NORGES HANDELSHØYSKOLE

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Determinants of Vessel Speed in the VLCC Market – Theory vs. Practice

by

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Abstract

A widely accepted relationship in optimal speed theory is that speeds of vessels respond positively to changes in freight rates and negatively to changes in bunkers. In this thesis we analyse how this hypothesis corresponds to what is actually practiced by market participants. In addition, an important contribution of this thesis is to examine how vessel specific and operational specific variables affect speed in practice. The analysis is based on the theoretical speed optimization models of Ronen (1982), and utilizes a comprehensive panel dataset with observed average daily speed of 607 VLCCs[1] in the period from Jan 2013 to Feb 2015. By applying a random effects panel data model, we are not only able to explain the variations *within* one vessel over time, but also variations *between* vessels. The empirical analysis shows considerable differences in how speed responds to changes in explanatory variables for the laden and the ballast leg. For the ballast leg, we find significant relationships between freight, bunkers and speed, in line with theory, but less in magnitude than theoretical models suggest. Conversely, for the laden leg we find no evidence for any relationship between speed and macro variables. Our analysis suggests that financing costs and the cost distribution among charterers and owners create split-incentive problems for VC contracts, leading to the discrepancies between theory and practice. The findings can also be caused by a larger share of the fleet sailing on TC contracts than first anticipated. Further, we find only slight evidence that vessel specific factors may have an influence on the speed decision. Cargo owners with operational control of the vessels are shown to have other speed incentives than traditional shipowners, with more emphasis on cargo value and the sourcing of cargo. Our findings substantiate that before introducing market-based measures to reduce emissions, regulating authorities should fully understand the true speed incentives of the market participants.

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[1] Very large crude carrier

Foreword

First and foremost we would like to thank our advisor, Roar Adland, for great support and knowledge during the progress of writing this thesis. Furthermore we would like to thank Genscape Vesseltracker and Marinetraffic for access to their comprehensive and detailed dataset, Haiying Jia for input regarding the choice of statistical method, Lisa Maria Aßmann for meaningful and inspiring discussions on optimal speed theory, Petter Haugen and DNB Markets for contributions related to speed models and ECO vessels, Fearnley Securities Shipping Team for helpful comments regarding the shipping market, Stein Kjølberg of Jotun Hull Performance Solutions for valuable input on hull fouling, and all other people making the thesis what it is today.

Mathias Owing Maanum & Henrik Prøsch Selnes, Oslo, June 2015

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1. Introduction

1.1 Background

In booming shipping markets the general view among market participants is that vessels should steam at as high speeds as possible. This can explain why the interest for optimal speed among researchers and market participants has seemingly been closely related to market conditions. The depressed shipping markets of late 1970's and early 1980's gave life to the first theories about how vessel owners could use speed optimization, and slow steaming in particular, as a profit enhancing measure. The poor market conditions in the wake of the 2008 financial crisis led to a resurgence where slow steaming again were the centre of attention. While slow steaming were relevant only for economical reasons in the first cycle of optimal speed theory, the environmental consequences of greenhouse gas emissions from burning ultra heavy fuel oil has lead to increased focus on speed also from organizations and authorities not directly involved in maritime transport. By introducing an environmental factor to the optimal speed equation, governing authorities such as the IMO have joined the discussion and made speed management more relevant than ever. The centre of focus is especially to eliminate uneconomically high speeds caused by ineffective speed decision systems or lack of up-to-date information on optimal speed theory. This paper is written in a time where the price of crude oil has dipped to levels not seen since 2008. In addition, freight rates surged in the end of 2014 and firmed at relatively high levels going into 2015. This has led to a boom in the crude tanker market and, at least in theory, incentives to speed up for shipowners.

1.2 Objectives

Environmental

The relation between vessel speed and emissions of CO_2, the main greenhouse gas (GHG) emitted through fuel burning, is well known. As highlighted in UNCTADs Review of Maritime Transport 2014, the International Maritime Organization (IMO) identifies speed management as a key-contributing measure in reducing the GHG emissions of the shipping industry. As market based measures remain controversial, regulations within the shipping industry has until date been kept within the scope of increasing fuel efficiency[2] and reducing the air pollution of SOx[3] and NOx[4] among vessels. Further knowledge about what truly matters in the speed decision will be valuable to market regulating authorities in the discussion of future potential speed reduction measures.

Economical

Measures to reduce the operational and voyage related expenditures are of great significance to profit maximizing shipowners and operators, especially in times of a through in freight rates. Since bunkers is the main cost of a voyage and fuel consumption is widely assumed to increase with speed through a cubic relationship, speed management is one way to stand out from the rest of the pack. Or looking at it from a different perspective: uneven distribution of information regarding optimal speed among speed determining parties may cause disadvantages for the less knowledgeable players paying less attention to speed management. Hence, an empirical study of the effects of various variables on speed can reveal relations that not only are beneficial to regulators, but also contribute to bridging the information gap between market participants. When looking at the VLCC fleet as a whole, the average speed of vessels will also be a contributing factor in the total vessel supply in the market. This may have effects for third parties such as ship builders, making the speed decision of operators relevant for all market participants.

1.3 Contribution

The aim of this thesis is to contribute to the empirical optimal speed literature by analysing the effects of vessel specific-, macro- and operational variables on the observed speed. In our study we employ a panel data set including average daily speed, move[5] draught and other voyage data for the complete VLCC fleet in the period from 1 January 2013 to 22 February 2015, comprising 305,106 average speed observations for 624 vessels.

