for additional investments. However, they did not incorporated this in their own model.

Maloni et al (2013) have researched the consequences of slow steaming for both the carriers and the shippers. They elaborated on existing equity effects and its consequences on the degree of slow steaming acceptability by stakeholders. Carriers solely enjoy the economic benefits of slower steaming, while the shipper experiences increased pipeline inventory costs. Extra slow steaming (±18 knots) is found to be the supply chain's overall net gain maximizing speed. Passing on some of the financial benefits from the carriers to the shipper (e.g. lower contractual rates and lower bunker surcharge reductions) will especially be advantageous for high-value cargo shippers.

So far most academic research has focused on the sustainability and cost effectiveness of slow steaming. All point out that slow steaming has a significant effect on reducing fuel costs and its corresponding CO_2 emissions. However, bunker prices are highly volatile and is generally assumed to be a given variable in other research, despite the case of Cariou (2010) and to a certain extent Notteboom and Vernimmen (2009). Some papers have calculated a profit optimizing speed ranging from 18 to 20 knots depending on the factors taken into account. Generally, effects of slow steaming are calculated by monitoring the effect of one speed reduction from for example 23 knots to 18 knots, neglecting the effect of other speed reductions possible.

This research is focused on all major cost changes from a carrier's perspective resulting from slow steaming on individual service level. The bunker price is treated as an endogenous variable and will therefore be determined by the model. The final result of this research will show a break-even bunker price corresponding to specific speed reductions ranging between 11 and 25 knots. This break-even bunker price is equal to the price needed to offset the cost increase faced by carriers resulting from sailing one knot slower consecutively on service level. Consequently, the break-even price multiplied with the saved fuel consumption is treated as a cost saving for decreasing vessel speed. The results in this paper will give important insights in how carriers should strategically optimize their services in terms of vessel speed, vessel size and amount of vessels deployed on the service. This will be further elaborated in section 3. This research complements earlier research by determining break-even bunker prices along the entire range of possible vessel speeds rather than selecting a specific speed reduction. For example, the effect of steaming at 18 knots instead of 25 knots. Therefore

[6] Price in U.S. dollars per ton of fuel (\$/t)

this research gives insights in marginal costs and revenues along the entire speed spectrum. Notteboom and Vernimmen (2009) examined the effect of slow steaming in case of eight or ten port calls per service. As will be shown later on in this research, the number of ports called are generally much higher implying a different network design and route structure compared to their research conducted in 2009. This research complements the work of Cariou (2010) by only taking the carrier perspective into account consideration rather than the supply chain as a whole. Also more variables like cost of capital, emission costs and carrier time costs are incorporated in this model, whereas Cariou (2010) only took carrier operating cost and shipper in-transit inventory cost as explanatory factors.

2.2 The practice of slow steaming

2.2.1 The Practise of Slow Steaming during the 2008-2016 time frame.

Full speed, or design speed, for a containership typically lies typically around 24 or 25 knots, which is generally between 85% (at most 70%) and 90% of engine capacity. Reducing vessel speed to 21 knots represents 'slow' steaming. Reducing to 18 and 15 knots represents 'extra slow' and 'super slow' steaming respectively (Maloni, Paul, & Gligor, 2013). Slow steaming is a consequence of overcapacity and the rise in fuel price in the period 2007-2008. In this time frame the supply of 240 container vessels increased total shipping capacity by 10%, while demand reduced 10% at the same time (Cariou, 2010). Simultaneously, fuel prices exceeded $700/t of IFO380[7] making carriers eager to use extra slow steaming and super slow steaming in their efforts to reduce fuel costs (ShipandBunker, 2014). Ever since, slow steaming has reduced overcapacity in the market to such an extent that this, in itself, will keep carriers from sailing faster. According to analyst agency Alphaliner, slow steaming has secured work for around 7,1% of the global container fleet, which otherwise would be idle (Shippingwatch, 2014a). Steaming faster, and consequently flooding the market with latent capacity, would have a decreasing effect on liner shipping freight rates and carrier revenues (Shippingwatch, 2014b). In summary, slow steaming positively addresses overcapacity and surges in the fuel cost by reducing them both (Cariou, 2010). However, other analysts have pointed out the benefits of speeding up in periods of low bunker prices. Even though it requires more fuel to sail faster, it is an effective way to meet customers' demand for on-time arrivals (Shippingwatch, 2014b). The second halve of 2014 saw a big drop in fuel prices, creating the anticipation of steaming faster for some carriers (Laursen, 2015). Still, for many shipping lines, slow steaming will be the way of doing business in the upcoming years (Shippingwatch, 2014b).

It can be seen that slow steaming is a phenomenon that will not be disappearing anytime soon. The relation between vessel speed, fuel costs and the amount of supplied vessel capacity is a complicated one to understand. In order to have a better understanding, the foremost advantages and disadvantages of slow steaming will be discussed.

[7] The main type of heavy fuel oil used in container shipping

2.2.2 The Practise of Slow steaming: The advantages and disadvantages.

Fuel efficiency

Lowering the vessel's speed generally improves fuel efficiency allowing shipping lines to save on bunker (marine fuel) costs, which is a volatile but expensive cost driver (Maloni, Paul, & Gligor, 2013). Given high fuel prices, for example $700/t, fuel costs can exceed over 50% of a vessel's operating costs (Rex, 2015; Notteboom & Vernimmen, 2009). Thus, changes in fuel costs have a significant impact on the transport costs per TEU (Notteboom & Vernimmen, 2009). Figure 2 in section 2.1 shows this relation between fuel consumption and vessel speed very clearly.

Lower greenhouse gas emissions

A reduction in fuel consumption is directly relating with lower levels of greenhouse gas emissions (Maloni, Paul, & Gligor, 2013). CO_2 Emissions are proportional to the amount of fuel burned with a factor of 3,17 ton emitted per ton of fuel (Cariou, 2010; Corbett et al, 2009). According to the International Maritime Organization (IMO), container shipping generated 205 million tonnes of CO_2 emissions in 2012, which equals 25,8% of the total CO_2 emissions from international shipping (IMO, 2015). In 2012, the container fleet accounted for only 9,6% of the total fleet (EMSA, 2012). Therefore it is worth studying what the effects of slow steaming are on the carbon footprint of container carriers. As Corbett et al (2009) and Cariou (2010) have demonstrated, CO_2 emission cost can be reduced up to 70% and slow steaming stays sustainable in the long if bunker prices are high. Shippers too benefit from slow steaming by reducing their supply chain carbon footprint (Maloni, Paul, & Gligor, 2013).

Absorption of excess fleet capacity and liner shipping freight rates

The shipping market, characterized by the emergence of ultra large container vessels (ULCVs) of 18.000 TEU+ and structural oversupply, keeps shipping lines struggling with low freight rates. In periods of slacking demand, pre-crisis multimillion investments in ULCV's may turn into investments in lower freight rates and ultimately worse (Laursen, 2015). As mentioned in section 2.2.1, slow steaming has secured work for 7,1% of the global container fleet which other wise would have been idle (Shippingwatch, 2014a). Slower service speed essentially reduces capacity on a service string, giving carriers the opportunity to deploy excess vessels using slow steaming to maintain service frequency instead of laying up hundred million dollar vessels incurring lay-up costs (Leach, 2008; Maloni et al, 2013).

Increased schedule reliability

Based on a research conducted by Notteboom (2006), container vessels face many sources of schedule unreliability during their voyage. About 86%[8] of this unreliability is caused by terminal congestion (65,5%) and below expectations terminal productivity (20,6%). When steaming at full speed, it is almost impossible for shipping lines to catch up lost time because it is simply not possible to steam faster than full speed. Unexpected delays will than cascade through the whole loop of port calls (Notteboom, 2006). However, vessels that operate under slow steaming have the flexibility to steam faster for a period of time to make up for time lost due to delays.

[8] Figures are based on survey data from the fourth quarter in 2004.

Pipeline inventory costs

Shippers pay a price for the positive effects that slow steaming has on their reduced supply chain carbon footprint. Namely, longer transit times will increase pipeline inventory[9] costs (Bonney & Leach, 2010; Maloni, Paul & Gligor, 2013). Although the earlier mentioned increase in schedule reliability and the resulting lower safety stock needed, vessel speed appears to be more important than the reliability of ocean shipping for the shippers (Saldanha, Tyworth, Swan, & Russel, 2009). Longer transit time extent the forecasting horizon needed for shippers to keep their stock at a sufficient level. The longer the forecasting horizon, the lower the accuracy of the prediction, which increases safety stock[10] needs (Maloni, Paul, & Gligor, 2013). However, according to the vice president of global freight and logistics at Electrolux, most shippers are already coping for many years with horrible carrier schedule reliability and have created a certain buffer in their inventory system anyway (Bonney & Leach, 2010). In other words, adding a week of transit times doesn't make much of a difference in terms of safety stock needs. For shippers obliviously of greater concern, are longer transit times for time sensitive and perishable goods (Page, 2011). According to the industry, slow steaming isn't going to disappear anytime soon implying that shippers can't do anything much more than adjusting to longer transit times (Shippingwatch, 2014b). Since this paper primarily focuses on slow steaming from a container carrier's perspective, the shipper's perspective will not be elaborated any further.

Vessel engine degradation and solutions

According to Faber et al (2010), the relationship between speed and fuel consumption depends on an engines type and its load. Most vessel engines are designed to be running between 70% and 90% of the maximum continuous rate (MCR) (Cariou, 2010). The MCR is the maximum rating required by the yard or owner for continuous operation of the engine (MAN, 2016a). However, slow steaming may cause engines to run below 50% MCR and even running near 10% MCR is reported[11] (MAN, 2012). The lifespan of an engine is expected to decrease due to suboptimal usage. Engine manufacturers offer special slow steaming kits, but these require additional investments by shipping lines (Meyer, Stahlbock, & Voß, 2012). Wärtsilä, an marine engine manufacturer, advices operators to take precautions when operating the engine continuously at loads below 60% (Motorship, 2010). Newly ordered megaships are nowadays getting equipped with so-called electronically controlled common rail-systems instead of the conventional mechanically controlled fuel injection pumps and exhaust valve drives. This new and more expensive type of control system allows for excellent fuel costs savings across the entire load range ultimately reducing time between overhauls and hence reduce maintenance (Santala, 2013). Still, investments are required by carriers and many vessels are still operated using conventional engines (MAN, 2016b; Meyer et al, 2012).

Overall rate of importance of slow steaming for shipping lines

MAN Diesel & Turbo (2012) conducted a web survey late 2011 among 200 representatives of the global container and bulk shipping industry of which 149 had

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9 Pipeline inventory: Goods that have left a firm's warehouse(s) but have not been bought by the ultimate consumers, customers, or users, and are therefore still within the firm's distribution chain. Source: www.businessdictionary.com

10 Safety stock: Inventory held as buffer against mismatch between forecasted and actual consumption or demand, between expected and actual delivery time, and unforeseen emergencies. Source: www.businessdictionary.com

11 Survey among 149 respondents using slow steaming outcomes for container vessels: 10-30% MCR (17,8%), 20-40% MCR (25,8%), 30-50% MCR (6,4%)

implemented slow steaming. Their responses about the foremost advantages of slow steaming are summarized in table 2.

Table 2: Main advantages for shipping lines

Main advantages of slow steaming	Considerers	Implementers
Fuel cost savings	93,7%*	94,70%
Greater Utilisation of existing Capacity	22,50%	34,20%
Avoiding of idling costs	29,70%	28,90%
Schedule reliability	10,00%	15,80%
Service and maintenance savings	17,10%	18,40%
Lower emissions	36,00%	42,10%

* Respondents were able to provide more than one answer
Source: (MAN, 2012)

For shipping lines fuel costs savings are, by far, the most important reason for using slow steaming, followed by creating a use for excess fleet capacity together with its corresponding reduce in opportunity costs associated with idle ships.

2.3 Environmental Legislation – Future Implications

Carriers are subject to environmental regulations that are imposed by IMO and the countries whose waters they pass. The U.S. and Europe have imposed so-called Emissions Control Area's (ECAs) within 200 nautical miles of their shores, requiring ships to burn low sulphur fuel, for example LS380, instead of conventional IFO380. These regulations will cause higher fuel costs over time due to the cleaner and more expensive types of fuels that must be used (VOLPE, 2013). Back in 2009, about 80% of the total bunker fuels was related to heavy fuel oil (HFO). About 70% of al marine fuel sales in Singapore concern the IFO380 grade. Other bunker fuels are marine diesel oil (MDO) and marine gas oil (MGO). The latter is typically burned when a container ship is in port, because most ports prohibit burning low-grade fuel in the port area (Notteboom & Vernimmen, 2009; VOLPE, 2013). High sulphur bunker fuel, like IFO380, has limited application causing it to be relatively cheap. Because of its impurities, it produces high emissions when burned in engines. This is the main reason that the application of high sulphur fuel grades is increasingly being prohibited in ports and near coast areas (VOLPE, 2013).

2.4 Shipping Lines Are Using the Bunker Adjustment Factor Against Fuel Costs Volatility

Due to a high degree of volatility in de oil industry, shipping lines can face very different costs structure due to highly fluctuation fuel costs. With bunker prices reaching over 700$/t, fuel costs may exceed 50% of the operating costs of a vessel. However with bunker prices around $250/t, fuel costs only account for 30% of the operating costs. In times of increasing bunker costs, ship-owners attempt to partially pass the extra fuel costs on to the customer using variable surcharges like the so-called Bunker Adjustment Factor (BAF) (Notteboom & Vernimmen, 2009). Fuel surcharge practices have considerably evolved since the abolition of the European liner conferences[12] in October 2008. This meant that shipping lines were banned from collectively setting freight rates

[12] liner conferences are agreements on co-operation among shipping lines. Source: www.globalnegotiator.com

and surcharges. Nowadays these surcharges are directly negotiated between shippers and shipping lines (VOLPE, 2013). For carriers serving the U.S. to Asia markets, a BAF calculator is suggested by the Westbound Transpacific Stabilization Agreement[13] (WTSA) and the Transpacific Stabilization Agreement[14] (TSA). Maersk is a worldwide carrier with its own BAF. After the banning of conference BAFs, Maersk created its own BAF for both its European and worldwide operations (VOLPE, 2013). The implementation of the BAF is widely debated as a way of fuel cost recovery on the on hand and as a way of making extra revenue on the other hand. Previous research indicated that the revenue-making character of BAF has not disappeared after the abolition of liner conferences. Most trade routes have even experienced an increasing gap between the BAF rate and actual fuel costs (Notteboom & Cariou, 2009). The BAF rate per FEU[15] carried was typically much higher than the average fuel cost per FEU.

The effect of the BAF rate will be neglected in this research due to technical considerations. The BAF rate is determined using the bunker price level. However, the purpose of this research is determine the bunker price itself which leaves the calculation of the BAF rate beyond the scope of this research.

[13] For carriers serving Asia to U.S. East and West Coast Market. Source: (VOLPE, 2013)
[14] For carriers serving Asia to U.S. West Coast Market. Source: (VOLPE, 2013)
[15] FEU = Forty Foot Equivalent

3. Methodology

3.1 Objectives

As discussed in section 2, the fundamental reason why slow steaming is implemented is because it offers huge costs savings, emission savings, and it operationalizes excess capacity. By developing a model that quantifies the trade-off between different vessel speeds in terms of costs and benefits, strategic implication for carriers can be determined. On the one hand, carriers could save fuel costs and maintain a weekly service frequency under slow steaming if they deploy more ships on the service. On the other hand, carriers can reduce transit times and increase annual vessel transport capacity if they increase vessel speeds. Both scenarios have their costs and their benefits. This research aims to create a clear framework for this trade-off by developing a model that calculates annual costs on service level for different speed levels.