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[2] *IMO, 2011, annex 19*: Adopted in 2012, introducing EEDI for new ships and the Ship Energy Efficiency Management Plan for all ships (UNCTAD, 2014)

[3] *MARPOL annex VI*: from 1 January 2015, ships operating in certain control areas will be required to burn fuel with no more than 0.1 per cent sulphur. Alternatively, ships must fit an exhaust gas cleaning system, or use any other technological method to limit SOx (Adland, 2013) emissions (UNCTAD, 2014)

[4] *MARPOL annex VI*: New tier III standards regarding NOx emissions to be applied to marine diesel engines installed on ships constructed on or after 1 January 2016 and which operates in certain control areas (UNCTAD, 2014)

[5] “Move” is generally referring to a dynamic measurement of a variable in the dataset at a single point in time

Data

Previous studies comparing optimal speed theory with observed data from the tanker market (see Assmann, 2015; Assmann, 2012) use AIS port data to estimate the average speed for each voyage. The fact that we utilize daily speed data on a per vessel basis allows us to perform a more detailed analysis of the dynamic relationship between explanatory variables and the speed of a vessel. A similar micro-level analysis has until date never been conducted for the tanker market. In addition, the inclusion of daily move draught makes it possible to analyse the differences between the laden leg and the ballast leg. A split between laden and ballast has previously been done in an empirical study of the dry bulk market in Adland (2013), and there are reasons to believe that the same externalities[6] affecting the speed choice for different loading conditions will be present in the tanker segment. The dataset also provides longitude- and latitude coordinates accompanying each speed observation, allowing us to identify vessels that shuttle between two destinations or are located in certain areas where cyclones and tropical storms are common for large parts of the year.

Variables

While previous empirical studies are based on the assumption that the vessel fleet is homogenous, differences between vessels regarding engine specifications, hull design, size and age will make the optimal speed vary among vessels. There are reasons to believe that knowledgeable and profit maximizing market participants take into account the characterization of a vessel when determining the speed, but to date there has been no work to quantify the effects. In order to capture the effects of vessel specifications on speed, we generate vessel specific explanatory variables by utilizing a comprehensive database with specifications for the complete VLCC fleet. The vessel specific explanatory variables come in addition to other variables related to macro, operations and cyclones.

Approach

Most literature on optimal speed has been written in times where low freight rates and high cost of bunkers has caused squeezed margins for shipowners and a need for speed reductions (slow steaming) to conserve fuel. By including the period from autumn 2014 until spring 2015 we captures a period of sharp decline in crude oil prices. Additionally, freight rates saw a rebound from late 2014 continuing into 2015. We are therefore able to test if theoretical

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[6] Such as speed clauses in the laden leg

optimal speed models composed in times with poor market fundamentals are applicable to cases of positive shocks in the crude oil price[7] (lower fuel prices) and high earnings (*Figure 1*).

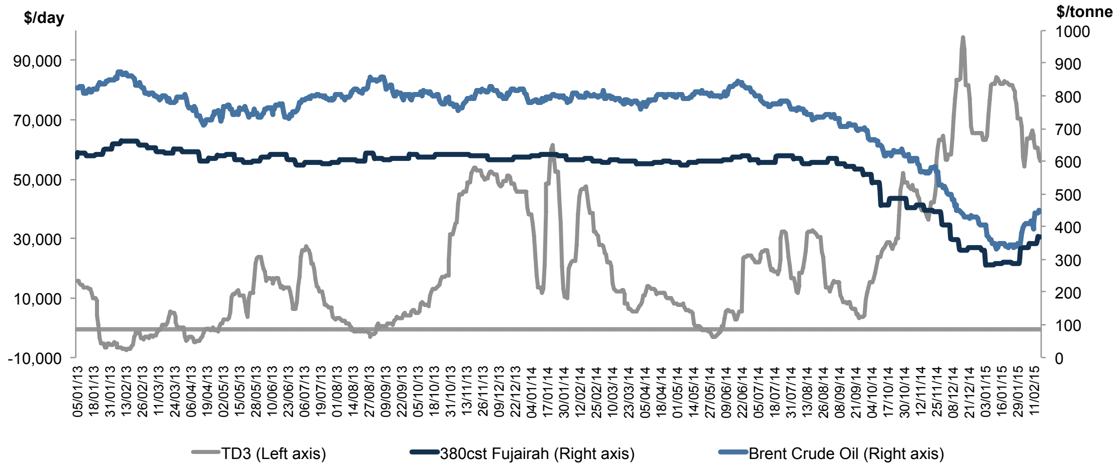

Figure 1: Freight rate (TD3), Bunkers (380cst) and Brent Crude prices for the period of relevance to this thesis

Source: Clarkson's (2015)

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[7] For the VLCC market, mostly trading out of the Middle East Gulf, Dubai (and Oman) Crude is the most relevant crude as this is used as benchmarks for Asian crude types. Throughout this thesis, however, Brent crude oil is used when unrefined oil is included as a part of the analysis. The reason is the availability of both daily and future crude oil prices. Brent and Dubai (Oman) use the same pricing formulas and the correlation is high (Koyama, 2011). For the purpose of this thesis, where crude oil is used for analytical discussions and not used directly in the calculation of theoretical optimal speed nor included as a variable (due to high correlation with bunkers) (Rehmatulla, Smith, & Wrobel, 2013), Brent crude is a reasonable proxy for the value of the cargo for VLCCs.

1.4 Structure

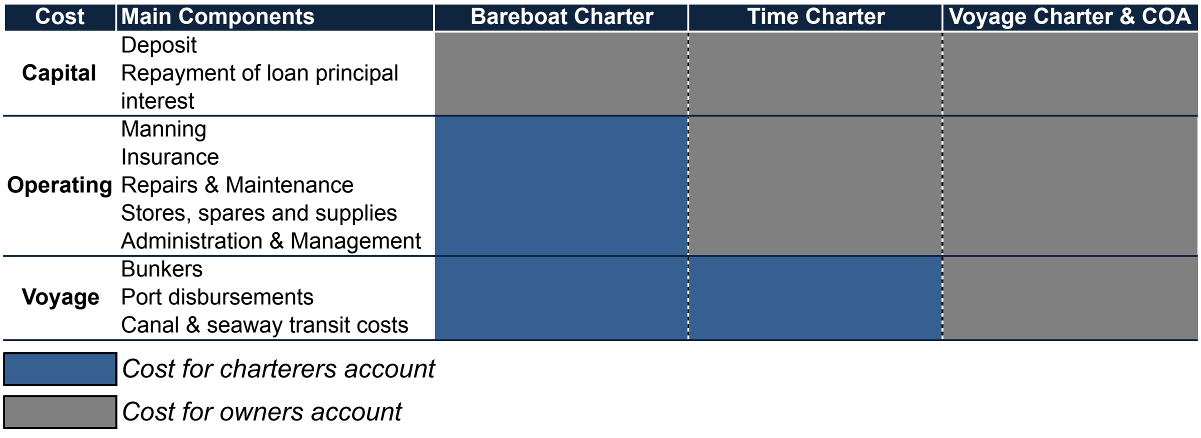
The remainder of this thesis is organized as following: In Chapter 2 – *Literature Review and Theory* we discuss which parties are involved in the speed decision and how the speed decision affects not only market participants, but also the environment. This is followed by an introduction to previous literature written on theoretical optimal speed and studies that compare the theoretical optimal speed with the actual observed speed of vessels. The chapter is concluded with a discussion on why vessel specific variables matter in the speed determining decision. In Chapter 3 – *The Model* we introduce a theoretical optimal speed model, in which we split between a profit-maximizing model for the laden leg and a cost-minimizing model for the ballast leg. We also introduce an alternative model for the laden leg for vessels operated by the cargo owner. We continue by deriving an empirical model from the theoretical optimal speed models, on logarithmic form. The empirical model is extended by adding explanatory variables related to vessel characteristics, operational strategy, the market and weather. In this part we describe ***why*** the variables are added and the expected functional relationships with speed. In Chapter 4 – *Data* we perform a nine-step cleaning process of the dataset to make it more suitable for analysis. We continue by describing ***how*** data for the explanatory variables are collected and calculated. In Chapter 5 – *Analysis & Discussion*, we present the main findings of our two empirical models and the statistical tests conducted, before we analyse and discuss the results. The chapter closes with limitations of our study and suggested topics for further research. The final chapter, Chapter 6, concludes on the thesis.

2. Literature Review and Theory

2.1 Optimal Speed – Optimal for Whom?

In the tanker market there are two main contracts (charterparties) for carriage of goods, voyage charter (VC) and time charter (TC) (Rehmatulla, Smith, & Wrobel, 2013). There are other hybrid contract forms such as contracts of affreightment (COA) and trip charters, but these can be reclassified to either TC or VC due to the similar cost allocation (Wilson, 2010; Stopford, 2009). Bareboat is another chartering form, but this is merely a leasing contract and not a contract for carrying goods (Rehmatulla, Smith, & Wrobel, 2013).

For a VC the shipowner is in control of the operations of the ship, while a TC is the hiring of a vessel for a given period of time where the charterers have commercial control. This implies that the voyage cost, in which bunkers constitutes a major proportion (Pokuka, 2006), has to be covered by the shipowner in a VC, but is for the charterers account in a TC (*Table 1*).



Cost	Main Components	Bareboat Charter	Time Charter	Voyage Charter & COA
Capital	Deposit Repayment of loan principal interest	⬛	⬛	⬛
Operating	Manning Insurance Repairs & Maintenance Stores, spares and supplies Administration & Management	🟦	⬛	⬛
Voyage	Bunkers Port disbursements Canal & seaway transit costs	🟦	🟦	⬛

🟦 *Cost for charterers account*

⬛ *Cost for owners account*

Table 1: Cost distribution between charterer and vessel owner
Source: Drewry Shipping Consultants Ltd.

As to be elaborated in section 2.2, the theoretical optimal speed of a vessel is often analysed from the view of a shipowner. For a VC the shipowner is the actual legally registered owner[8], while the charterer can be viewed as the disponent owner[9] for a TC. All "owners" will according to the theory of Devanney (2009) respond similar to changes in freight rate and bunkers in their speed decision. Since vessels can be chartered and re-let at current spot

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[8] The name of the company that appears on the ship's registration documents (IHS Fairplay, 2015)
[9] The disponent owner is the effective owner with the legal responsibilities of the registered owner (Shipinspection, 2015)

market rates all vessels are effectively in the spot market, regardless of the vessel being on VC or TC (Devanney, 2009).

While Devanney's theory suggests that speed incentives of owners should be independent of contract type, the cost distribution relative to the charterer's control of the vessel could lead to split-incentive problems[10]. This could cause market failures and barriers to energy efficiency in form of efficiency and usage problems (Rehmatulla, Smith, & Wrobel, 2013).

The efficiency problem is related to TC contracts. Since the shipowner decides the specifications determining the energy efficiency of the vessel but the charterer is the party that bears the cost of bunkers, there are barriers for the shipowner to induce energy efficient measures for the vessel (Rehmatulla, Smith, & Wrobel, 2013). Even though difficult to measure, this barrier to energy efficiency might affect the speed choice.

The usage problem is related to VC contracts for the laden leg. As the charterer for a VC neither selects the energy efficiency technology of a vessel nor bears the cost of fuel consumption, the shipowner is not able to make the charterer internalize bunkers cost (IEA, 2007). The usage problem suggests that there might be market failures in the cost structure of the shipping industry (Rehmatulla, Smith, & Wrobel, 2013), potentially affecting the speed decision for VCs.

Even though considered a relatively environmental friendly transportation method in terms of grams of CO_2 emissions per tonne-km[11], the seaborne trade of crude oil through VLCCs entails substantial amounts of greenhouse gas (GHG) emissions[12] in which there has been a growing concern about[13]. As GHG emissions increase proportionally with fuel consumption, steaming at as low speeds as possible are generally considered to be the most environmental friendly. Some would argue against this by stating that lower speeds cause higher emissions in form of more vessels needed for supply to keep up with demand. A study by Transport and Environment from 2012, however, disregards this argument by showing that reductions

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[10] A form of principal agent problem (Rehmatulla, Smith, & Wrobel, 2013)

[11] VLCCs (+200,000 dwt) with 2.9 g/tonne-km compared to trucks at 80 g/tonnne-km and planes at 435 g/tonnne-km (IMO, 2009)

[12] International Shipping accounted for more 2.7% of global C02 emissions in 2007 and Crude oil amounts to about 30% of world seaborne trade (IMO, 2009)

[13] IMO (2009) addressed this concern by presenting ways to reduce GHG emissions for the shipping industry, and Rehmatulla et al. (2013) builds on this discussion by further addressing increased energy efficiency as a strategy towards lower carbon emissions.

in speed cause a significant decrease in CO2 emissions, even after the inclusion of additional ships needed to keep supply constant (Faber, Nelissen, Hon, Haifeng, & Tsimplis, 2012).