The ultimate purpose of the model itself is to provide a tool for assessing cost changes as a result of changes in vessel speed. Comparing these cost changes with the savings in fuel consumption creates the opportunity to measure bunker prices needed to equal cost savings with cost increases. Therefore it is important that the ultimate model has the form of a first difference model. This way, changes in factor X result in a change of factor Y, which is in an abstract way exactly that what must be measured for each speed reduction. An important aspect is that the model must be internally consistent and produce outputs that are representative for the given service and vessel types used rather than be absolute definitive (Cullinane & Khanna, Economies of Scale in Large Container Ships, 1999). In case other values or different variables are used instead of the ones selected in this model, final results would obviously be different.

The model typically focuses primarily on cost incurred by the shipping lines. This implies that the freight rates, or the revenue side of the shipping lines, is not taken into account. The reason is that including freight rate changes as a result of vessel supply changes is to difficult to measure and would therefore negatively affect the accuracy of this research. Meyer et al (2012) incorporated the freight rate in their model as an exogenous variable. Given the freight rate, total revenue per annum was directly associated with the effective capacity supplied and the maximum number of round-trips per year (and thus vessel speed). However since this doesn't incorporate freight rate differences due to differences in vessel supply rate, which has been claimed to directly influence each other (section 2.2.1), the freight rate is ignored in this research.

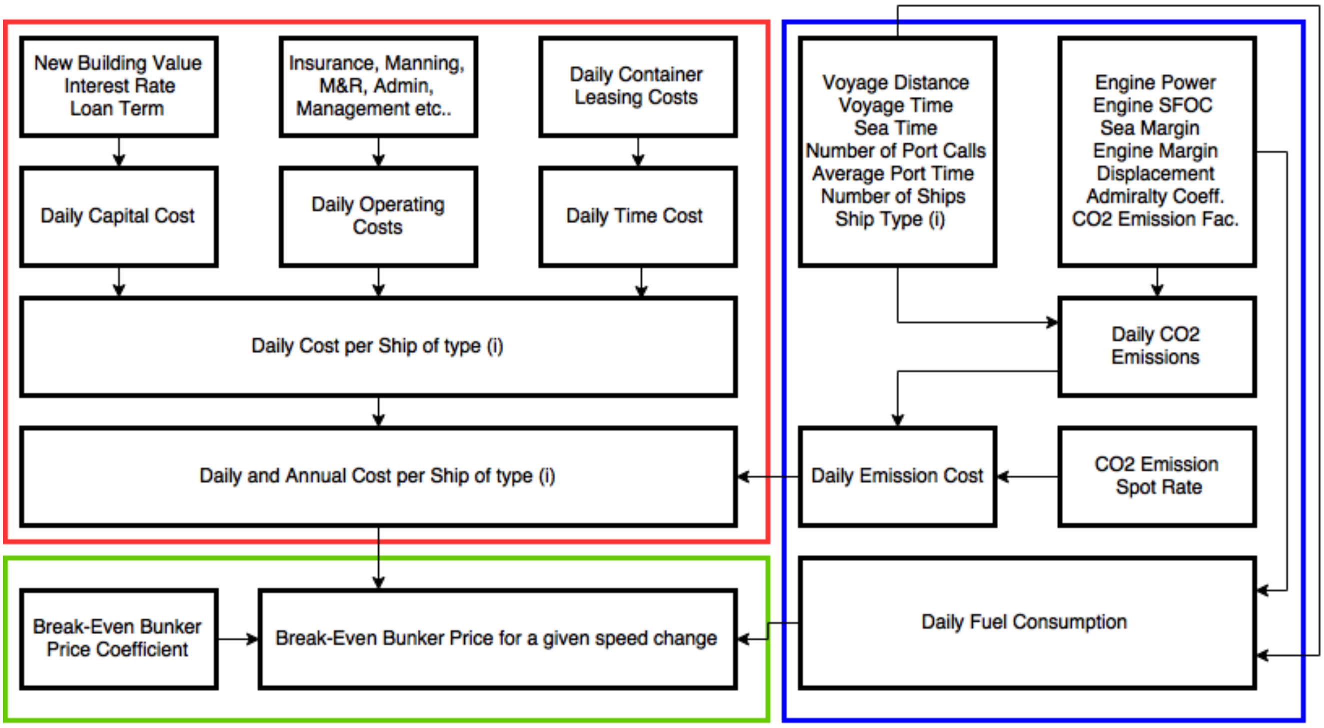
3.2 A Conceptual Model

To understand the connection between lower speed and the associated cost savings on the one hand and the corresponding costs of deploying extra vessels and increased transit times on the other hand, it is necessary to identify factors which lead to this cost change.

For sea transport, the time it takes to deliver the containers and the distance travelled per voyage, strongly influences the total cost incurred. The variability of specific cost factors can highlight ship-related costs over a range of different vessel types and sizes (Cullinane & Khanna, Economies of Scale in Large Container Ships, 1999). Combining this with vessel specific characteristics concerning fuel consumption, engine power and service characteristics insights can be obtained into a vessel's fuel cost on a specific service. In order to create a clear view on what will be incorporated in the model a relation diagram is constructed, figure 3.

The first factor analysed is the fuel consumption for a given service route and its corresponding ship type for each investigated speed level. The relation between fuel consumption and vessel speed becomes clear in this part and is summarized by the blue relation in figure 3. The second factor analysed considers the environmental aspect of container shipping and quantifies the annual tons of CO_2 emitted in monetary units. Since CO_2 emissions are directly associated with fuel consumption, this factor is also captured in the blue relation. The third and last factor analysed are the cost associated with the deployment of vessels itself. This vessel cost factor consists of operating cost, capital cost and time cost and is captured in the red relation in figure 3. All three factors combined, together with a bunker price coefficient results in a break-even bunker price, hence the green relation. This break-even bunker price is calculated by taking the first difference of the total cost on the one hand and the total fuel consumption on the other hand. The result states what the bunker price for each consecutive speed reduction must be to offset the cost changes associated the vessel cost factor en the CO_2 emissions cost factor.

Figure 3: Conceptual vision of aggregated cost factors



Source: author's own elaborations

3.3 Data Sources and Data Modification

The major source of liner shipping service data are the shipping lines liner service schedules that are publicly available on the carrier's website. The services used in this research are collected from Maersk, MSC, CMA CGM, COSCO and Evergreen. These are the biggest carriers with the most market share in terms of fleet capacity. As mentioned earlier in this paper, Maersk and MSC are collaborating under the 2M Alliance and the rest is part of the Ocean Alliance. All 232 east- and westbound services from the big five are investigated which all are serving the following service route segments:

(1) Asia – North Europe (ANE)
(2) Asia – Mediterranean (AM)
(3) Asia – U.S. West Coast (TWCU)
(4) Asia – U.S. East Coast (TECU)
(5) U.S. East Coast - North Europe (TE)

The east- and westbound services are converted to round-trips in order to measure the influence of slow steaming for the entire voyage. This way also duplicate port calls in east- and westbound legs are cancelled out against each other. This creates the opportunity to calculate the number of round-trips possible on an annual basis. Services for which it was not possible to convert both legs into a round-trip service due to discrepancies between the east- and westbound leg are disregarded. Vessel information was either obtained from carrier's service outline documents or where found by entering route specific information into a carrier's schedule finder to determine which vessels sail between which ports on which services. When no further vessel details were given besides vessel name and service of deployment, additional vessel information is obtained from containership-info.com. Information concerning which ports are called on which service is retrieved from the carrier's website. Port to port distance for every port in the selected data set is calculated using the distance calculator found at portworld.com.

Vessel general characteristics per ship type are obtain from MAN Diesel & Turbo (2016b). Vessel information from carrier websites is compared with this general characteristics from MAN (2016b) in order to assign generalized vessel characteristics to each individual service. An important assumption in this respect is that vessels being deployed on the same route share the same characteristics.

Information regarding CO_2 emissions is obtained using information from Corbett et al (2009). The monetary value of these emissions is calculated using information form The European Energy Exchange (EEX). Other cost information is mainly gathered from Maersk Broker (2016), Murray (2015), Notteboom and Verbeke (2004), Streng (2012) and Baird (2006). Information from these sources are compared with the ultimate cost figures from this research in order to say something about the model's comparability and validity.

3.4 Operationalizing the Model's Variables and Modal Assumptions

This section describes how individual model components are measured and the assumptions that are made in order to make the calculations in the analysis section.

In order to measure the relation between speed and fuel consumption a specific formula known as the 'admirality formula' is used to correct fuel consumption for different vessel sizes. The formula calculating the admiralty coefficient (AC) is adopted from MAN (2016a) and is shown in [1].

[1] $$AC = \frac{\varepsilon^{2/3} V^3}{P} = \frac{\varepsilon_{des}^{2/3} V_{des}^3}{P_{des}}$$

The (ε) variable denotes a vessel's displacement volume. This coefficient is assumed to be 1,365 times the deadweight of a vessel (MAN, 2016a). The other two variables (V) and (P) represent the vessel (design) speed measured in knots and the required (design) engine power respectively. Another popular method to calculate the fuel consumption at any speed is to make use of the cube rule (Notteboom & Cariou, 2009). However, vessel size characteristics are not accounted for in this formula, which is why the admiralty formula is used in this research instead of the cube rule.

Most researchers assume a fixed specific fuel oil consumption (SFOC) rate for any engine load level. However this is not the case in reality and fuel propulsion differs in a parabolic relation over the entire engine load range. In order to correct for this, the SFOC-engine power relation of four different engines types corresponding to different vessel sizes is collected. This makes sure that fuel propulsion (measured in g/kWh) is different for different energy levels and thus different speed levels. This assumption is in accordance with (MAN, 2016a and 2016b). Each engine also corresponds to a different type of ship and thus in terms of power capacity. The SFOCs for each engine type are shown in appendix 1, 2 and 3 and are denoted by [2] through [5]. In this research the fuel propulsion of auxiliary engines is ignored even as fuel consumption in port. The former because according to Stopford's (2009) assumptions, auxiliary fuel consumption is only around 3% of the main engine's fuel consumption. The latter, because fuel consumption in ports typically consists of cleaner fuels, see section 2.2, and port fuel consumption is not affected by speed differences at sea.

An engine margin of 10% and a sea margin of 15% are assumed in the model. The sea margin is a correction added because the power required to reach a certain speed is higher due to hull fouling, wind resistance and wave resistance and residual resistance. The engine margin typically fully accounts for the added power needed because hull fouling (Eide, 2015 and MAN, 2016a). The general vessel characteristics used from (MAN, 2016b) already have incorporated these margins in their dataset.

[2] $SFOC_{10K98ME7} = 0{,}0071M2 - 0{,}9577M + 195{,}73$ M = engine load %

[3] $SFOC_{11K98ME7} = 0{,}0067M2 - 0{,}9476M + 194{,}43$ M = engine load %

[4] $SFOC_{12K98ME7} = 0{,}0061M2 - 0{,}8774M + 189{,}69$ M = engine load %

[5] $SFOC_{S70MC\text{-}C8} = 0{,}0031M2 - 0{,}4733M + 182{,}98$ M = engine load %

The calculation of the daily fuel consumption for one ship of type (i) on a specific route (j) is done using [6]. The fuel consumption is measured in metric tons (mt). formula [6] is based on the author's own elaboration on Cullinane (2011) and Cariou (2010) given the fact that the engine and sea margin are already incorporated in the engine propulsion formulas [2] through [5] as explained earlier.

$$[6] \qquad FC[mt]_{day,i,j,V_N} = \frac{SFOC_{i,V_N} \times kWh_{i,V_N} \times 24}{10^6}$$

The SFOC of ship type (i) is measured in (g/kWh). Multiplying the SFOC with the power needed per hour (kWh) at a certain vessel speed (V_n) gives the fuel consumption in grams per hour. Multiplying this by 24 gives the vessel's daily fuel consumption in grams. The last step is to convert this amount in grams to metric tonnes by dividing the above mentioned by 10^6 which equals one metric ton in terms of grams.

The average port time per port call is assumed to be 0,916 days per port call. This is the average port time taken from four studies, namely Notteboom and Vernimmen (2009), Notteboom and Cariou (2009), Ting and Tzeng (2003) and van Elswijk (2011). The sea time needed to complete a full round-trip is calculated by using [7], which is in accordance with Notteboom and Vernimmen (2009). Formula [7] divides the total voyage distance in nautical miles (D) by the vessel's daily speed. It is assumed that vessel speed is constant over the entire round-trip. Total voyage time is calculated by summing up the total port time and total sea time, see [8]. The former is calculated by multiplying the number of ports calls per round-trip[16] with the average port time.

$$[7] \qquad T_{sea,days} = \frac{D_{voyage,nm}}{V_n \times 24}$$

$$[8] \qquad T_{voyage,days} = T_{sea,days} + T_{port,days}$$

The number of days a vessel is operational per year is assumed to be equal to 350 days, which is in line with Baird (2006) and Stopford (2009). The remaining days are used for bigger periodic maintenance (Meyer, Stahlbock, & Voß, 2012). The annual fuel consumption per ship of type (i) on route (j) is then a function of the daily fuel consumption, the sea time per round-trip and the number of round-trips per year. Calculating the fuel consumption on annual service level can be expressed mathematically using [9]. Formula [9] is a combination of [6] [7] and [8]. The latter is used to calculate the number of annual round-trips possible given the number of operational days per annum. (K) represents the total number of ships needed to maintain a weekly service frequency[17] for a certain speed. This is an assumption that must be enforced at all times.

$$[9] \qquad FC[mt]_{year,i,j,V_n} = \sum_{k=1}^{K} FC[mt]_{day,i,j,V} \times T_{sea,days} \times \frac{350}{T_{voyage,days}}$$

The cost calculation of other costs that will be discussed in this paper is twofold. The first part concerns the CO_2 emission costs (EC) on an annual service level for various vessel speeds. The second part concerns the costs incurred due to longer transit times and additional vessels deployed. These cost category covers vessel operating cost, (OC), capital cost (CC) and time cost (TC).

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16 One port is substracted from the total number of port calls because the last port called on the round trip counts as the first port call on the next round-trip.

17 The weekly service frequency assumption states that $T_{voyage,days} \leq K \times 7$. Source: (Notteboom & Vernimmen, 2009)

First, emission costs are calculating making use of the emission factor of 3,17 established by Corbett et al (2009). This means that per ton of fuel consumption a total of 3,17 of CO_2 is emitted. The 3,17 is computed by multiplying a fuels' carbon fraction (86,4%) with its 'carbon to CO_2 converting factor '(44/12) (Corbet, Wang, & Winbrake, 2009). The monetary value of one metric ton of CO_2 is calculated using the EU Emission Allowance Index sport rate per ton of CO_2 which equals €6,07 [18] (EEX, 2016). Furthermore a euro/dollar exchange rate of 1,1154 (Bloomberg, 2016) is used to calculate the dollar value of $7,46. The total emission costs for each liner service per year is then calculated using [10], which is in accordance with Corbett et al (2009) where (K) is the total number of ships (appendix 4) deployed on a service given constant speed (V_n). The variable (N) denotes the number of round-trips per year.

[10] $$EC_{year,i,j,V_n} = \sum_{k=1}^{K} 3{,}17 \times \$7{,}46 \times FC_{i,j,voyage} \times N$$

In order to calculate the daily operating cost (OC_D) per vessel, information is retrieved from HSH Nordbank (2008), Greiner (2014 and 2015), Hofstra (2016) and mainly Murray (2015). Figures concerning OC_D vary considerably per publication. The composition of the OC_D is not uniform for each publication and in some publications fuel costs are also incorporated in the daily operating cost. The latter must be threated as a separate component in this research. HSH Nordbank, one of the world's leading financial service providers in the global shipping industry, published an OC_D trend in 2008 for various vessel sizes covering the years 2000-2008. The article suggested that the OC_D for al ships of 3000 TEU and bigger where converging to an OC_D of around $9000 in 2009 (HSH Nordbank, 2008). However, Greiner (2014 and 2015) published OC_D growth-indices that showed a minor decline OC_D in ever since its 2008 peak and settling at 6,9%[19] lower OC_D level in 2014. Hofstra (2016) published another OC_D distribution suggesting a more diverged cost distribution varying from $8300 and $11700 for 4000 TEU and 10000 TEU vessels respectively. Murray (2015) offers a solution by expressing OC_D per TUE for different vessel sizes. The OC_D per TEU suggested by Murray (2015) is displayed in figure 4. This figure will be used as a basis to calculate the daily and annual operating cost for al different vessel sizes that are part of this research.

The annual capital cost per vessel is calculated using the following steps. First, the new build value for each ship type is calculated. Second, the annual interest percentage must be determined in order to calculate annual interest costs for each vessel. Generally, vessels are financed via a 5% to 10% down payment and an interest-bearing loan. Banks are more willing to come in with finance, ultimately providing somewhere between 50% and 75% of the price of the vessel, or up to 80% with export credit (OECD, 2007). However for convenience, it is assumed that the entire new building value of a vessel is financed using credit. The interest rates for these credits depend on the state of the economy. In order to assign capital costs to ship it is assumed that the entire ship is purchased using a bank credit. The economic life, and hence the loan term, of a vessel is assumed to be 20 years, which is in accordance with Stopford (2009). The interest rate is assumed to be equal 6,125%, which is in line with Baird (2006), Stopford (2009)[20]

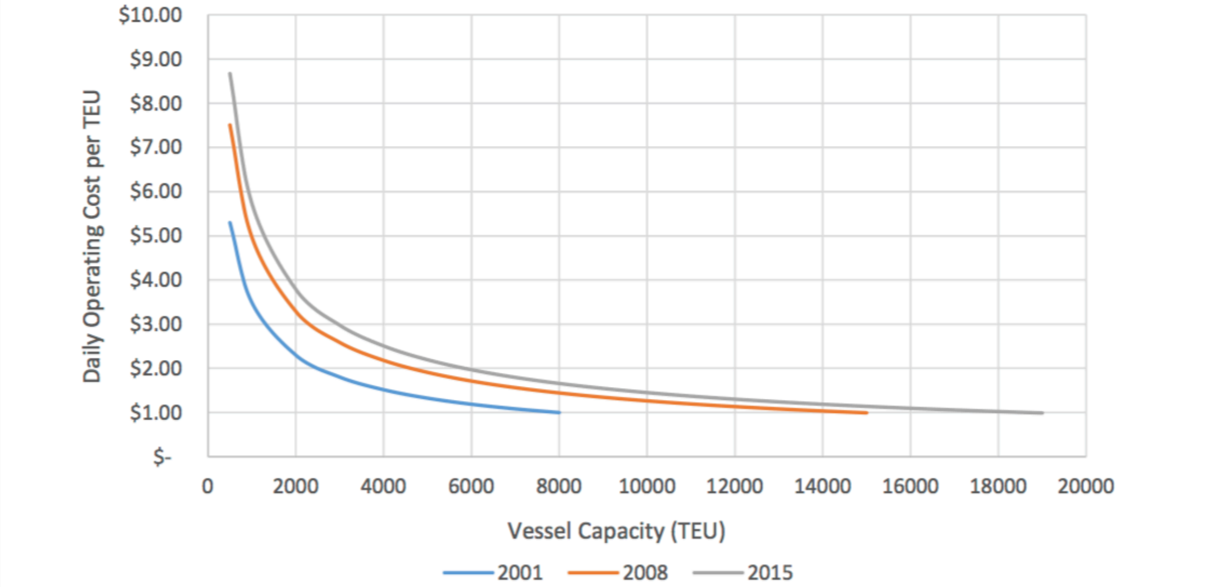
[18] This is the spot rate on 2016-5-31. Using the exchange rate of 2016-5-31 the price in $ per ton CO_2 equals $7,46.

[19] The OC_D index in 2008 was 173 and in 2014 it was 163, which equals a decrease of 6,9%

[20] Stopford (2009) assumes 6% and 8% in his own calculations, see blz 224 and 540 of Stopford (2009)

and AECOM (2012). Nowadays, the current 12-month USD-LIBOR interest rate[21] equals 1,32840% which is much lower than 6,125%.

Figure 4: Daily Operating Cost[22] per TEU for Various Vessel Sizes



Source: (Murray, 2015)

The LIBOR is the London interbank offered rate and is used as a basis to finance most shipping loans (Stopford, 2009). The point is that all vessels that are currently deployed are ordered in the past and bear costs based on interest rates set in the past. Since mostly the biggest ships of 15.000 TEU plus are constructed the last couple of years, and the smaller ships are approximately some years older it is assumed that the older interest rate is still valid. In order to calculate the annual interest payments. When other interest rates are used capital cost will obviously be different. The calculation of the annual interest cost is done using the annuity formula [11][23].

$$[11] \quad CC_{year,i} = A_{year,i} = P \times \frac{i \times (1+r)^n}{(1+r)^n - 1} = P \times AF$$

The fraction part of equation [11] represents the annuity factor (AF) and variable (P) is equal to the new build value, and thus the loan value of a vessel. (A_{year}) represents the annual annuity. The annual interest rate is represented by (r) and the number of years before the loan matures is equal to (n). The CC_D is calculated by dividing the annual annuity (CC_{year}) by the amount of operational days, which is assumed to be 350 days. In order to get these capital costs on annual service level, the annual capital costs per ship have to be multiplied with the number of ships deployed at a certain speed.

From a shipper's perspective, time cost can be calculated by monetizing additional pipeline inventory costs due to longer transit times. However, container carriers do not face these cost. So it is necessary to monetize additional transit time in a different way.

[21] The USD-LIBOR rate at 2016-6-1, source: http://www.global-rates.com/interest-rates/libor/american-dollar/usd-libor-interest-rate-12-months.aspx
[22] Operating cost include: Crewing, Manning, Insurance, Stores and Lubes, Repairs and Maintenance
[23] Also known as the Equated Monthly installment (EMI) formula using the annual interest rate. Source: (Ghosh, 2014)

Streng (2012) quantified time costs in terms of additional container costs. These costs are borne by the carrier for the reservation of a container slot and the lease of the container itself. Notteboom and Verbeke (2004) quantified these specific cost category by using a lease price coefficient per container of €0,02708 per hour. Converting this coefficient to dollars using the same exchange rate used in the emission cost formula results in a lease cost of $0,03021 per hour.

Multiplying this coefficient with the number of hours per year[24], the vessel's capacity (TEU) and a load factor of 87,5%[25] equals the total annual time cost per vessel. Multiplying this with the number of vessels deployed for different speeds (appendix 1) gives the time cost per ship. The formula used in this research will then be:

[12] $$TC_{year,i,j,V_n} = \sum_{k=1}^{K} 0,03021 \times 8400 \times 0,875 \times TEU_i$$

Where (K) is the total number of vessels deployed at a service at a certain speed level (v) and (TEU_i) is the capacity of the vessel type used on that service. As can be seen from [12], the annual time cost for each service route dependents on the amount of vessels deployed and the capacity of these vessels. This is because the total voyage time on an annual level is the same for every vessel on the service regardless of the vessel's speed. The only thing varying as a result of increasing vessel speed in this respect is the amount of round-trips a vessel can make in one year, which in turn, influences the number of vessels needed to maintain a weekly service frequency. The formula is in line with the statements of Notteboom (2006) about the need to value time from a carrier perspective. Streng (2012) used a similar calculation, however, he based the time cost in terms of additional sailing hours instead of total sailing hours. This research corrects for this fact by taking the first difference of each cost category in the end.

The break-even bunker price (BEP) will be calculated by means of a first difference equation. This way the required fuel cost savings[26] necessary to offset the cost increase resulting from additional transit times and extra vessel deployment is calculated. Formula [13] mathematically represents this description. In this paper it is assumed that there is only one type of fuel used, namely IFO380. As mentioned in section 2.2, about 70% of al marine fuel sales in Singapore in 2009 concerned the IFO380 grade. This indicates that it is the most important fuel source in container shipping. Revising equation [13] to an equation for which the BEP is the dependent factor can be done by dividing both sides of equation [13] by ΔFC leading to equation [14]:

[13] $$\Delta FC \times BEP_{IFO380} = \Delta CC + \Delta OC + \Delta TC + \Delta EC$$

[14] $$BEP_{IFO380} = \frac{\Delta CC + \Delta OC + \Delta TC + \Delta EC}{\Delta FC}$$

Equation [14] is in accordance with Cariou (2010), who calculated a break-even bunker price on supply chain level by using pipeline inventory costs as time costs from the shipper's perspective and operating cost from the carrier's perspective.

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[24] Assuming 350 operational days and 24 hours per day, the total number of hours per year equals 8400 hours

[25] Average load factor of eastbound legs (80%) and westbound legs (95%). Source: (Notteboom & Vernimmen, 2009)

[26] Defined as the break-even bunker price multiplied with reduction in fuel consumption due to a speed decrease of one knots

4. Data Analysis

The data analysis is organized in the following structure. Per cost factor discussed in section 3.2 the results are calculated based on formulas explained in section 3.4. Per individual cost component the results are explained on a daily and annual basis for each service route. This is mainly done in order to compare the results from this research with figures from other research. First the services investigated are discussed together with its corresponding descriptive characteristics. Afterwards the results of individual model cost components are discussed and are compared to other research.

4.1 Model Descriptive Statistics – Service and Vessel Characteristics

Based on the route analysis a model summary is created to give an overview of each of the service segments investigated. Per segment the service with the largest[27] vessels, the route with the smallest vessels and the route containing all average route characteristics are selected to be part of the model.

Table 3: Descriptive Statistics of Liner shipping Services investigated in this research.

Route Name	Ranking (TEU)	Ship size (TEU)	Average Ship Type (CLASS)	Distance (NM)	Ships (K)	Port Calls (Nr.)	Voyage Time (DAYS)	Port Time (DAYS)	Sea Time (DAYS)	Engine (TYPE)
Dragon	AM Max	13727	New Panamax II	21.474	10,0	20,0	74,0	18,3	55,7	[3]
AVG[AM]	AM Avg	9229	Post Panamax IV	21.003	10,2	16	69,4	14,6	54,8	[3]
ABX	AM Min	5600	Post-Panamax I	17.656	8,0	10,0	56,0	9,9	46,1	[2]
AEC1	ANE Max	19114	ULVC II	21.213	11,0	15,0	77,0	13,7	63,3	[4]
AVG[ANE]	ANE Avg	13306	New Panamax II	23.056	10,3	15	75,4	13,5	61,9	[3]
ADR	ANE Min	7549	Post Panamax III	19.281	10,0	21,0	70,0	19,2	50,8	[2]
NEUATL3	TE Max	7715	Post Panamax III	12.071	6,0	15,0	47,0	13,7	33,3	[2]
AVG[TE]	TE Avg	5406	Post Panamax I	9.366	4,4	8,8	32,7	8,1	24,6	[2]
CAE	TE Min	2940	< Panamax	7.164	4,0	5,0	29,0	7,6	21,4	[5]
Empire	TECU Max	9002	Post Panamax IV	274.07	12,0	15,0	82,0	13,7	68,3	[3]
AVG[TECU]	TECU Avg	6003	Post Panamax II	24.431	11,2	11	74,5	9,7	64,8	[2]
Man.Bridge	TECU Min	4326	Panamax II	21.966	10,0	8,0	70,0	7,3	62,7	[5]
Pearl	TWCU Max	12675	New Panamax I	16.398	8,0	14,0	58,0	12,8	45,2	[3]
AVG[TWCU]	TWCU Avg	7371	Post Panamax III	14.747	8,1	9	50,0	8,0	41,9	[2]
PSW3	TWCU Min	4250	Panamax I	10.579	5,0	7,0	35,0	6,4	28,6	[5]

Source: Author's own elaborations on carrier data, containeship-info.com and portworld.com

The descriptive statistics are displayed in table 3. It must be noted that the average routes do not exist in reality but are acting as a dummy to represent average trade lane characteristics. The descriptive figures are based on data provided by shipping lines and represents current voyage time figures. However, since it is not possible to calculate actual port time based on available carrier data, the assumption of 0,916 days per port call is implemented. The engine type in the last column in table 3 corresponding to each service is denoted by the engine propulsion formula described in section 4.2. The selection is done based on vessel and engine characteristics obtained from MAN (2016a). Furthermore, table 3 shows the routes with the biggest, and smallest vessels

[27] When referred to size, the maximum TEU capacity is meant unless stated otherwise.

operating on a specific service segment denoted under 'Ranking (TEU)', the codes for each segment are explained at the start of section 3.3.

Table 4: Vessel Characteristics per Vessel Type

Vessel Type (CLASS)	Ship size (TEU)	DWT_{design} (DWT)	Displacement (ε)	D_{design} (M)	LOA[28] (M)	LPP[29] (M)	LWL[30] (M)	B (M)	V_{design} knots	P_{des} (SMCR) (kW)*	AC (AC)
<Panamax	2800	30.800	42.042	10,7	211	196	202	32,2	22,5	25000	519
Panamax I	4000	43.200	58.968	11,8	269	256	264	32,2	24	35500	545
Panamax II	4500	48.600	66.339	12	286	271	279	32,2	24,5	40100	553
Panamax III	5100	54.000	73.710	12	294	283	292	32,2	24,8	45000	554
Post-Panamax I	5500	58.000	79.170	12,5	276	263	271	40	25	49800	533
Post-Panamax II	6500	67.000	91.455	13	300	286	295	40	25	53900	543
Post-Panamax III	8000	81.000	110.565	13	323	308	318	42,8	25	60000	550
Post-Panamax IV	10000	101.000	1378.65	13	349	334	344	45,6	25	67700	555
New Panamax I	12500	123.000	167.895	13,5	366	350	361	49,4	25	74000	577
New Panamax II	14000	136.000	185.640	15	366	350	361	48,4	25	78000	583
ULCV I	15500	149.000	203.385	14	397	375	387	56,4	25	84000	573
ULCV II	18000	178.000	242.970	15	420	395	407	56,4	25	91500	574

** a 15% sea margin and a 10% engine margin are assumed.*
Source: Author's own elaboration of MAN (2016b)

The average of each segment (e.g. AVG[AM]) contains al average characteristics of the services offered on that specific segment based on carrier information. On the contrary, the max and minimum routes consist only route specific characteristic of the service itself. The 'Average Ship Type' column is used to create a link to key vessel characteristics that are shown in table 4. Combining table 3 and table 4 opens up the opportunity to match vessel specific characteristics to specific routes. The admiralty coefficient in table 4 is denoted by (AC). The displacement volume is denoted by (ε). Table 4 is established by MAN (2016b) using the Holtrop & Mennen's Method, which has proved to be a highly effective method for ship design in order to estimate required propulsive power and given vessel characteristics and resistance forces (MARIN, 2010). As mentioned in section 3.4, a very important assumption that must hold at any time is that the amount of ships on a service must at least maintain a weekly frequency. This minimum amount of vessels is calculated by dividing the total voyage time per round-trip by seven days to see how many ships are needed to call each week at each port in the loop. The results are shown in appendix 4.