2.2 Optimal Speed Theory

Literature written on speed in the shipping market can broadly be divided into three main groups based on the optimization criterion of the models presented: profit, cost and fuel consumption. Perakis and Papadakis (1989) and Lindstad et al. (2011) are two identifiable exceptions with respectively time- and pareto analysis as optimization criterions. While there are a considerable number of papers written with the aim of cost minimization in shipping transportation, only a handful of published papers analyse theoretical optimal speed as a derivative of profit maximization where both fuel price and freight rates are considered explicit input variables (*Table 2*). The common basis of these publications is that rational shipowners operating in competitive markets with vessels on VC freight contracts want to maximize profits through speed optimization, taking into account the trade-off between fuel consumption and income generation (Assmann, Andersson, & Eskeland, 2015; Psaraftis & Kontovas, 2013). It is worth to notice that the constraints and models vary between the segments.

Publication	Decision Maker	Segment	Fuel Price Input	Freight rate input	Various Legs
Alderdon (1981)	Shipowner	General	X	X	X
Ronen (1982)	Shipowner	Tramp	X	X	X
Corbett et al. (2010)	Shipowner	Container	X	X	Round trip
Gkonis and Psaraftis (2012)	Shipowner	Tanker, LNG, LPG	X	X	X

Table 2: Papers containing optimal speed models with profit as optimization criteria
Source: Based on Psaraftis and Kontovas (2013)

As mentioned in 1.1, literature written on the relation between freight rates, bunker price and the economically optimal speed of vessels has typically been analysed in times of poor market fundamental (Ronen, 2011).

In the late 1970's, soaring bunkers prices, falling demand for tonnage and overcapacity in the oil tanker market lead to high operational costs, depressed freight rates and squeezed margins for shipowners (Stopford, 2009). Through the empirical studies of (Manning, 1956) it was already then well recognized in the market that that fuel consumption of a motor ship is directly related to the third power of the speed, and the relation between bunker price and speed had previously been addressed through Artz Jr. (1975) and Avi-Itzhak (1974) (Later Devanney (2010) has further analysed the relation between bunker prices and VLCC spot rates). Shipowners were slowing down to conserve fuel, but this was an observation rather than explained by explicit theory (Artz Jr., 1975). In a depressed shipping market where optimal speed still was determined by trial and error rather than analytical models (Ronen, 1982; Zannatos, 1959), theoretical models for how speed could be optimized in relation to freight rates and bunkers costs started to become relevant.

Theoretical optimal speed in shipping was first implicitly covered as a subject through transport supply capacity models and the effect of increased bunker prices on freight rates in Norman and Wergeland (1979), where the optimal speed is given by the equality between the extra income gained from speeding up and the corresponding extra fuel cost (Assmann, 2012). However, Alderton (1981) and Ronen (1982) were the first to formulate explicit theories for optimal speed based on profit optimization with freight rates and fuel cost as input variables.

Alderton (1981) argued that optimal speed could only be achieved by considering two factors:

1. **Potential speed:** Determined by ship specific variables and weather
2. **Preferred speed:** The preferred speed when taking into account revenues, costs and schedules

Ronen (1982) followed with a paper further highlighting the trade-off between lower fuel cost when slow steaming and lower income generation in the determination of theoretical optimal speed. In particular, the paper analyses the effect of oil price[14] on theoretical optimal speed and introduces three mathematical models for the determination of theoretical optimal speed: an income generating leg (laden), a position leg with no income (ballast) and a mixed leg with some degree of income generation.

The market tone in shipping stayed depressed until the late 1980's, when demand growth started to pick up. However, an expanding fleet led to a competitive tanker market in the decade to come. From the late 1990's the demand growth accelerated and a shortage of supply led to a boom in the tanker market (Stopford, 2009). This lasted until the 2007/2008 financial crisis rocked the shipping markets, causing the freight rates to plummet. The poor

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[14] Through bunker fuel prices

market fundamentals for shipowners led to a new wave of interest for cost reductions through slow steaming and optimization of speed.

Ronen (2011) followed up his 1982 paper by including service frequency to his previous models. This is relevant for the container market when modelling the trade-off between the cost of adding more vessels to the fleet in order to maintain the fixed service frequency when slow steaming, and the fuel cost savings from slow steaming. As discussed in section 2.1, a similar argument has been used for other shipping segments when analysing the environmental gains of slow steaming.

Common for both Ronen (1982) and Alderton (1981) is the focus on optimal speed for various legs. This view is shared by Gkonis and Psaraftis (2012), where optimal speed is determined for laden and ballast as a function of fuel price, freight rate and additional parameters such as inventory costs. The model also allows for including more than one vessel and considers the emissions for the tanker fleet segment based on the output of the optimization.

By viewing voyages as round trips instead of individual legs, Corbett et al. (2009) takes a different starting point in the determination of theoretical optimal speed. The theory states that since there is only one income generating leg, shipowners should optimize the speed by distributing these revenues to both legs.

Most recently Psaraftis and Kontovas (2013) and Psaraftis and Kontovas (2014) have reviewed the fundamental parameters of previously published models where speed is one of the decision variables and analysed the concepts and combined speed-routing scenarios.

When modelling the effect of freight rates on speeds it is important to note the presence of the simultaneity problem (Adland, 2013; Norman & Wergeland, 1979; Strandenes, 1999). While an individual shipowner act as a price taker in the market, the collective speed decision of all shipowners will affect the supply and demand balance of the market. This will move freight rates, which again would affect the theoretical optimal speed. For simplification, most research is therefore based on the assumption that all shipowners are price takers (Adland, 2013).

2.3 Theoretical Optimal Speed vs. Practice

The basis of theoretical optimal speed models is that speeds vary positively with freight rates and negatively with fuel prices. This hypothesis was apparently first tested in empirical studies by Jonkeren et al. (2012)[15], analysing the observed speeds of carriers in North-West Europe using micro panel data in the period from 2003 to 2007. Jonkeren et al. (2012) confirmed the optimal speed theory hypothesis, finding that freight rates have positive impact on speed[16], while bunkers have negative impact[17]. The empirical studies of Notteblom and Vernimmen (2009) show that operators of container vessels slow down and increase fleet size in cases of high bunker prices. However, the service frequency element of liners, as described by Ronen (2011) and empirically proven by Notteblon and Vernimmen (2009), leads to a different speed optimization problem for liner ship operators than for other segments such as bulk and tankers (Adland, 2013).