4.2 Individual Model Components

4.2.1 Total Fuel Consumption per Vessel Type (i) on route (j) per round-trip

The calculation of the Daily fuel consumption per vessel type (i) on route (j) requires four steps: First the admiralty coefficient (AC) for each ship type must be calculated using [1]. Secondly, the required engine power per engine type must be calculated for all speeds between V_{11} and V_{25}. Specific engine information is given in appendix table 1,2,

28 LOA is 'Length Overall'
29 LPP is 'length between perpendiculars
30 LWL is 'length of waterline'

and 3. Required engine power for different speed levels is calculated using [1] while keeping the earlier calculated AC and the displacement volume (ε) constant. Third, in order to calculate the SFOC (g/kWh) for each engine type for a given speed level (V_n), the corresponding engine loads (M) from step two must be filled into formulas [2] through [5]. Finally [6] is used to obtain the daily fuel consumption measured in metric tons for ship type (i) given speed V_n. The results for each corresponding route (j) are given in appendix 5. Knowing the daily fuel consumption, the voyage distance of each round-trip and the average port time per port, opens up the possibility to calculate the sea time in days using relation [7]. Adding port time and sea time using [8] gives the voyage time per service for a given vessel speed. Consequently, it is possible to calculate the number of round-trips for each speed level on an annual basis. This has been calculated using [9]. The sea time, port time, voyage time, amount of round-trips per year and the fuel consumption are summarized in appendix 6. Annual fuel consumption on service level for different speed levels is shown in appendix 7.

4.2.2 Total CO_2 Emission Cost per Vessel Type (i) on route (j) per Year

Using the fuel consumption values given in appendix 7, the amount of round-trips possible per year from appendix 6 and formula [10], the CO_2 costs for each fuel consumption level is calculated. The results are shown in appendix 8. As can be seen in appendix 8, the CO_2 emission cost are very substantial and the results show that slow steaming allows for a great reduction in this cost category. It is not per se the fact that shipping lines actually pay these costs, but it is important to incorporate them for long-term sustainability. As can seen, by reducing speed from 25 knots to 11 knots, over 70% of CO_2 emissions and its corresponding costs can be reduced which was also explained by Corbett et al (2009).

4.2.3 Annual Cost per Vessel Type (i)

In order to calculate the costs of deploying additional ships on each route, the daily operating, capital costs and time costs must be gathered for each vessel type. This is done in the next section, which first addresses operating cost, afterwards capital costs and finally time costs.

4.2.3.1 Annual Operating Cost per Vessel Type (i)

The first vessel specific cost component, the operating costs, is calculated using figure 4 from section 3.4. Figure 4 corrects for the fact that economies of scale exist in increasing vessel size due to its convex cost curves. Carefully interpreting this figure creates the opportunity to estimate operating costs per TEU for various vessel sizes. The results of this estimation are shown in table 5. The 2015 OC_D-curve is used for the interpretation of the daily operating costs per TEU. Multiplying the daily OC_D with 350 days gives the annual operating costs for each service.

One point of attention: when comparing the results in table 5 with figures suggested by HSH Nordbank (2008), Hofstra (2016) and Stopford (2009) the results tend to be relatively high. Especially when index figures from Greiner (2014 and 2015) are used, the results tend to be relatively high. However, Murray (2015) sampled 1078 vessels covering a high percentage of each vessel size category (appendix 9). Particularly the share of 10000+ TEU vessels is substantial and represents at least 59% of the entire fleet of this category (Murray, 2015). This 10000+ TEU vessel category was lacking in older figures from HSH Nordbank (2008). Stopford's (2009) figures are based on cost information dating from the period 2000-2004[31] and are therefore somewhat out-dated. Figure 4 shows a big gap between daily operating costs per TEU for the years 2001 and 2015. This indicates that operating cost in the past were lower than nowadays. Therefore table 5 is selected to be a sufficient estimation of this cost category. Results will obviously differ when other values were selected.

Table 5: Daily and annual operating cost ($) per vessel of type (i) for each service (j).

Route Name	Ship Type (i)	Ship Size	$OC_{D,TEU}$	OC_D	OC_{year} [32]
Dragon	New Panamax II	14000	1,1	15,400	5.390.000
AVG[AM]	Post Panamax IV	10000	1,45	14.500	5.075.000
ABX	Post-Panamax I	5500	2,05	11.275	3.946.250
AEC1	ULVC II	18000	1	18.000	6.300.000
ADR	Post Panamax III	8000	1,8	14.400	5.040.000
NEUATL3	Post Panamax III	8000	1,8	14,.00	5.040.000
AVG [TE]	Post Panamax I	5500	2,05	11.275	3.946.250
CAE	< Panamax	2800	3,1	8.680	3.038.000
Empire	Post Panamax IV	10000	1,45	14.000	5.075.000
AVG [TECU]	Post Panamax II	6500	1,9	12.350	4.322.500
Man. Bridge	Panamax II	5100	2,08	10.608	3.712.800
Pearl	New Panamax I	12500	1,25	15.625	5.468.750
AVG [TWCU]	Post Panamax III	8000	1,8	14.400	5.040.000
PSW3	Panamax I	4000	2,5	10.000	3.500.000

Source: Own elaboration on estimates Murray (2015)

4.2.3.2 Annual Capital Cost per Vessel Type (i)

For the calculation of the vessel capital cost, the construction values for each vessel type must be known. Murray (2015) analysed the nominal cost of construction in terms of capacity and has summarized its findings as shown in appendix 10. Actual new ship building values are taken from Maersk Broker (2016) and are also shown in appendix 10. It must be noted that new building costs vary over time. Murray (2015) has regressed new build cost data concerning 1078 vessels over a period of 10 years representing the cost of new build vessels of different vessel sizes. Together with the actual average new build cost from Maersk Broker (2016), an average new building value is calculated with its corresponding annuity payment using [11]. The results are shown in table 6. On individual service level, the average ship value is calculated by comparing the figures in table 6 with the vessel size characteristics coupled to the service described in table 3 and 4. So for example, a vessel with a capacity of 10500 TEU has a value that equals the average value of the 10000 TEU and 11000 TEU vessels in table 6. Comparing the new building prices found in this research with figures assumed by with Stopford (2009), Streng (2012), AECOM (2012), van Elswijk (2012) and several news articles (appendix 11) shows that the new build values for each vessel size category varies considerably per ship. It really depends on the vessel's specifics and year of construction what price tag a vessel bears. Referring to figure 5, showing the variability of average construction cost per TEU over the period 2006-2017, it can be

[31] Operating cost estimates of Stopford (2009) are based on the operating cost study 2006 of HSH Nordbank that covered the period 2000-2004.
Source: Stopford (2009) and http://www.investorvillage.com/mbthread.asp?mb=5966&tid=1106223&showall=1
[32] An operational year is 350 days assuming 15 days of big maintenance, which is in line with Baird (2006)

shown that the vessel cost change considerably and that table 6 can be seen as a fitting approximation of vessel new build cost and interest cost. The outcomes are used to calculate the new build value and corresponding capital costs for vessels and their corresponding service routes.

Table 6: Average New Build cost per vessel size and its corresponding cost of capital ($)

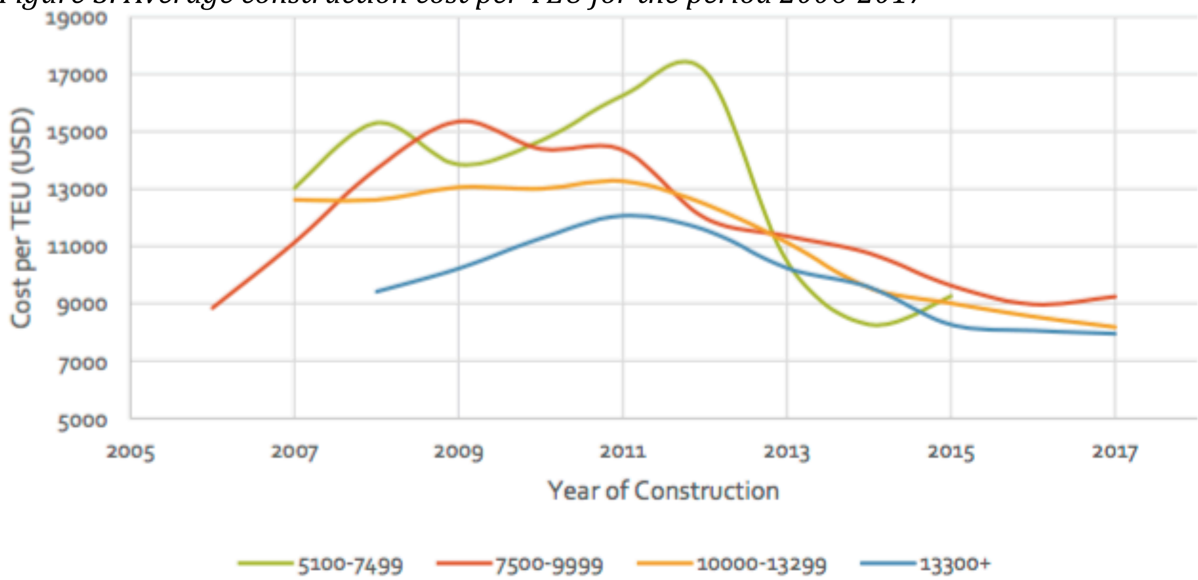
Ship size (TEU)	Maersk Broker (2016)*	Maersk Broker (2016)**	Murray (2015)	Average (P)	interest rate (i)	term(n)	Annuity factor (AF)	CC(year)	CC(day)
2000	25.231.200	23.791.200	32.872.860	27.298.420	0,06125	20	0,088	2.404.209	6.869
3000	32.846.800	31.186.800	48.766.350	37.599.983	0,06125	20	0,088	3.311.481	9.461
4000	40.462.400	38.582.400	58.690.160	45.911.653	0,06125	20	0,088	4.043.501	11.553
5000	48.078.000	45.978.000	73.362.700	55.806.233	0,06125	20	0,088	4.914.930	14.043
6000	55.693.600	53.373.600	83.472.960	64.180.053	0,06125	20	0,088	5.652.424	16.150
7000	63.309.200	60.769.200	97.385.120	73.821.173	0,06125	20	0,088	6.501.530	18.576
8000	70.924.800	68.164.800	91.930.880	77.006.827	0,06125	20	0,088	6.782.095	19.377
9000	78.540.400	75.560.400	103.422.240	85.841.013	0,06125	20	0,088	7.560.134	21.600
10000	86.156.000	82.956.000	112.346.300	93.819.433	0,06125	20	0,088	8.262.804	23.608
11000	93.771.600	90.351.600	123.580.930	102.568.043	0,06125	20	0,088	9.033.306	25.809
12000	101.387.200	97.747.200	134.815.560	111.316.653	0,06125	20	0,088	9.803.807	28.011
13000	109.002.800	105.142.800	146.050.190	120.065.263	0,06125	20	0,088	10.574.309	30.212
14000	116.618.400	112.538.400	130.183.480	119.780.093	0,06125	20	0,088	10.549.194	30.141
15000	124.234.000	119.934.000	139.482.300	127.883.433	0,06125	20	0,088	11.262.866	32.180
16000	131.849.600	127.329.600	148.781.120	135.986.773	0,06125	20	0,088	11.976.538	34.219
17000	139.465.200	134.725.200	158.079.940	144.090.113	0,06125	20	0,088	12.690.210	36.258
18000	147.080.800	142.120.800	167.378.760	152.193.453	0,06125	20	0,088	13.403.882	38.297

* Own elaboration on data Maersk Broker (2016) using Appendix 10: P = 7615,6TEU + 10000000; R^2 = 0,99737

** Own elaboration on data Maersk Broker (2016) using Appendix 10: P = 7395,6TEU + 9000000; R^2 = 0,99484

*** Own elaboration on data Murray (2015) using Appendix 10

Figure 5: Average construction cost per TEU for the period 2006-2017



Source: (Murray, 2015)

4.2.3.3 Annual Time Cost per Vessel Type (i)
Using [12], the time costs in terms of leasing costs per container per hour are calculated for each route. Multiplying this with the vessel capacity and adding it up for al vessels deployed at a service given a constant speed gives the container leasing costs, hence the time costs, per year on service level. The results are shown in appendix 12.

As can be seen from appendix 12 is that the time costs for carriers are be substantial amount if converted to an annual basis. Total time costs, varying between $24mln dollars to $44mln dollars for the Dragon route given the 25 and 11 knots respectively. For the calculation of annual container cost a slot utilization factor of 87,5% is assumed.

4.3 Break-even price calculation and future implications for container carriers

4.3.1 The Calculation of the Break Even Bunker Price.

As mentioned earlier in this paper, it is assumed that the entire fuel consumption is attributed to IFO380. Since the fuel price is the dependent variable in this research, the first thing that must be done is to convert all cost components described in section 4.2 into a first difference relation. The first differences, or the cost differences resulting from changes in speed from V(n) to V(n-1), are shown in Appendix 13 through 18. Appendix 18 is an overview of total cost changes resulting from specific speed changes, hence the right side of equation [13]. The break-even bunker price (BEP) is the price level for which the additional costs resulting from slow steaming are offset by the savings in fuel costs due to slower steaming.

Fuel costs savings are calculated by multiplying the fuel consumption (FC) with the BEP using the left part of equation [13]. Since the entire right side of equation [14] is determined in section 4.2 it is possible to calculate the break-even bunker price at each speed change level for each individual service. The results per service are shown in table 7. The BEP is calculated for each speed reduction on individual service level. This is done because the non-linear relationship present in the fuel consumption function results in different marginal fuel consumption savings at different speed levels. As can be seen, the break-even prices range between $743 and -$74 for various routes for different speeds. For each service route in table 7, speed decreases till 23 knots and for some services till 22 knots would even be justified if the carrier gets a cash payment for each metric ton of fuel consumed. This shows that the amount of fuel consumption savings and emission cost savings at higher speeds are significant in such a degree that these savings alone offset overall vessel cost increases[33]. In other words, without paying anything for fuel consumption at all (fuel price ≤ 0). This implies, according to this model, that the maximum vessel design speed in any case should never exceed 23 knots for long distance services as investigated in this research. Results may be different for shorter distance services because economies of scale and trade characteristics are different for those services. For further consecutive speed decreases, the break-even price has an increasing trend. For a part, this can be explained by the following two factors:

(1) The amount of fuel savings declines exponentially with each speed reduction.
(2) The amount of emission cost savings declines exponentially with each speed reduction, because its direct linear relationship with fuel consumption.

[33] Operating coast, capital cost and time cost

Both factors create a need for higher fuel prices needed to offset cost increases in terms of OC, CC and TC resulting from steaming slower. On the other side it appears that the cost increases for each consecutive speed decrease are slightly above linearly. This may be due to the fact that the number of vessels needed to maintain a weekly frequency is directly related to the voyage time per round-trip. Voyage time, in turn, has a slightly non-linear decreasing trend when relating it to speed increases. This implies that if the speed is decreased, the amount of extra voyage time increases slightly more than linearly for each consecutive speed decrease. This creates a higher than linear demand for vessel capacity, implying more than linear cost increases for the part which is directly associated with the amount of vessels deployed.

Table 7: IFO 380 break-even price ($) levels for various vessel speeds on specific routes

Service Lane	Route/Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Asia-Mediterranean Max	Dragon	549	415	319	248	195	152	116	85	56	28	0	-27	-52	-74	
Asia-Mediterranean Avg	AVG [AM]	641	491	384	305	244	196	157	122	89	58	27	-2	-29	-53	
Asia-Mediterranean Min	ABX	600	464	365	293	237	192	155	122	92	62	34	8	-16	-37	
Asia-North Europe Max	AEC1	762	588	462	370	299	243	196	156	120	85	51	19	-11	-37	
Asia-North Europe Avg	AVG [ANE]	683	525	411	327	263	213	171	134	99	66	33	2	-27	-52	
Asia-North Europe Min	ADR	618	471	365	286	226	178	138	102	69	38	8	-21	-47	-69	
Translantic-Europe Max	NEUATL3	678	527	417	335	273	222	181	144	111	79	49	21	-4	-25	
Translantic-Europe Avg	AVG [TE]	654	513	410	334	275	228	189	155	124	95	67	41	19	-1	
Translantic-Europe Min	CAE	637	491	386	307	248	201	164	134	108	86	66	48	31	16	
Transpasific-East Coast USA Max	Empire	743	586	472	387	322	270	226	189	155	123	93	66	41	19	
Transpasific-East Coast USA Avg	AVG [TECU]	566	428	330	257	202	158	121	88	57	26	-4	-32	-59	-82	
Transpasific-East Coast USA Min	Man. Bridge	673	511	394	307	241	190	150	116	88	63	41	21	2	-15	
Transpasific-West Coast USA Max	Pearl	706	545	429	344	279	228	185	147	112	78	45	13	-17	-43	
Transpasific-West Coast USA Avg	AVG [TWCU]	643	497	393	315	256	209	169	134	101	70	39	10	-16	-39	
Transpasific-West Coast USA Min	PSW3	589	444	339	263	205	160	124	95	70	49	29	10	-7	-23	

Source: author's own calculations

In order to link the outcomes from the model used in this research to the current and future situation in container shipping, the results will be compared with current bunker prices and the current carrier operational strategy. The latter means what are the current sailing speeds implemented by different carriers and how many vessels do they deploy? This comparison will give insights in the rationality of current container carriers in implementing their service specific strategic operations.