Adland (2013) analysed some 18,000 voyages in the dry bulk sector, investigating differences in speed across loading condition (laden and ballast) and main trading routes. The survey finds evidence of speed reductions during depressed markets, but speeds showed much lower volatility than what optimal speed theory suggests. The micro-level panel data did also unveil that vessels steams at consistently higher speeds in the ballast leg, compared to the laden leg.

Assmann (2012) tested the theoretical log-linear relationship between speed and the freight/bunkers ratio for laden VLCC voyages between Middle East Gulf (MEG) and Japan (TD3), employing time series data with voyage duration and distance. However, no significant relation between speed and the explanatory variables was found. Later Assmann (2015) employed actual AIS[18] port data for all VLCCs leaving from MEG to Far East[19] and found support for the theory. In this analysis, average speed was computed on a voyage basis using endpoint data. As previously found in the bulk market survey of Adland (2013), Assmann (2015) found the elasticities for both bunkers and freight rate to be of smaller

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[15] The first empirical study of the tanker market was apparantly performed by Beenstock & Vergottis (1989). The study estimated an aggregate econometric model based on Beenstock (1985), testing the interdependence of the freight market and the market of tankers using annual dynamically determined freight rates and tanker prices drawn from 1956 to 1986.

[16] Found the freight price elasticity of speed to be 0.17. Jonkeren et al. (2012) use the water level in the Rhine river as an instrument variable for freight rate as freight rate itself being endogenous (due to the simultaneity problem)

[17] Found the fuel price elasticity of speed to be -0.11

[18] Automated Identification System

[19] Japan, South Korea, China

magnitude than expected. Another finding of Assmann (2015) is that the observed speed of the ballast leg is considerably more in line with optimal speed theory than for the laden leg and that vessels assumed to shuttle MEG-Japan are almost completely insensitive to changes in freight rate.

2.4 Potential Speed Differs Among Vessels - Shouldn't Preferred Too?

As described by Alderton (1981), to estimate the theoretical optimal speed of a vessel, both potential vessel speed and preferred speed have to be considered. Previous literature comparing theoretical optimal speed and observed speed data (Assmann, 2012; Assmann, Andersson, & Eskeland, 2015; Adland, 2013; Jonkeren, Ommeren, & Rietveld, 2012) are written with the assumption that the vessel fleet is homogenous in terms of vessel specifications. Hence the empirical studies do not analyse the differences in potential speed and preferred speed among vessels and how this affects the optimal speed and thus the observed speeds.

The potential speed of a vessel is a function of two factors (MAN Diesel & Turbo, 2013a):

1. **Potential effective brake power**
2. **Hull resistance and weight**

The factors determining the potential speed of a vessel will also have an impact on the fuel consumption for a given speed and thus the fuel efficiency. This is summarized in *Table 3* where weight is implicitly included as a variable through the wetted area of the hull, varying with the loading condition of the vessel.

Main determinants	Sub determinants	Description
Hull resistance	**Frictional resistance**	*Dependent on the size of wetted area of the hull (varies with the loading condition and weight of the ship) and a frictional coefficient dependent on hull design and fouling. Represents 70-90% of a VLCCs total resistance.*
	Residual resistance	*Wave resistance and loss caused by flow seperation (eddy resistance). 8-25% of total resistance*
	Air resistance	*Represents about 2% of the total resistance of a VLCC*
Effective brake power	**Engine speed**	*Measured in revolutions per minute (RPM)*
	Mean effective pressure	*The average pressure being exerted on the top of the piston during the power stroke that would result in the measured power output of an engine*
	Constant	*Engine specific*

Table 3: Vessels specific fuel consumption determinants at a given speed
Source: Own table based on Man Diesel & Turbo (2013) and Harleyc.com (2015)

Hence, according to the theoretical models where fuel consumption is regarded an input variable, vessel specific factors such as Effective brake power, hull resistance and weight should affect both **potential speed** and the **preferred speed** of a vessel. The paper at hand is the first of its kind to employ dynamic daily speed data on a per vessel basis in combination with detailed vessel information. This allows us to analyse if market participants consider the potential speed of a vessel when determining speed, or if assumptions made in previous literature on the homogeneity of the fleet is justified.

3. The Model

3.1 Theoretical Optimal Speed Model

In order to establish an empirical model we need a theoretical optimal speed model to determine which variables to include and decide on the functional relationships. There are two common ways to interpret the VLCC market. The first orientation is based on the view that the laden and the ballast leg should be seen as a round-trip since the vessels typically return to the same loading port after discharge. According to this theory the income should be distributed over the entire trip, not only the laden leg. Alternatively one can argue that the economic nature of the laden and the ballast legs are different, and hence the speed choice differs as well.

We are of the opinion that operators after discharge have a more forward-looking view with primary focus on fuel costs and the next fixture. Hence, we will argue that it is beneficial to analyse the speed choice for two legs separately and therefore split into two separate models. This view is in line with what is practiced by market participants such as Euronav (2015), which use the ballast leg as a position leg for the next fixture and therefore treats it separately to the laden leg. The trade-off in the ballast leg is between bidding on an earlier contract at the expense of increased fuel costs or slow steam to save fuel and bid for a later contract. Slow steaming increases the time before a new income generating leg can be undertaken, but the incentives to slow down could also be fuelled by a belief in an uptick in the market. Thus, for the ballast leg we choose to use a cost-minimizing approach, as outlined in section 3.1.2.

Our models are based on Ronen (1982) and Assmann (2012), assuming that the vessels are sailing spot, i.e. on a voyage charter (VC). The models estimate the theoretical optimal vessel speed from the perspective of shipowners, which for VC contracts are both receivers of freight rates and bears the cost of bunkers. While the models require assumptions regarding the contract type, according to Devanney (2009) the identical speed incentives of any disponent owner leads to optimal speed being independent of whether a vessel is on VC, TC or is operated by the owner of the cargo (see section 2.1). For the laden leg we will challenge Devanney’s statement by introducing an alternative model for vessels operated by cargo owners in section 3.1.3.