It must be noted, that if in section 4.3.2 conclusions are drawn based on profitability, it considers the profitability of a certain speed reduction, not overall service profitability. The rationale is: does a speed reduction creates more cost savings than cost increases?

4.3.2 Linking theoretical results with reality: implications for container carriers

As implied by the term break-even bunker price in a first difference model, it is the price for which cost increases equal cost savings. Thus, in case cost savings (implies: actual fuel prices exceed break-even fuel prices) exceed cost increases, carriers are making a profit by steaming slower. For example, if the current IFO380 bunker price is $300, the Dragon service operator (table 7) makes an additional profit equal to the fuel consumption(FC) saved multiplied with the price difference (actual bunker price –

break-even bunker price). So when considering a speed reduction from 16 to 15 knots, the dragon route operator makes a profit of ($300-$195) multiplied with ΔFC ($FC_{16\ knots} - FC_{15\ knots}$)[34] creating an additional profit made on fuel cost savings of over $3mln on an annual basis. This indicates that carriers should, at least, sail a speed for which the route specific break-even bunker price is lower than the actual bunker price level. Otherwise cost increases due to steaming slower will be bigger than cost reductions due to slow steaming reducing profits. Table 7 shows that, if the current bunker price is higher than the 11 knots route specific break-even bunker price, steaming slower for any speed reduction is justified (current bunker price exceeds al BEPs) and that steaming on the lowest speed is most profitable. Using the carrier service information shown earlier in table 3, the current average sailing speeds can be calculated for each specific service. These speed levels and its corresponding BEP are shown in table 8. Table 8 shows that most carriers currently implement a service speed between 14 and 17 knots. Speeds vary due to differences in route distance and the number of port calls on the voyage.

Table 8: Current route specific speed levels and corresponding break-even bunker price

Service lane	Route	Distance	Duration	Number of ports called	Port time	Sea time	Vessel Speed/ (optimal speed)	BEP
		(nm)	(days)		(days)	(days)	N(m/h)	($)
Asia-Mediterranean Max	Dragon	21.474	74	20	18	56	16 (15)	152
Asia-Mediterranean Avg	AVG [AM]	21.003	69	16	15	55	16 (15)	196
Asia-Mediterranean Min	ABX	176.56	56	10	10	46	16 (15)	192
Asia-North Europe Max	AEC1	21.213	77	15	14	63	14 (17)	370
Asia-North Europe Avg	AVG [ANE]	23.056	75	15	14	62	16 (16)	213
Asia-North Europe Min	ADR	19.281	70	21	19	51	16 (15)	178
Translantic-Europe Max	NEUATL3	12.071	47	15	14	33	15 (16)	273
Translantic-Europe Avg	AVG [TE]	9.366	33	9	8	25	16 (16)	228
Translantic-Europe Min	CAE	7.164	29	5	8	21	14 (16)	307
Transpasific-East Coast USA Max	Empire	27.407	82	15	14	68	17 (17)	226
Transpasific-East Coast USA Avg	AVG[TECU]	24.431	75	11	10	65	16 (15)	158
Transpasific-East Coast USA Min	Man. Bridge	21.966	70	8	7	63	15 (15)	241
Transpasific-West Coast USA Max	Pearl	16.398	58	14	13	45	15 (16)	279
Transpasific-West Coast USA Avg	AVG [TWCU]	14.747	50	9	8	42	15 (16)	256
Transpasific-West Coast USA Min	PSW3	10.579	35	7	6	29	15 (16)	205

Source: Author's own elaborations on carrier data

Comparing speed and price information from table 8 with current IFO380 bunker price information from table 9, will give insight into a carrier's operational strategy. For the Asian-Mediterranean routes, using the Piraeus bunker price of $245,5 as reference price, it can be seen that the routes are operated at a profitable speed. However, comparing the BEPs from table 7 with the Piraeus bunker price, it can be derived that steaming at 15 knots will create even more marginal profits (BEP < current bunker price).

For the Asia-North Europe routes, taking Rotterdam's Bunker price of $227,5 as reference price, it can be derived that all services except the AEC1 service are on a profitable speed. For the AEC1 service, a speed of 17 knots would be more profitable, because the cost increases created by steaming 14 knots instead of 17 knots would not

[34] For a speed reduction from 16 to 15 knots for the dragon route ΔFC equals 29.858 mt, see appendix 13

be offset by savings in fuel costs. This is because the bunker price of $227,5 is lower than the BEPs for each speed decline between 14 and 17 knots for the AEC1 service. For the ADR service, steaming at 15 knots instead of 16 knots would create additional cost savings.

Table 9: Current IFO380 bunker prices[35] in major bunker ports

Country	Bunker Price Base	Bunker Price $/mt
Singapore	Singapore	235
China	Hong Kong	241
US	Houston	223,5
US	Long Beach	216
US	New York	243,5
UAE	Fujairah	248
Netherlands	Rotterdam	227,5
Turkey	Istanbul	250,5
Greece	Piraeus	245,5
Gibraltar	Spain	245,5

Source: http://shipandbunker.com/prices

When looking at the Transatlantic-Europe services, using the average bunker price of Rotterdam and New York as reference price (±$235), it can be derived that the average route (AVG ([TE]) sails a profitable speed, while the other two sail too slow. The BEPs of $273 and $307 are bigger than actual fuel prices on this service lane causing the cost increases to be bigger than fuel cost savings. A speed of 16 knots is the most profitable given current bunker prices. Considering the Transpasific-East Coast USA services, and an average current bunker price of around $241 (Hong Kong, New York and Singapore), it can be seen that both the Empire and Manhatten Bridge services are sailing at optimal speeds. The average service (AVG [TECU]) would create more cost savings when slowing down by one knot to 15 knots. For the Transpasific-West Coast USA services, it can be seen from table 8 that all services are currently implementing a service speed of 15 knots. With current average bunker prices of around $225 (Hong Kong, Long Beach and Houston) and the BEP information from table 7 that all services except the PSW3 service should increase it's speed by at least one knot to a average sailing speed of 16 knots.

In summary, Considering the optimal speeds suggested in the previous section and the optimal speed figures shown in table 8, it can be concluded that most of the services are not sailing at its most profitable speeds. In other words, the marginal cost increases exceed the marginal cost savings in case services are implementing an average speed level that is too slow on the one hand. Services which sail too fast fail to fully exploit the cost savings possible from sailing one or several knots slower. For seven out of fifteen services investigated the optimum speed given current bunker prices would be 16 knots, for six routes this would be 15 knots and for the last two services the optimum speed would be 17 knots.
Comparing the results of this research with the findings of van Elswijk (2011) and Cariou (2010) gives important insights some important insights. Van Elswijk (2011)

[35] Price levels at *2016-6-7*

found that a speed of 17 knots is the most efficient speed on chain level accounting for time cost for shippers in terms of pipeline inventory costs. However in this paper a bunker price of $625/mt is used which is in this paper is associated with speeds reaching 11 or 12 knots. Van Elswijk's measure of time costs results in values reaching levels almost twice as high compared to this research for some services. This may partially explain his higher level of optimal speed because an increase in a cost factor resulting from steaming slower indirectly increases the right side of [13] and thus pushes optimal speeds upwards. Break-even prices of $125 to $150 per ton of fuel found by Notteboom and Vernimmen (2009) indicated that steaming at 20 knots is always preferred above sailing at 23 knots when bunker prices exceed $150. Similar findings are found in this research. However, the reduction from 23 knots to 20 knots would in this case be justified for even lower levels of bunker prices when considering consecutive one-knot speed reductions. Cariou (2010) finds break-even bunker prices varying between $259 and $568 for speed reductions of 30% compared to design speed for various trade lanes. Since the way Cariou (2010) measured his break-even price differs significantly from this research it is difficult to make any direct comparisons. It must be mentioned that Cariou (2010) only took vessel operating cost and shipper inventory cost as main determinants of the break-even bunker price, making this research the only research that solely took the carrier's perspective into consideration in a first difference setting.

5. Conclusion

5.1 Conclusion

Once again the great importance of the practise of slow steaming has been elaborated. In an era where container shipping is all about size, consolidation and ultimately cost cutting, all opportunities that container carriers could exploit to lower costs are of significant importance. This research analysed the strategic considerations faced by container carriers in their decision which average vessel speed should be adopted and how many vessels should be deployed on individual service level. Taken into consideration all factors dependent on vessel speed and a weekly service frequency constraint, a framework is developed to determine the optimum vessel speed assuming the IFO380 bunker price as the determinant factor. In a first difference analysis, the carrier is facing a different marginal cost situation at each consecutive speed level. Therefore carriers can accurately determine whether a change in vessel speed results in a cost savings or a cost increase at various levels along the speed spectrum given the actual IFO380 bunker prices. As such, this research thrived to give more insights in the economics of slow steaming with the ultimate purpose to formulate an adequate answer on the following research question:

What is the break-even bunker price for east-west intercontinental liner services from the container carriers' perspective on individual service level?

As explained in this research, a selection of fifteen services is made out of 232 services serving the major east-west container shipping corridor based on vessels size characteristics. Of these fifteen services, five services contain all average characteristics of the specific trade lanes and are therefore only serve for indicative purposes of the specific trade lane in general. This research has computed the break-even IFO380 bunker prices for all fifteen services selected for each change in speed level ranging between 11 and 25 knots. Each break-even price from table 7 is based on the change in costs and fuel consumption from a carrier perspective resulting from a change in vessel speed. These changes are different at different speed levels by amongst others exploiting the exponential relation between fuel consumption and vessel speed. The mathematical outcomes answering the research question (table 7) can be seen as an accurate basis for future carrier strategic decision making[36].

This research is the first of its kind to implement a first difference analysis focussed on vessel speed considerations on a service level that is completely focussed on the carrier's perspective. Most papers consider time cost faced by shippers of facing longer transit times, but forget to include the time costs faced by the carrier itself. This research, in turn, has accounted for this cost factor in the break-even analysis. This research has shown that speed levels above 23 knots should be avoided at any cost implying a vessel's maximum design speed of 23 knots for most services. The optimum speed for all services investigated given current bunker prices are 15 or 16 knots in 87% of the services investigated. By analysing all major east-west service segments and by selecting three services with different characteristics per segment, the research has a solid foundation for making general conclusions. Emphasis is placed at the high impact

[36] Obviously, these figures only hold given the fact that the assumptions made and data used in this research hold.

of fuel savings on its corresponding CO_2 emission savings that both are especially significant at higher speeds. The relationship between the number of vessels needed to maintain weekly service frequency and its corresponding costs in terms of operating, capital and time cost is also accounted for. These vessel costs together with CO_2 emission costs, gives a good approximation of the trade-off that carriers face between obtaining cost savings (fuel and emissions) on the one hand and cost increases (operating, capital and time) on the other hand resulting from slower steaming.

5.2 Limitations

This paper has made some assumptions restricting the overall generalizability of the results. Assuming an equal port time for different vessel sizes is unlikely to hold in reality. Larger vessels are likely to need more time to manoeuvre through the port area; the same holds for loading and unloading time. Besides, it is unlikely for carriers to implement a constant speed throughout the year due to factors like terminal delays, defect equipment, weather conditions etcetera. Also, this research recommends an optimal speed per service given current bunker prices. However, bunker prices have a high variability and are likely to change considerably over the year, making it almost impossible in reality to derive an optimum vessel speed on an annual basis. Technical elements concerning resistance forces working on the vessel are not taken into consideration, but are partially accounted for by assuming both an engine margin and a sea margin. This paper assumes that only one type of fuel (IFO380) is consumed, while in reality, vessels consume different kinds of fuel for different purposes. Also the fuel consumption of auxiliary engines is neglected in this research due to it small share of fuel consumption. The degrading effect slow steaming has on vessel engines resulting from suboptimal usage is not accounted for causing the results to be subject to a degree of omitted variable bias. This is not taken into account because it was not possible to measure the engine degrading effect given the data available.

The connection between supplied vessel capacity and its effect on the freight rate is neglected in this research because the information was unavailable en too technical of nature. Including the freight rate as a variable would have lowered the quality of the outcomes. However, if good information was present, it would have improved the overall picture of the effect of slow steaming by also accounting for the revenue side of carriers. According to important actors in the container shipping industry freight rates are a main determinant of slow steaming as explained in section 2. When considering the daily operating cost, a trade-off is made between recent information and older, more frequently cited information. However, since the former included more megaship data and did used an acknowledged dataset (IHS: World Shipping Encyclopaedia), the more recent and higher cost estimates are used. However, it could be the case that older and smaller vessels face other operating cost figures in realty. When lower daily operating costs were assumed, the break-even prices would be lower than stated in this research, due to a lower denominator in equation [14] depending on the cost level assumed. The same holds for using a lower interest rate on capital cost or selecting a longer economic life of a vessel. Increasing a vessel's life span from 20 years to 25 years results in a annual capital cost decrease of 10%. Assuming an interest rate to 4% instead of 6,125% results in an annual capital cost decrease of 16,5%. Measuring time costs (container lease costs) assuming fully loaded vessels instead of a load factor of 87,5% results in a time costs increase of 14,3%. Making use of the cube rule instead of the admiralty formula [1] in the calculation of the daily fuel consumption would underestimate fuel cost of vessels above a certain threshold and would overestimate the daily fuel consumption of vessels below the same threshold (the threshold depends on the assumptions concerning fuel propulsion). This is because differences in vessel size is not incorporated in the cube rule formula. Emissions cost do not change very much by selecting a different emission factor. Most emission factors selected in other literature are a fixed number somewhere between 3,17 and 3,5 per ton of fuel. However, selecting an emission spot price that is, for example, 30% higher (lower) than the one assumed in this research results in a linear increase (decrease) of 30% in emission cost. Since 2014, the carbon emission index price varied between €4,34 and €8,78 with a mean of €7,01[37], implying that this cost component can vary relatively much and results in higher (lower) break-even bunker prices when the spot rate increases (decreases).

5.3 Recommendations

The engine types assumed in this research are from an older mechanical category of shipping engines with design speeds reaching 25 knots. Whereas new and future vessels are equipped with more modern, slow steaming optimized engines with lower design speeds. Since this will probably become the new standard for long haul services in the future, the use of this kind of engines must be investigated too. Also the effect of freight rates on the slow steaming decision making process should be incorporated in models estimating optimal vessel speed. This way, the revenue part of the decision making process is also taken into consideration. Therefore it is important to construct a model that is able to predict the freight rates for each trade lane (both east- and westbound) given a set of explanatory variables. As discussed, researchers investigated the efficiency of slow steaming from an supply chain point of view by incorporating the shipper's stake into the equation. However, what is not investigated so far: what is the optimum situation from a society point of view? How can slow steaming be maintained when, for example, freight rates are rising again to such a level that faster steaming is profitable again (resulting in higher emissions)? Like Cariou (2010) suggests, what marked based solutions (e.g. a tax-levy or cap-and-trade system) can be implemented to ensure long-term sustainability and low vessel speeds?

[37] Source: http://www.investing.com/commodities/carbon-emissions-historical-data

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6. Appendix

Appendix 1: Four Engine Types with Corresponding Vessel Types and the relation between the engine's SFOC (Y) and its engine load measured in MCR % (X)

Engine Type	Type of vessels	Formula
10K98ME7*	Post Panamax I, Post Panamax II, Post Panamax III,	[1a] $y = 0{,}0071x^2 - 0{,}9577x + 195{,}73$
11K98ME7*	Post Panamax IV, New Panamax I, New Panamax II	[1b] $y = 0{,}0067x^2 - 0{,}9476x + 194{,}43$
12K98ME7*	ULCV	[1c] $y = 0{,}0061x^2 - 0{,}8774x + 189{,}69$
S70MC-C8**	< Panamax, Panamax I, Panamax II	[1d] $y = 0{,}0031x^2 - 0{,}4733x + 182{,}98$

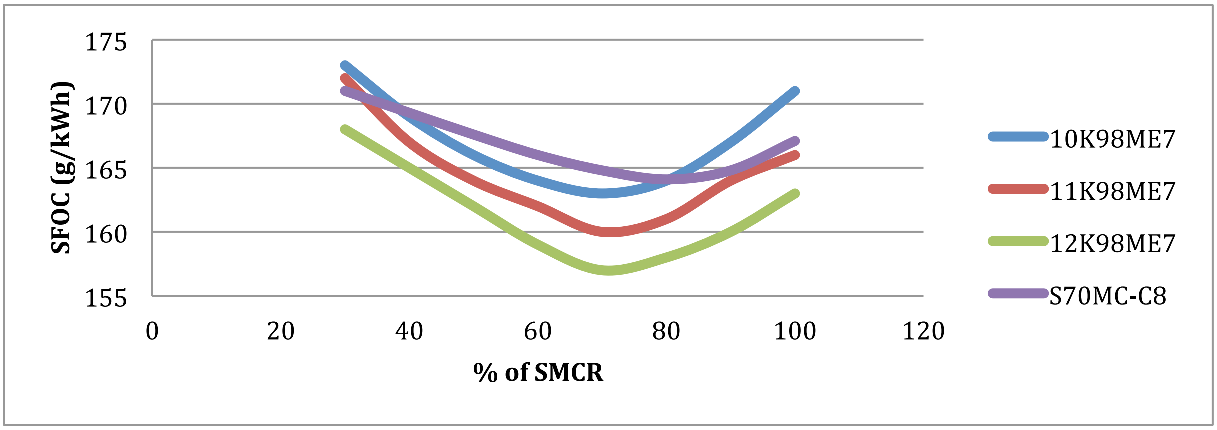
* Source: http://marine.man.eu/docs/librariesprovider6/technical-papers/low-container-ship-speed-facilitated-by.pdf?sfvrsn=20
** Source: http://engine.od.ua/ufiles/MAN-S70mc-c8.pdf

Appendix 2: Engine SFOC for four different engine types

% SMCR	10K98ME7 SFOC (g/kWh)	11K98ME7 SFOC (g/kWh)	12K98ME7 SFOC (g/kWh)	S70MC-C8 SFOC (g/kWh)
30	173	172	168	171
40	169	167	165	169,3
50	166	164	162	167,6
60	164	162	159	166
70	163	160	157	164,8
80	164	161	158	164,1
90	167	164	160	164,8
100	171	166	163	167,1

Source: Author's own elaboration on marine.man.edu and engine.od.ua, see appendix 2

Appendix 3: SFOC and MCR load relationships per engine type



Source: Author's own elaboration on marine.man.edu and engine.od.ua, see appendix 2

Appendix 4: Number of vessels needed on each route given the vessel's speed

speed	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon Voyage Time	14	13	12	12	11	11	10	10	9	9	9	8	8	8	8
AVG[AM] Voyage Time	13	13	12	11	10	10	9	9	9	8	8	8	8	7	7
ABX Voyage Time	11	10	10	9	8	8	8	7	7	7	6	6	6	6	6
AEC1 Voyage Time	13	12	12	11	10	10	9	9	9	8	8	8	7	7	7
AVG [ANE] Voyage Time	14	13	12	12	11	11	10	10	9	9	8	8	8	8	7
ADR Voyage Time	13	12	12	11	10	10	9	9	9	8	8	8	8	8	7
NEUATL3 Voyage Time	8	8	7	7	7	6	6	6	6	6	5	5	5	5	5
AVG [TE] Voyage Time	6	6	5	5	5	5	4	4	4	4	4	4	4	3	3
CAE Voyage Time	5	5	4	4	4	4	4	3	3	3	3	3	3	3	3
Empire Voyage Time	17	16	15	14	13	12	12	11	11	10	10	9	9	9	8
AVG [TECU] Voyage Time	15	14	13	12	11	10	10	9	9	9	8	8	8	7	7
Manhatten Bridge Voyage Time	13	12	11	10	10	9	9	8	8	8	7	7	7	6	6
Pearl Voyage Time	11	10	9	9	8	8	8	7	7	7	6	6	6	6	6
AVG [TWCU] Voyage Time	9	8	8	7	7	7	6	6	6	6	5	5	5	5	5
PSW3 Voyage Time	7	6	6	5	5	5	5	4	4	4	4	4	4	4	3

Source: Author's own calculations

Appendix 5: Daily fuel consumption in metric tonnes per service at different speed levels

Vessel Type	Speed (V)	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
New Panamax II	Dragon FC	35	45	56	69	84	100	118	138	160	184	211	241	276	317	366
Post Panamax IV	AVG[AM]	26	33	42	51	62	74	87	102	118	136	156	178	204	234	271
Post-Panamax I	ABX FC	19	25	31	38	46	55	65	76	88	101	116	133	153	176	204
ULVC II	AEC1	34	44	55	68	82	98	116	136	157	181	207	237	271	310	358
New Panamax II	AVG[ANE]	35	45	56	69	84	100	118	138	160	184	211	241	276	317	366
Post Panamax III	ADR	23	30	37	46	55	66	78	91	106	122	140	160	184	212	246
Post Panamax III	NEUATL3	23	30	37	46	55	66	78	91	106	122	140	160	184	212	246
Post Panamax I	AVG[TE]	19	25	31	38	46	55	65	76	88	101	116	133	153	176	204
Post Panamax IV	Empire	26	33	42	51	62	74	87	102	118	136	156	178	204	234	271
Post Panamax II	AVG[TECU]	21	27	33	41	50	60	70	82	95	109	126	144	165	191	221
New Panamax I	Pearl/lion	28	36	46	56	68	81	96	112	129	149	129	195	223	256	296
Post Panamax III	AVG[TWCU]	23	30	37	46	55	66	78	91	106	122	140	160	184	212	246
Panamax II	Man. Bridge	16	20	25	32	38	46	55	65	75	87	100	115	131	150	170
Panamax I	PSW3	15	19	24	30	36	44	52	61	71	82	95	108	124	141	160
< Panamax	CAE	13	16	20	25	31	37	44	52	61	70	81	93	106	120	137

Source: Author's own calculations

Appendix 6: Service specific figures for different vessel speeds

speed	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Dragon FC(d)	35,0	44,9	56,3	69,4	84,0	100,3	118,3	138,0	159,8	183,8	210,6	240,9	275,8	316,8	366,0
sea time	81,3	74,6	68,8	63,9	59,7	55,9	52,6	49,7	47,1	44,7	42,6	40,7	38,9	37,3	35,8
Total FC(v)	2843,0	3345,9	3877,0	4432,9	5010,5	5607,7	6223,9	6861,0	7524,2	8223,0	8973,0	9797,2	10727,9	11809,3	13099,4
Port time	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3	18,3
Voyage Time	99,7	92,9	87,1	82,2	78,0	74,2	71,0	68,0	65,4	63,1	60,9	59,0	57,2	55,6	54,1
# Round Trips	3,5	3,8	4,0	4,3	4,5	4,7	4,9	5,1	5,4	5,6	5,7	5,9	6,1	6,3	6,5
AVG [AM] FC(d)	25,9	33,2	41,7	51,3	62,2	74,2	87,5	102,1	118,2	136,0	155,8	178,2	204,0	234,4	270,8
sea time	79,6	72,9	67,3	62,5	58,3	54,7	51,5	48,6	46,1	43,8	41,7	39,8	38,0	36,5	35,0
Total FC(v)	2057,4	2421,3	2805,7	3208,0	3626,0	4058,1	4504,0	4965,1	5445,0	5950,7	6493,5	7089,9	7763,5	8546,0	9479,6
Port time	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6	14,6
Voyage Time	94,1	87,5	81,9	77,1	72,9	69,3	66,1	63,2	60,6	58,3	56,3	54,4	52,6	51,1	49,6
# Round Trips	3,7	4,0	4,3	4,5	4,8	5,1	5,3	5,5	5,8	6,0	6,2	6,4	6,6	6,9	7,1
ABX FC(d)	19,1	24,6	30,9	38,0	46,0	55,0	64,9	75,8	87,8	101,2	116,1	133,1	152,8	176,1	204,3
sea time	66,9	61,3	56,6	52,5	49,0	46,0	43,3	40,9	38,7	36,8	35,0	33,4	32,0	30,7	29,4
Total FC(v)	1280,7	1507,3	1746,7	1997,5	2258,3	2528,3	2807,6	3097,3	3400,1	3721,0	4067,6	4451,4	4888,2	5399,2	6012,8
Port time	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9	9,9
Voyage Time	76,8	71,2	66,5	62,5	59,0	55,9	53,2	50,8	48,6	46,7	44,9	43,4	41,9	40,6	39,3
# Round Trips	4,6	4,9	5,3	5,6	5,9	6,3	6,6	6,9	7,2	7,5	7,8	8,1	8,4	8,6	8,9
AEC1(d)	34,2	43,9	55,1	67,9	82,3	98,4	116,1	135,6	157,1	180,7	207,1	236,8	270,8	310,5	357,8
sea time	80,4	73,7	68,0	63,1	58,9	55,2	52,0	49,1	46,5	44,2	42,1	40,2	38,4	36,8	35,4
Total FC(v)	2745,6	3233,0	3748,7	4289,3	4851,8	5434,3	6036,2	6658,8	7306,6	7988,1	8716,9	9513,4	10406,4	11435,1	12651,6
Port time	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7
Voyage Time	94,1	87,4	81,7	76,9	72,7	69,0	65,7	62,8	60,3	57,9	55,8	53,9	52,2	50,6	49,1
# Round Trips	3,7	4,0	4,3	4,6	4,8	5,1	5,3	5,6	5,8	6,0	6,3	6,5	6,7	6,9	7,1
AVG [ANE] FC(d)	29,8	38,3	48,0	59,1	71,6	85,5	100,8	117,7	136,2	156,7	179,5	205,4	235,1	270,0	312,0
sea time	87,3	80,1	73,9	68,6	64,0	60,0	56,5	53,4	50,6	48,0	45,7	43,7	41,8	40,0	38,4
Total FC(v)	2602,1	3062,3	3548,5	4057,3	4585,9	5132,5	5696,5	6279,6	6886,5	7526,1	8212,6	8966,9	9818,8	10808,5	11989,3
Port time	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5	13,5
Voyage Time	100,9	93,6	87,4	82,1	77,6	73,6	70,0	66,9	64,1	61,6	59,3	57,2	55,3	53,6	51,9
# Round Trips	3,5	3,7	4,0	4,3	4,5	4,8	5,0	5,2	5,5	5,7	5,9	6,1	6,3	6,5	6,7
ADR FC(d)	23,1	29,6	37,2	45,8	55,5	66,3	78,2	91,3	105,8	121,9	139,9	160,4	184,1	212,2	246,2
sea time	73,0	66,9	61,8	57,4	53,6	50,2	47,3	44,6	42,3	40,2	38,3	36,5	34,9	33,5	32,1
Total FC(v)	1685,0	1983,1	2298,2	2628,1	2971,2	3326,5	3694,0	4075,1	4473,5	4895,7	5351,8	5856,8	6431,4	7103,8	7911,1
Port time	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2
Voyage Time	92,3	86,2	81,0	76,6	72,8	69,4	66,5	63,9	61,5	59,4	57,5	55,8	54,2	52,7	51,4
# Round Trips	3,8	4,1	4,3	4,6	4,8	5,0	5,3	5,5	5,7	5,9	6,1	6,3	6,5	6,6	6,8
NEUATL3 FC(d)	23,1	29,6	37,2	45,8	55,5	66,3	78,2	91,3	105,8	121,9	139,9	160,4	184,1	212,2	246,2
sea time	45,7	41,9	38,7	35,9	33,5	31,4	29,6	27,9	26,5	25,1	24,0	22,9	21,9	21,0	20,1
Total FC(v)	1054,9	1241,5	1438,8	1645,3	1860,1	2082,6	2312,6	2551,2	2800,6	3065,0	3350,5	3666,6	4026,4	4447,4	4952,7
Port time	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7
Voyage Time	59,5	55,7	52,4	49,7	47,3	45,2	43,3	41,7	40,2	38,9	37,7	36,6	35,6	34,7	33,9
# Round Trips	5,9	6,3	6,7	7,0	7,4	7,7	8,1	8,4	8,7	9,0	9,3	9,6	9,8	10,1	10,3
AVG [TE] FC(d)	19,1	24,6	30,9	38,0	46,0	55,0	64,9	75,8	87,8	101,2	116,1	133,1	152,8	176,1	204,3
sea time	35,5	32,5	30,0	27,9	26,0	24,4	23,0	21,7	20,5	19,5	18,6	17,7	17,0	16,3	15,6
Total FC(v)	679,4	799,6	926,6	1059,6	1197,9	1341,2	1489,4	1643,0	1803,7	1973,9	2157,8	2361,4	2593,1	2864,2	3189,6
Port time	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1	8,1
Voyage Time	43,5	40,6	38,1	35,9	34,1	32,5	31,0	29,7	28,6	27,6	26,6	25,8	25,0	24,3	23,7
# Round Trips	8,0	8,6	9,2	9,7	10,3	10,8	11,3	11,8	12,2	12,7	13,1	13,6	14,0	14,4	14,8
Empire FC(d)	25,9	33,2	41,7	51,3	62,2	74,2	87,5	102,1	118,2	136,0	155,8	178,2	204,0	234,4	270,8
sea time	103,8	95,2	87,8	81,6	76,1	71,4	67,2	63,4	60,1	57,1	54,4	51,9	49,7	47,6	45,7
Total FC(v)	2684,7	3159,5	3661,1	4186,1	4731,5	5295,4	5877,3	6478,9	7105,2	7765,1	8473,3	9251,6	10130,5	11151,7	12369,9
Port time	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7	13,7
Voyage Time	117,6	108,9	101,6	95,3	89,9	85,1	80,9	77,2	73,8	70,8	68,1	65,6	63,4	61,3	59,4
# Round Trips	3,0	3,2	3,4	3,7	3,9	4,1	4,3	4,5	4,7	4,9	5,1	5,3	5,5	5,7	5,9