Further, it is assumed perfect competition in the shipping market and that market actors behave rationally, with no ability to affect the total supply and rates. Hence, the shipowners are price takers in the spot market setting speed to optimize profits for each single trip.

3.1.1 Profit Maximizing Model – Laden Leg

For the laden leg a simple profit-maximizing model from the view of a shipowner chartering out his vessel on VC contract is taken. The owner charters out his vessel in the spot market for a dollar/tonne rate of R, on a given route from A to B. The distance for the route is given by D, and the size of the cargo transported in tonnes is W. The freight rate is assumed independent of speed, but the speed has to be set between V_{min}, the minimum speed for manoeuvrability, and the maximum speed V_{max}, limited by the engines maximum performance.

As previously described in *Table 1*, costs are usually split into three categories. The first two categories are **capital and operating costs** that accrue regardless of employment of the vessel. These costs are not relevant for the speed decisions since they are neither voyage nor speed dependent. The second category are the costs related to a voyage, or **the voyage variable costs**, such as fuel costs, port costs, canal fees, towage and pilotage. While all these costs are relevant on a voyage basis, bunkers is the only cost dependent on speed and thus the only one included in the model. Payments (fees) for being early (late) specified in the charter clause[20] are relatively small and ignored for the purpose of establishing a theoretical optimal speed model, even though it might be of relevance to the shipowner. Finally, it is assumed that the shipowner does not own the cargo and hence any depreciation of the value of the cargo is not included.

R – Spot freight rate in dollar/tonne on a leg
W – Weight of the cargo transported, tonnes
L – Leg distance
d – days it takes for the vessel to complete the leg
V – Vessel speed
V_d – Design speed
V_{min} – Minimum vessel speed

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[20] Commonly refered to as demurrage and despatch fees

V_{max} – Maximum vessel speed
F – Daily fuel consumption (tpd – tonnes per day)
F_d – Fuel consumption at design speed (V_d)
P_B – Price of bunker fuel, dollars/tonne
∇ – Displacement[21] of a ship
∇_d – Displacement at design draught
D – Draught of a ship (depth measure)
D_d – Design draught of a ship (depth measure)

We start off with a simple profit function per day[22] for the shipowner (Ronen, 1982):

$$\frac{\pi}{d} = \left(\frac{RW}{\frac{L}{24V}} - FP_B \right) \tag{1}$$

The daily fuel consumption needs to be determined, and in literature a well-known approach is the cubic rule (MAN Diesel & Turbo, 2013a), which is explained thoroughly in Appendix A

$$F = \left(\frac{V}{V_d}\right)^{\epsilon} F_d \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}} \tag{2}$$

According to MAN Diesel & Turbo (2013a) the displacement ratio can alternatively be replaced by the draught ratio (D/D_d) as an approximation[23]. We will use this proxy in the remainder of this thesis due to information available for the draught ratio, but not for the displacement ratio. This gives us

$$F = \left(\frac{V}{V_d}\right)^{\epsilon} F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} \tag{3}$$

And leaves us with the following profit formula

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[21] Displacement is the weight of the vessel herself and the cargo, crew etc., that is the lightweight plus the deadweight. It is the weight of the water a ship *displaces* when it is floating

[22] $\frac{L}{24V}$ gives the trip length in number of days

[23] To be exact it should be scaled by the block coefficient relative to the design block coefficient

$$\frac{\pi}{d} = \left(\frac{RW}{\frac{L}{24V}} - \left(\frac{V}{V_d}\right)^{\varepsilon} F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \right) \tag{4}$$

Hence, the operator should only slow down if the reduction in fuel costs offsets the lost daily freight income resulting from increased number of voyage days. To find the speed that maximize revenue, the daily profit function is optimized with respect to the speed chosen:

$$\frac{\partial \frac{\pi}{d}}{\partial V} = \frac{24RW}{L} - \varepsilon F_d P_B \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} \left(\frac{V}{V_d}\right)^{\varepsilon-1} \frac{1}{V_d} = 0 \tag{5}$$

Subject to $V_{min} \leq V_L \leq V_{max}$

$$V_L^* = \left(\frac{24RWV_d^{\varepsilon}}{\varepsilon P_B L F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}}} \right)^{\frac{1}{\varepsilon-1}} \tag{6}$$

From this theoretical formula for the optimal speed choice, there can be drawn certain conclusions. Firstly, the speed is increasing with freight rate R, design speed V_d and the cargo transported W. On the other hand, optimal speed is decreasing with the price of bunker fuel oil P_B, the trip distance L, fuel consumption at design speed F_d and draught ratio D/D_d. Thus, one should pay attention to the fact that increasing cargo have two conflicting effects, increasing freight income while at the same time increasing resistance thus fuel consumption.

3.1.2 A Cost-Minimizing Model – The Ballast Leg

For the ballast leg, the empty positioning leg, we use the cost-minimizing model of Ronen (1982) with the modified consumption formula presented in Appendix A. This leg does not generate any income for the shipowner and the objectives are therefore to minimize the costs and position the vessel for future freight contracts. For each day the trip is extended due to slower steaming, a cost equal to the alternative daily value C_a of the vessel is incurred. Hence, the cost function consists of the alternative daily value of the vessel and the fuel costs:

$$C = \left(\frac{L}{24V} C_a + \left(\frac{V}{V_d}\right)^{\varepsilon} F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \frac{L}{24V} \right) \tag{7}$$

The trade off is whether it is beneficial to go faster in order to get an earlier fixture at the expense of burning more fuel. The cost-function is minimized with respect to speed in order to find a theoretical optimal speed

$$\frac{\partial C}{\partial V} = -\frac{1}{V^2}\left(\frac{LC_a}{24}\right) + (\varepsilon - 1)V^{\varepsilon-2}\left(F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \frac{L}{24}\left(\frac{1}{V_d^{\varepsilon}}\right) \right) = 0 \tag{8}$$

Subject to $V_{\min} \leq V_B \leq V_{\max}$

$$V_B^* = V_d \left(\frac{C_a}{(\varepsilon - 1) F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B} \right)^{\frac{1}{\varepsilon}} \tag{9}$$

From the optimal speed formula the speed is increasing with design speed V_d and the alternative income generation of the vessel C_a. It is decreasing with bunker fuel price P_B, fuel consumption at design speed F_d and draught ratio (D/D_d).

3.1.3 An Alternative Optimal Speed Model For a Cargo Owning Operator – Laden Leg

Despite Devanney (2009) claiming that the incentives for an operator who owns the cargo and an owner chartering out his vessel in the spot market are coinciding, his reasoning do not account for the alternative value of the cargo, or more specifically, the financing cost of the cargo. Therefore we will present a model including this factor to check if such an approach is more in line with reality. With starting point in the presented cost minimizing model of Ronen (1982) we can formulate a model by using the alternative value of cargo instead of the alternative cost of the vessel (Assmann, 2012). The cargo owner needs to weigh the fuel savings from going slower with the financing cost of the cargo. Thus, we introduce the price of the cargo P_0, and the alternative value of the cargo per day r. The latter could either be seen as what the owner alternatively could earn on the cargo per day, or as we assume; the financing cost reflecting the capital bound in the cargo. If the vessel is on a TC, the TC rate does not need to be included, as it does not depend on speed. Assuming that the cargo owner moves an amount equal to the maximum cargo capacity of the ship, the cost-minimizing problem for the laden leg can be written as:

$$C = \left(WP_0(1+r)^{\frac{L}{24V}} + \left(\frac{V}{V_d}\right)^{\varepsilon} F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \frac{L}{24V} \right) \tag{10}$$

Minimizing the cost with respect to speed gives

$$\frac{\partial C}{\partial V} = -\frac{L}{24V^2} WP_0(1+r)^{\frac{L}{24V}} ln(1+r) + (\varepsilon - 1)V^{\varepsilon - 2} \left(F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \frac{L}{24} \left(\frac{1}{V_d^{\varepsilon}}\right) \right) = 0 \tag{11}$$

Subject to $V_{min} \leq V_L \leq V_{max}$ and $\varepsilon = 3$ (see section 3.2 for discussion on parameter)

$$\frac{\partial C}{\partial V} = -\underbrace{\frac{L}{24V^2} WP_0(1+r)^{\frac{L}{24V}} ln(1+r)}_{-} + \underbrace{2V \left(F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} P_B \frac{L}{24} \left(\frac{1}{V_d^{3}}\right) \right)}_{+} = 0 \tag{12}$$

Solving this for *V* to get an equation for optimal speed is a complex mathematical exercise, beyond the scope of this thesis, but at least this minimization problem gives us insight on which factors that will increase and reduce costs. The first term being negative indicates that increasing speed reduces costs related to the alternative value of the cargo. The second part of the equation indicates that reducing the speed reduce fuel costs. Hence, it is evident that the price of crude oil pulls optimal speed in two opposite directions. A higher crude oil price will increase the value of the cargo (boosting the speed incentives of cargo owners), but at the same time come simultaneously as higher bunkers prices[24] (incentives to slow down). Which effect is the largest depends on the relative size of the different parameters in the equation. Due to high multicollinearity between crude and bunkers, it is hard to perform a statistical analysis of these two effects separately. Consequently, one must omit one of the two. As a result, the crude price measure kept in the equation will capture both the effect of cargo value decrease and bunkers costs increase. The key takeaway is that we are uncertain about the sign of the crude price coefficient for vessels operated by cargo owners.

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[24] Assuming that that there exists a close correlation between bunker fuel oil and cargo price

An issue with the alternative theoretical model addressed by Assmann, Andersson, & Eskeland (2015) is that if the value of cargo is included as a speed-increasing variable, the storage situation for crude oil at destination should be accounted for. If the cargo cannot be sold or used immediately and the storage costs are high, it might be beneficial to sail slower for the cargo owner. As data on storage costs are hard to obtain, it is not accounted for in our analysis. However, it should be kept in mind when interpreting the results.

3.2 From Theory to an Empirical Model

In order to be able to analyse how the speed choice is influenced by different factors, we need to formulate an empirical model. With basis in the theoretical model for the laden leg presented in the section 3.1.1, we can formulate a statistical model that can give us a good impression of the functional relationship between speed and its main determinants.

Our expectations arising from the theoretical optimal speed model are based solely on a simplistic model of economic theory. In practice there will be unobservable factors such as currents and weather conditions that will affect the speed. We might also experience measurement errors, leading to untrue observations. In order to allow for variations between the observed speeds and the theoretical optimal relationship we need to add a stochastic element. Therefore we multiply an error term ω, where $\omega = e^{v}$, to the optimal speed formula:

$$V_L^* = \left(\frac{24RWV_d^{\varepsilon}}{\varepsilon P_B L F_d \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}}} \right)^{\frac{1}{\varepsilon - 1}} e^{v} \qquad (13)$$

By taking the natural logarithm of this equation we can model the relationship between speed and the main determinants as a linear relationship. Linearity, being a key assumption, allows us to apply the panel data models discussed in the following through a log-linear relationship (Wooldridge, 2010):

$$\ln V_L^* = \beta_0 + \beta_1 lnR - \beta_2 lnP_B + \beta_3 lnW + \beta_4 lnV_d - \beta_5 lnL - \beta_6 lnF_d - \beta_7 (^{\mathrm{D}}/_{\mathrm{D}_d}) + v \qquad (14)$$

This regression model, which is derived from the theoretical optimal speed formula, tells us the expected signs of the coefficients. Determining the speed-consumption power coefficient

ε allows us to get insight on the expected size of the coefficients for the explanatory variables. The speed-consumption power coefficient is dependent on vessel type, and for VLCCs generally assumed by the industry to be between 2.6 and 3.2 (Assmann, Andersson, & Eskeland, 2015; MAN Diesel & Turbo, 2013a). If we use a coefficient of 3, we would expect the following optimal speed relationship

$$\ln V_L = \frac{1}{2} ln8 + \frac{1}{2} lnR - \frac{1}{2} lnP_B + \frac{1}{2} lnW + \frac{3}{2} lnV_d - \frac{1}{2} lnD - \frac{1}{2} lnF_d - \frac{1}{3} ln({}^{\mathrm{D}}/_{\mathrm{D}_d}) + v \quad (15)$$

Since the dataset do not enable us to categorize observations into individual trips and routes, the variable distance is dropped from the equation.