AVG [TECU] FC(d)	20,7	26,6	33,4	41,1	49,8	59,5	70,2	82,0	95,0	109,5	125,7	144,1	165,4	190,6	221,2
sea time	92,5	84,8	78,3	72,7	67,9	63,6	59,9	56,6	53,6	50,9	48,5	46,3	44,3	42,4	40,7
Total FC(v)	1918,0	2257,4	2616,0	2991,5	3382,1	3786,5	4204,8	4638,6	5092,1	5572,7	6091,9	6666,7	7320,7	8086,1	9005,0
Port time	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7	9,7
Voyage Time	102,2	94,5	88,0	82,4	77,5	73,3	69,6	66,2	63,3	60,6	58,2	56,0	53,9	52,1	50,4
# Round Trips	3,4	3,7	4,0	4,2	4,5	4,8	5,0	5,3	5,5	5,8	6,0	6,3	6,5	6,7	6,9
Pearl FC(d)	28,3	36,3	45,6	56,1	67,9	81,1	95,6	111,6	129,2	148,7	170,3	194,8	223,0	256,2	296,0
sea time	62,1	56,9	52,6	48,8	45,5	42,7	40,2	38,0	36,0	34,2	32,5	31,1	29,7	28,5	27,3
Total FC(v)	1755,7	2066,3	2394,3	2737,6	3094,3	3463,1	3843,6	4237,1	4646,6	5078,1	5541,3	6050,3	6625,1	7292,9	8089,6
Port time	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8	12,8
Voyage Time	74,9	69,8	65,4	61,6	58,4	55,5	53,0	50,8	48,8	47,0	45,4	43,9	42,5	41,3	40,2
# Round Trips	4,7	5,0	5,4	5,7	6,0	6,3	6,6	6,9	7,2	7,4	7,7	8,0	8,2	8,5	8,7
AVG[TWCU] FC(d)	23,1	29,6	37,2	45,8	55,5	66,3	78,2	91,3	105,8	121,9	139,9	160,4	184,1	212,2	246,2
sea time	83,2	76,3	70,4	65,4	61,0	57,2	53,8	50,8	48,2	45,8	43,6	41,6	39,8	38,1	36,6
Total FC(v)	1919,7	2259,3	2618,2	2994,0	3385,0	3789,7	4208,4	4642,6	5096,5	5577,5	6097,1	6672,4	7327,0	8093,1	9012,7
Port time	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0	8,0
Voyage Time	91,3	84,3	78,5	73,4	69,1	65,3	61,9	58,9	56,2	53,8	51,6	49,6	47,8	46,2	44,7
# Round Trips	3,8	4,2	4,5	4,8	5,1	5,4	5,7	5,9	6,2	6,5	6,8	7,0	7,3	7,6	7,8
Man. Bridge FC(d)	15,6	20,1	25,4	31,5	38,5	46,3	55,0	64,7	75,5	87,4	100,5	115,1	131,3	149,6	170,4
sea time	83,2	76,3	70,4	65,4	61,0	57,2	53,8	50,8	48,2	45,8	43,6	41,6	39,8	38,1	36,6
Total FC(v)	1298,5	1536,3	1791,0	2061,8	2347,7	2648,1	2962,8	3291,9	3636,4	3998,0	4379,9	4786,8	5225,5	5705,3	6238,5
Port time	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3
Voyage Time	90,5	83,6	77,7	72,7	68,3	64,5	61,2	58,2	55,5	53,1	50,9	48,9	47,1	45,5	43,9
# Round Trips	3,9	4,2	4,5	4,8	5,1	5,4	5,7	6,0	6,3	6,6	6,9	7,2	7,4	7,7	8,0
PSW3 FC(d)	14,7	19,0	24,0	29,7	36,2	43,6	51,8	61,0	71,1	82,3	94,6	108,4	123,7	140,9	160,5
sea time	40,1	36,7	33,9	31,5	29,4	27,5	25,9	24,5	23,2	22,0	21,0	20,0	19,2	18,4	17,6
Total FC(v)	589,0	696,8	812,4	935,1	1064,8	1201,1	1343,8	1493,1	1649,4	1813,4	1986,6	2171,2	2370,1	2587,7	2829,6
Port time	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4	6,4
Voyage Time	46,5	43,1	40,3	37,9	35,8	34,0	32,3	30,9	29,6	28,5	27,4	26,4	25,6	24,8	24,0
# Round Trips	7,5	8,1	8,7	9,2	9,8	10,3	10,8	11,3	11,8	12,3	12,8	13,2	13,7	14,1	14,6
CAE FC(d)	12,6	16,2	20,5	25,4	31,0	37,3	44,3	52,1	60,8	70,3	80,9	92,6	105,7	120,4	137,2
sea time	27,1	24,9	23,0	21,3	19,9	18,7	17,6	16,6	15,7	14,9	14,2	13,6	13,0	12,4	11,9
Total FC(v)	340,9	403,3	470,2	541,2	616,3	695,2	777,8	864,2	954,6	1049,5	1149,8	1256,6	1371,7	1497,7	1637,7
Port time	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6	7,6
Voyage Time	34,7	32,5	30,5	28,9	27,5	26,2	25,1	24,2	23,3	22,5	21,8	21,1	20,6	20,0	19,5
# Round Trips	10,1	10,8	11,5	12,1	12,7	13,3	13,9	14,5	15,0	15,6	16,1	16,6	17,0	17,5	17,9

Source: Author's own calculations

Appendix 7: Total annual fuel consumption (mt) per year for each service for a different speed levels for al vessels deployed combined

Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	142.151	167.293	193.851	221.647	250.527	280.386	311.196	343.051	376.208	411.149	448.650	489.859	536.397	590.464	654.970
GEM[AM])	102.870	121.064	140.284	160.399	181.298	202.906	225.202	248.255	272.249	297.535	324.673	354.495	388.173	427.299	473.980
ABX	64.035	75.364	87.336	99.873	112.913	126.415	140.379	154.863	170.004	186.048	203.382	222.572	244.409	269.962	300.640
AEC1	137.280	161.652	187.435	214.463	242.591	271.717	301.808	332.939	365.331	399.405	435.845	475.670	520.320	571.757	632.580
GEM[ANE]	130.104	153.116	177.424	202.864	229.297	256.625	284.825	313.980	344.327	376.307	410.630	448.347	490.941	540.426	599.466
ADR	84.251	99.157	114.908	131.404	148.560	166.325	184.698	203.755	223.676	244.786	267.592	292.840	321.571	355.192	395.555
NEUATL3	52.745	62.077	71.938	82.265	93.006	104.128	115.630	127.560	140.032	153.248	167.526	183.332	201.319	222.368	247.637
GEM[TE]	33.969	39.979	46.329	52.980	59.897	67.060	74.468	82.151	90.183	98.694	107.889	118.069	129.653	143.208	159.482
Empire)	134.235	157.977	183.056	209.305	236.576	264.772	293.867	323.947	355.258	388.254	423.666	462.580	506.526	557.583	618.497
GEM[TECU]	95.901	112.868	130.798	149.574	169.103	189.324	210.238	231.929	254.605	278.634	304.594	333.333	366.037	404.307	450.251
Pearl	87.786	103.313	119.714	136.879	154.714	173.154	192.181	211.853	232.329	253.907	277.066	302.515	331.255	364.644	404.480
GEM[TWCU]	64.441	75.842	87.889	100.506	113.628	127.216	141.269	155.844	171.081	187.227	204.671	223.982	245.958	271.673	302.545
Man. Bridge	64.927	76.816	89.552	103.088	117.383	132.406	148.141	164.597	181.820	199.901	218.996	239.342	261.277	285.265	311.927
PSW3	29.449	34.841	40.618	46.757	53.241	60.055	67.192	74.656	82.468	90.669	99.330	108.558	118.507	129.387	141.480
CAE	17.044	20.165	23.508	27.061	30.814	34.758	38.888	43.208	47.729	52.476	57.488	62.829	68.587	74.885	81.883

Source: Author's own calculations

Appendix 8: CO_2 emission costs per liner service per year (×$1000)

Speed V co2	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	47.879	52.515	57.094	61.598	66.017	70.352	74.623	78.872	83.168	87.621	92.383	97.662	103.734	110.955	119.776
GEM[AM]	32.732	35.809	38.834	41.795	44.688	47.513	50.286	53.033	55.805	58.672	61.737	65.138	69.057	73.729	79.447
ABX	16.620	18.141	19.631	21.084	22.500	23.881	25.236	26.581	27.944	29.364	30.896	32.614	34.612	37.015	39.976
AEC1	43.656	47.748	51.774	55.720	59.577	63.348	67.049	70.715	74.403	78.203	82.238	86.677	91.741	97.716	104.962
GEM[ANE]	44.348	48.425	52.420	56.318	60.111	63.803	67.414	70.984	74.575	78.287	82.253	86.657	91.740	97.808	105.249
ADR	26.273	28.882	31.470	34.027	36.549	39.038	41.506	43.981	46.505	49.145	51.994	55.179	58.867	63.274	68.675
NEUATL3	10.600	11.676	12.747	13.808	14.858	15.898	16.931	17.969	19.030	20.141	21.339	22.678	24.227	26.075	28.337
GEM[TE]	4.998	5.483	5.963	6.435	6.898	7.355	7.806	8.257	8.717	9.197	9.715	10.295	10.967	11.771	12.758
Empire	15.750	17.328	18.895	20.444	21.971	23.477	24.967	26.455	27.964	29.530	31.206	33.062	35.193	37.721	40.802
GEM[TECU]	38.101	41.542	44.905	48.180	51.362	54.459	57.492	60.499	63.541	66.707	70.123	73.955	78.419	83.791	90.417
Pearl	30.329	33.001	35.599	38.117	40.548	42.899	45.182	47.425	49.672	51.986	54.458	57.208	60.390	64.205	68.900
GEM[TWCU]	19.717	21.428	23.089	24.696	26.246	27.745	29.203	30.641	32.090	33.594	35.216	37.040	39.170	41.743	44.927
Man. Bridge	16.443	18.111	19.788	21.471	23.157	24.847	26.542	28.249	29.977	31.743	33.571	35.494	37.555	39.809	42.330
PSW3	6.361	6.977	7.593	8.208	8.819	9.428	10.036	10.644	11.257	11.881	12.524	13.200	13.923	14.715	15.601
CAE	2.678	2.940	3.203	3.466	3.728	3.989	4.251	4.512	4.777	5.046	5.324	5.616	5.929	6.271	6.654

Source: Author's own calculations

Appendix 9: Percentage of fleet represented in 1078 vessel sample of Murray (2015)

Vessel Size (TEU)	% of Fleet Represented
0-999	5%
1000-1499	26%
1500-1999	20%
2000-2999	28%
3000-3999	46%
4000-5099	385%
5100-7499	41%
7500-9999	40%
10000-13300	59%
13300+	68%

Source: Murray (2015)

Appendix 10: Vessel new building value information

Vessel Size	CC(TEU)	Source
0-999	23065,11	Murray (2015)
1000-1499	20606,62	Murray (2015)
1500-1999	19215,59	Murray (2015)
2000-2999	16436,43	Murray (2015)
3000-3999	16255,45	Murray (2015)
4000-5099	14672,54	Murray (2015)
5100-7499	13912,16	Murray (2015)
7500-9999	11491,36	Murray (2015)
10000-13300	11234,63	Murray (2015)
13300+	9298,82	Murray (2015)

	Korea		China		
TEU	**CC(total)**	**CC(TEU)**	**CC(total)**	**CC(TEU)**	**Source**
1800	26.000.000	14444,44	24.000.000	1661,54	Maersk Broker (2016)
2700	32.000.000	11851,85	30.000.000	2531,25	Maersk Broker (2016)
5400	49.000.000	9074,07	45.000.000	4959,18	Maersk Broker (2016)
6600	61.000.000	9242,42	57.000.000	6167,21	Maersk Broker (2016)
9200	83.000.000	9021,74	80.000.000	8867,47	Maersk Broker (2016)
14000	117.500.000	8392,86	112.500.000	13404,26	Maersk Broker (2016)

Source: Author's own Elaborations on Mearsk (2016) and Murray (2015)

Appendix 11: New build value figures assumed in other research or based from news articles

Ship size in TEU	New Build Value ($)	Source
1200	25.000.000	Stopford (2009)
1713	23.000.000	Streng (2012)
2600	48.000.000	Stopford (2009)
4000	60.000.000	AECOM (2012)
4300	67.000.000	Stopford (2009)
4430	43.000.000	Streng (2012)
6500	89.000.000	Stopford (2009)
8500	110.000.000	Stopford (2009)
8500	132.500.000	van Elswijk (2011)
8652	90.000.000	Streng (2012)
10000	95.238.095	[1]
11000	130.000.000	Stopford (2009)
11000	93.500.000	[2]
12000	120.000.000	AECOM (2012)
13880	170.000.000	Streng (2012)
18000	190.000.000	[3]
18000	163.000.000	[4]
18000	136.000.000	[5]

[1] http://yangzijiang.listedcompany.com/newsroom/YZJ_PressRelease_Delivery_of_10000_TEU_Eng_Final.pdf
[2] https://www.vesselfinder.com/news/3302-Seaspan-Places-Order-For-Seven-Boxships
[3] http://www.ship-technology.com/projects/triple-e-class/
[4] http://www.ft.com/cms/s/0/ae1f8bfe-093a-11e5-8534-00144feabdc0.html#axzz4AFc2kcEP
[5] http://shipandbunker.com/news/apac/839662-cosco-places-15-billion-order-for-11-newbuild-mega-box-ships

Appendix 12: Annual time costs per route per year for various speed levels (×$1000)

Route Name	Ship Size (TEU)	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	14000	44.258	41.248	38.700	36.517	34.625	32.969	31.509	30.210	29.048	28.003	27.057	26.197	25.411	24.691	24.029
AVG[AM]	10000	29.864	27.761	25.982	24.456	23.134	21.978	20.957	20.050	19.238	18.508	17.847	17.246	16.697	16.194	15.732
ABX	5500	13.398	12.426	11.603	10.898	10.287	9.752	9.280	8.860	8.485	8.147	7.842	7.564	7.310	7.078	6.864
AEC1	18000	53.724	49.901	46.666	43.893	41.490	39.387	37.532	35.882	34.407	33.078	31.877	30.785	29.787	28.873	28.032
AVG [ANE]	14000	44.789	41.557	38.822	36.478	34.446	32.669	31.100	29.706	28.459	27.336	26.320	25.397	24.554	23.781	23.070
ADR	8000	23.415	21.870	20.563	19.443	18.472	17.623	16.873	16.207	15.611	15.075	14.589	14.148	13.745	13.376	13.036
NEUATL3	8000	15.089	14.123	13.304	12.603	11.995	11.464	10.994	10.577	10.204	9.868	9.564	9.288	9.036	8.805	8.592
AVG [TE]	5500	7.596	7.080	6.644	6.269	5.945	5.662	5.411	5.189	4.990	4.810	4.648	4.501	4.366	4.243	4.130
CAE	2800	3.083	2.883	2.713	2.567	2.441	2.330	2.233	2.146	2.069	1.999	1.936	1.878	1.826	1.778	1.734
Empire	10000	37.289	34.544	32.222	30.232	28.507	26.998	25.666	24.482	23.423	22.470	21.607	20.823	20.108	19.451	18.848
AVG [TECU]	6500	21.077	19.487	18.142	16.988	15.989	15.114	14.343	13.657	13.043	12.491	11.991	11.537	11.122	10.742	10.392
Man. Bridge	5100	14.646	13.524	12.575	11.761	11.056	10.439	9.895	9.411	8.978	8.589	8.236	7.916	7.623	7.355	7.108
Pearl	12500	29.712	27.660	25.923	24.435	23.145	22.016	21.020	20.135	19.343	18.630	17.985	17.398	16.863	16.372	15.921
AVG [TWCU]	8000	16.218	15.036	14.037	13.180	12.438	11.788	11.215	10.705	10.249	9.839	9.467	9.130	8.822	8.539	8.279
PSW3	4000	5.898	5.474	5.116	4.808	4.542	4.309	4.103	3.921	3.757	3.610	3.477	3.356	3.245	3.144	3.051

Source: Author's own calculations

Appendix 13: First difference annual fuel consumption per service per year (mt)

Speed V	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Dragon	25.142	26.558	27.796	28.880	29.858	30.810	31.855	33.157	34.941	37.501	41.209	46.538	54.067	64.506	
GEM[AM]	18.195	19.219	20.115	20.900	21.607	22.297	23.052	23.995	25.286	27.138	29.822	33.678	39.127	46.681	
ABX	11.329	11.972	12.538	13.040	13.502	13.964	14.484	15.141	16.044	17.334	19.190	21.837	25.553	30.677	
AEC1	24.372	25.783	27.028	28.128	29.126	30.092	31.131	32.392	34.074	36.440	39.825	44.650	51.438	60.823	
GEM[ANE]	23.012	24.308	25.441	26.433	27.328	28.199	29.155	30.347	31.980	34.323	37.717	42.594	49.485	59.040	
ADR	14.906	15.751	16.496	17.156	17.765	18.373	19.057	19.921	21.110	22.806	25.248	28.731	33.621	40.363	
NEUATL3	9.332	9.861	10.327	10.741	11.122	11.502	11.930	12.472	13.216	14.278	15.807	17.987	21.048	25.269	
GEM[TE]	6.010	6.351	6.651	6.917	7.163	7.408	7.683	8.032	8.511	9.195	10.180	11.584	13.555	16.274	
Empire	23.742	25.079	26.248	27.272	28.196	29.095	30.081	31.311	32.996	35.412	38.914	43.946	51.056	60.914	
GEM[TECU]	16.967	17.929	18.777	19.529	20.221	20.913	21.692	22.676	24.029	25.960	28.739	32.704	38.270	45.944	
Pearl	15.527	16.401	17.166	17.835	18.439	19.027	19.672	20.476	21.578	23.159	25.449	28.740	33.389	39.836	
GEM[TWCU]	11.401	12.048	12.617	13.122	13.588	14.053	14.576	15.237	16.146	17.444	19.311	21.975	25.715	30.872	
Man. Bridge	11.889	12.735	13.536	14.295	15.023	15.735	16.456	17.223	18.081	19.095	20.346	21.935	23.989	26.661	
PSW3	5.393	5.776	6.139	6.484	6.814	7.137	7.464	7.812	8.201	8.661	9.228	9.949	10.880	12.093	
CAE	3.121	3.343	3.553	3.753	3.944	4.131	4.320	4.521	4.746	5.013	5.341	5.758	6.297	6.999	

Source: Author's own calculations

Appendix 14: First difference CO_2 emission costs per service per year (×$1mln)

Speed V	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Dragon	4,64	4,58	4,50	4,42	4,34	4,27	4,25	4,30	4,45	4,76	5,28	6,07	7,22	8,82	
GEM[AM]	3,08	3,03	2,96	2,89	2,83	2,77	2,75	2,77	2,87	3,07	3,40	3,92	4,67	5,72	
ABX	1,52	1,49	1,45	1,42	1,38	1,35	1,35	1,36	1,42	1,53	1,72	2,00	2,40	2,96	
AEC1	4,09	4,03	3,95	3,86	3,77	3,70	3,67	3,69	3,80	4,03	4,44	5,06	5,98	7,25	
GEM[ANE]	4,08	4,00	3,90	3,79	3,69	3,61	3,57	3,59	3,71	3,97	4,40	5,08	6,07	7,44	
ADR	2,61	2,59	2,56	2,52	2,49	2,47	2,47	2,52	2,64	2,85	3,18	3,69	4,41	5,40	
NEUATL3	1,08	1,07	1,06	1,05	1,04	1,03	1,04	1,06	1,11	1,20	1,34	1,55	1,85	2,26	
GEM[TE]	0,48	0,48	0,47	0,46	0,46	0,45	0,45	0,46	0,48	0,52	0,58	0,67	0,80	0,99	
Empire	1,58	1,57	1,55	1,53	1,51	1,49	1,49	1,51	1,57	1,68	1,86	2,13	2,53	3,08	
GEM[TECU]	3,44	3,36	3,27	3,18	3,10	3,03	3,01	3,04	3,17	3,42	3,83	4,46	5,37	6,63	
Pearl	2,67	2,60	2,52	2,43	2,35	2,28	2,24	2,25	2,31	2,47	2,75	3,18	3,81	4,69	
GEM[TWCU]	2,55	2,47	2,39	2,31	2,23	2,17	2,14	2,16	2,24	2,42	2,72	3,17	3,83	4,74	
Man. Bridge	1,67	1,68	1,68	1,69	1,69	1,70	1,71	1,73	1,77	1,83	1,92	2,06	2,25	2,52	
PSW3	0,85	0,84	0,83	0,82	0,82	0,81	0,81	0,81	0,82	0,84	0,88	0,94	1,03	1,16	
CAE	0,26	0,26	0,26	0,26	0,26	0,26	0,26	0,26	0,27	0,28	0,29	0,31	0,34	0,38	

Source: Author's own calculations

Appendix 15: First difference time costs per service per year (×$1mln)

Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	-3,01	-2,55	-2,18	-1,89	-1,66	-1,46	-1,30	-1,16	-1,05	-0,95	-0,86	-0,79	-0,72	-0,66	
AVG [AM]	-2,10	-1,78	-1,53	-1,32	-1,16	-1,02	-0,91	-0,81	-0,73	-0,66	-0,60	-0,55	-0,50	-0,46	
ABX	-0,97	-0,82	-0,71	-0,61	-0,53	-0,47	-0,42	-0,38	-0,34	-0,31	-0,28	-0,25	-0,23	-0,21	
AEC1	-3,82	-3,24	-2,77	-2,40	-2,10	-1,86	-1,65	-1,48	-1,33	-1,20	-1,09	-1,00	-0,91	-0,84	
AVG [ANE]	-3,23	-2,73	-2,34	-2,03	-1,78	-1,57	-1,39	-1,25	-1,12	-1,02	-0,92	-0,84	-0,77	-0,71	
ADR	-1,54	-1,31	-1,12	-0,97	-0,85	-0,75	-0,67	-0,60	-0,54	-0,49	-0,44	-0,40	-0,37	-0,34	
NEUATL3	-0,97	-0,82	-0,70	-0,61	-0,53	-0,47	-0,42	-0,37	-0,34	-0,30	-0,28	-0,25	-0,23	-0,21	
AVG [TE]	-0,52	-0,44	-0,37	-0,32	-0,28	-0,25	-0,22	-0,20	-0,18	-0,16	-0,15	-0,13	-0,12	-0,11	
Empire	-2,74	-2,32	-1,99	-1,72	-1,51	-1,33	-1,18	-1,06	-0,95	-0,86	-0,78	-0,72	-0,66	-0,60	
AVG [TECU]	-1,59	-1,35	-1,15	-1,00	-0,87	-0,77	-0,69	-0,61	-0,55	-0,50	-0,45	-0,41	-0,38	-0,35	
Pearl	-2,05	-1,74	-1,49	-1,29	-1,13	-1,00	-0,89	-0,79	-0,71	-0,65	-0,59	-0,54	-0,49	-0,45	
AVG [TWCU]	-1,76	-1,49	-1,28	-1,11	-0,97	-0,85	-0,76	-0,68	-0,61	-0,55	-0,50	-0,46	-0,42	-0,39	
Man. Bridge	-1,12	-0,95	-0,81	-0,71	-0,62	-0,54	-0,48	-0,43	-0,39	-0,35	-0,32	-0,29	-0,27	-0,25	
PSW3	-0,42	-0,36	-0,31	-0,27	-0,23	-0,21	-0,18	-0,16	-0,15	-0,13	-0,12	-0,11	-0,10	-0,09	
CAE	-0,20	-0,17	-0,15	-0,13	-0,11	-0,10	-0,09	-0,08	-0,07	-0,06	-0,06	-0,05	-0,05	-0,04	

Source: Author's own calculations

Appendix 16: First difference operating cost per service per year (×$1mln)

Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	-5,22	-4,42	-3,79	-3,28	-2,87	-2,53	-2,25	-2,01	-1,81	-1,64	-1,49	-1,36	-1,25	-1,15	
AVG [AM]	-4,81	-4,07	-3,49	-3,02	-2,64	-2,33	-2,07	-1,86	-1,67	-1,51	-1,37	-1,25	-1,15	-1,06	
ABX	-3,14	-2,66	-2,28	-1,97	-1,73	-1,52	-1,36	-1,21	-1,09	-0,99	-0,90	-0,82	-0,75	-0,69	
AEC1	-6,03	-5,10	-4,37	-3,79	-3,31	-2,92	-2,60	-2,33	-2,09	-1,89	-1,72	-1,57	-1,44	-1,33	
AVG [ANE]	-5,60	-4,74	-4,06	-3,52	-3,08	-2,72	-2,42	-2,16	-1,95	-1,76	-1,60	-1,46	-1,34	-1,23	
ADR	-4,38	-3,71	-3,18	-2,75	-2,41	-2,13	-1,89	-1,69	-1,52	-1,38	-1,25	-1,14	-1,05	-0,96	
NEUATL3	-2,74	-2,32	-1,99	-1,72	-1,51	-1,33	-1,18	-1,06	-0,95	-0,86	-0,78	-0,72	-0,66	-0,60	
AVG [TE]	-1,67	-1,41	-1,21	-1,05	-0,92	-0,81	-0,72	-0,64	-0,58	-0,52	-0,48	-0,43	-0,40	-0,37	
Empire	-6,27	-5,31	-4,55	-3,94	-3,45	-3,04	-2,71	-2,42	-2,18	-1,97	-1,79	-1,64	-1,50	-1,38	
AVG [TECU]	-4,76	-4,03	-3,45	-2,99	-2,62	-2,31	-2,05	-1,84	-1,65	-1,50	-1,36	-1,24	-1,14	-1,05	
Pearl	-4,04	-3,42	-2,93	-2,54	-2,22	-1,96	-1,74	-1,56	-1,40	-1,27	-1,16	-1,05	-0,97	-0,89	
AVG [TWCU]	-4,99	-4,22	-3,62	-3,14	-2,75	-2,42	-2,15	-1,93	-1,73	-1,57	-1,43	-1,30	-1,19	-1,10	
Man. Bridge	-3,68	-3,11	-2,67	-2,31	-2,02	-1,78	-1,59	-1,42	-1,28	-1,16	-1,05	-0,96	-0,88	-0,81	
PSW3	-1,67	-1,41	-1,21	-1,05	-0,92	-0,81	-0,72	-0,64	-0,58	-0,52	-0,48	-0,44	-0,40	-0,37	
CAE	-0,98	-0,83	-0,71	-0,62	-0,54	-0,48	-0,42	-0,38	-0,34	-0,31	-0,28	-0,26	-0,23	-0,22	

Source: Author's own calculations

Appendix 17: First difference capital cost per service per year (×$1mln)

Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	-10,22	-8,64	-7,41	-6,42	-5,62	-4,96	-4,41	-3,94	-3,55	-3,21	-2,92	-2,66	-2,44	-2,25	
AVG[AM]	-7,83	-6,62	-5,68	-4,92	-4,30	-3,80	-3,38	-3,02	-2,72	-2,46	-2,24	-2,04	-1,87	-1,72	
ABX	-4,21	-3,56	-3,05	-2,64	-2,31	-2,04	-1,81	-1,62	-1,46	-1,32	-1,20	-1,10	-1,01	-0,93	
AEC1	-12,82	-10,85	-9,30	-8,06	-7,05	-6,22	-5,53	-4,95	-4,45	-4,03	-3,66	-3,34	-3,07	-2,82	
AVG [ANE]	-10,97	-9,28	-7,95	-6,89	-6,03	-5,32	-4,73	-4,23	-3,81	-3,45	-3,13	-2,86	-2,62	-2,41	
ADR	-5,90	-4,99	-4,28	-3,71	-3,24	-2,86	-2,54	-2,28	-2,05	-1,85	-1,68	-1,54	-1,41	-1,30	
NEUATL3	-3,69	-3,12	-2,68	-2,32	-2,03	-1,79	-1,59	-1,42	-1,28	-1,16	-1,05	-0,96	-0,88	-0,81	
AVG [TE]	-2,23	-1,89	-1,62	-1,40	-1,23	-1,08	-0,96	-0,86	-0,78	-0,70	-0,64	-0,58	-0,53	-0,49	
Empire	-10,21	-8,64	-7,41	-6,42	-5,62	-4,96	-4,41	-3,94	-3,55	-3,21	-2,92	-2,66	-2,44	-2,25	
AVG [TECU]	-6,69	-5,66	-4,86	-4,21	-3,68	-3,25	-2,89	-2,58	-2,33	-2,10	-1,91	-1,75	-1,60	-1,47	
Pearl	-7,53	-6,37	-5,46	-4,74	-4,14	-3,66	-3,25	-2,91	-2,62	-2,37	-2,15	-1,97	-1,80	-1,66	
AVG [TWCU]	-6,72	-5,68	-4,87	-4,22	-3,69	-3,26	-2,90	-2,59	-2,33	-2,11	-1,92	-1,75	-1,61	-1,48	
Man. Bridge	-4,87	-4,12	-3,53	-3,06	-2,68	-2,36	-2,10	-1,88	-1,69	-1,53	-1,39	-1,27	-1,16	-1,07	
PSW3	-1,93	-1,63	-1,40	-1,21	-1,06	-0,94	-0,83	-0,74	-0,67	-0,61	-0,55	-0,50	-0,46	-0,42	
CAE	-1,07	-0,91	-0,78	-0,67	-0,59	-0,52	-0,46	-0,41	-0,37	-0,34	-0,31	-0,28	-0,26	-0,24	

Source: Author's own calculations

Appendix 18: First difference overall cost per service per year (×$1mln)

Speed V	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dragon	13,81	11,03	8,87	7,18	5,81	4,68	3,71	2,82	1,95	1,04	-0,01	-1,26	-2,81	-4,76	
AVG [AM]	11,66	9,44	7,73	6,37	5,28	4,38	3,61	2,92	2,25	1,57	0,81	-0,08	-1,15	-2,48	
ABX	6,80	5,55	4,58	3,81	3,20	2,68	2,24	1,85	1,47	1,08	0,66	0,17	-0,41	-1,13	
AEC1	18,58	15,16	12,50	10,39	8,70	7,30	6,11	5,06	4,08	3,09	2,04	0,85	-0,55	-2,26	
AVG [ANE]	15,73	12,76	10,47	8,66	7,20	6,00	4,97	4,05	3,17	2,26	1,25	0,08	-1,33	-3,08	
ADR	9,21	7,42	6,02	4,91	4,01	3,27	2,63	2,04	1,47	0,87	0,19	-0,60	-1,58	-2,80	
NEUATL3	6,33	5,19	4,31	3,60	3,03	2,56	2,15	1,80	1,46	1,13	0,78	0,38	-0,08	-0,63	
AVG [TE]	3,93	3,26	2,73	2,31	1,97	1,69	1,45	1,24	1,05	0,87	0,68	0,48	0,25	-0,02	
Empire	17,65	14,70	12,40	10,56	9,07	7,84	6,81	5,91	5,11	4,37	3,64	2,88	2,07	1,15	
AVG [TECU]	9,61	7,68	6,19	5,02	4,08	3,30	2,62	1,99	1,37	0,68	-0,10	-1,06	-2,25	-3,76	
Pearl	10,96	8,93	7,37	6,14	5,15	4,33	3,64	3,01	2,42	1,81	1,14	0,37	-0,56	-1,70	
AVG [TWCU]	10,92	8,92	7,38	6,16	5,18	4,36	3,67	3,04	2,44	1,82	1,13	0,34	-0,61	-1,78	
Man. Bridge	8,00	6,50	5,33	4,39	3,63	3,00	2,46	2,00	1,59	1,21	0,84	0,46	0,06	-0,39	
PSW3	3,18	2,56	2,08	1,70	1,40	1,14	0,93	0,74	0,58	0,42	0,27	0,10	-0,07	-0,27	
CAE	1,99	1,64	1,37	1,15	0,98	0,83	0,71	0,60	0,51	0,43	0,35	0,27	0,20	0,11	

Source: Author's own calculations