As we have a panel data, with data varying both across time and vessels, the error term v is composed of two elements (Wooldridge, 2012)

$$v_{it} = \alpha_i + u_{it} \quad (16)$$

Here the u_{it} is the idiosyncratic error term that change over time for each vessel, while the α_i is the unobservable vessel specific effect that varies across vessels but not over time. Our model to be estimated would at this point be

$$\ln V_L = \beta_0 + \beta_1 lnR + \beta_2 lnP_B + \beta_3 lnW + \beta_4 lnV_d + \beta_5 lnF_d + \beta_6 \ln\,({}^{D}/_{D_d}) + \alpha_i + u_{it} \quad (17)$$

A similar exercise can be done for the ballast leg model, giving us the following expected relationship[25]

$$\ln V_B = \frac{1}{3} ln0.5 + \frac{1}{3} lnC_a - \frac{1}{3} lnP_B + lnV_d - \frac{1}{3} lnF_d - \frac{2}{9} ln({}^{\mathrm{D}}/_{\mathrm{D}_d}) + v \quad (18)$$

The model to be estimated is

$$\ln V_B = \beta_0 + \beta_1 lnC_a + \beta_2 lnP_B + \beta_3 lnV_d + \beta_4 lnF_d + \beta_5 \ln\,({}^{D}/_{D_d}) + \alpha_i + u_{it} \quad (19)$$

We now have two equations to be estimated based on the theoretical optimal speed formulas, one for the laden leg (17) and another for the ballast leg (19). Nevertheless, in order to fully

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[25] Given a consumption coefficient equal to 3

utilize the fact that we have a panel data we need to include variables that tells us something about the variation between different vessels, not only variations over time. This is a key contribution of our thesis to the existing research on optimal speed in the VLCC market. The inclusion of vessel specific variables will also contribute in reducing the unobservable vessel specific error term α_i, improving the performance of the model and reducing a potential omitted variable bias (Bell & Jones, 2015).

3.3 Building the Model

Having a panel data implies that we have two dimensions; a cross sectional dimension and a time-series dimension. In our case the cross section is the total VLCC fleet, which we observe over the time period from January 2013 to February 2015. The irregular nature of the utilization of VLCCs, e.g. vessels at anchorage or in port/yards, means that we do not observe average daily speeds for each vessel for every date. Hence, our panel data is unbalanced.

There are two main models for statistical analysis of panel data; the fixed effects (FE) model and the random effects (RE) model. The main difference between these two is how they treat the unobservable individual specific effects, α_i. If the unobservable effect is correlated with the independent variables in the regression, it will bias the estimates[26]. Hence, the two models use two different approaches to deal with this issue (Wooldridge, 2012).

In order to get rid of the omitted variable bias problem[27] the fixed effects model control for unobservable effects by removing them. In the process of doing this, the model eliminates all time-invariant variables, which makes us unable to exploit vessel specific variables. Employing the random effects model allows us to not only utilize the within variation (i.e. the changes over time), but also the variation between the vessels. Since a key contributory factor of our thesis is to analyse the particular effect of vessels specific variables on speed, the properties of RE makes it the preferred model of choice. The major challenge of RE is the assumption that the unobserved individual specific effects α_i are uncorrelated with the explanatory variables in all time periods. However, a correct specification of the model will

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[26] Correlation between x_{it} and α_i violates the conditional mean zero given X condition $E(\alpha|X)=0$, biasing our estimates

[27] First differencing (FD) and within group (WG) estimators removes the unobservable effects entirely from the equation, while least squares dummy variable approach (LSDV) remove the unobservable effects from the error term through inclusion of dummies (Wooldridge, 2012)

eliminate this issue. Hence, both for the sake of the value of our analysis and the statistical inference of the model it is crucial to include the individual specific factors that can explain variation between vessels (Bell & Jones, 2015).

Independent variable	Unit	Exp. Sign		Description
		Laden	Ballast	
Macro Variables				
lFreight	$/tonne	+	+	Log of freight rate for voyage charter
lFFA	$/tonne	+	+	Log of forward freight agreement
TCE	$/day		+	Time charter equivalent (ballast only)
lBunkers	$/tonne	-	-	Price of bunker fuel oil
lFreight/Bunkers		+	+	Log of ratio between freight and bunkers
Vessel Specific Variables				
lDraughtRatio		-	-	Log of draught ratio, not to be combined with lCargoFloating
lCargoConstant		+		Log of deadweight*0.95
lCargoFloating		+(?*)		Log of the weight of cargo transported (laden only)
ldSpeed	knots	+	+	Log of vessel design speed
lFuelCons	tpd	-	-	Log of fuel consumption at design speed
lConsumptionDSpeed	tpd/knots	-	-	Log measure of fuel efficiency at design speed
BlockCoefficient		-	-	Hull shape: Deadweight divided by width*length*max draught
Length/Beam		+	+	Hull shape: Length of the vessel divided by width (beam)
Beam/Draught		-	-	Hull shape: Width (beam) divided by max draught
Built2000_D		+	+	Dummy for vessels built before 2000
EVDI		-	-	Rightships Existing Vessel Design Index
Drydock_D		-	-	Dummy for vessels likely having a high degree of fouling
ECO_D		-	-	Dummy for vessels with extra fuel efficient engines
Operational Specific Variables				
Japan_D		+	+	Dummy for vessels with main activity to/from Japan
LogChain_D		+	+	Dummy for vessels part of a larger internal logistical chain
LpOw_D		-	-	Dummy for vessels operated by large pool or owner
Other Variables				
Cyclone_D		-	-	Dummy for vessels located in an area with a cyclone
Contango_D		-		Dummy for period of contango in crude price (laden only)

** Uncertain whether the increased cargo effect or -hull resistance effect is the larger*

Table 4: Independent variable overview

In *Table 4* we have summarized our variables and their expected coefficients. The remainder of this chapter will be devoted to discussing ***why*** we add the variables ***not already included*** through the theoretical models, and their expected relationship with speed. In chapter 4-Data we will explain ***how all*** the variables are estimated and how we have collected data. The variables are split into four groups. The first group is (i) macro variables, of which the reasoning to include them and their expected coefficients are already discussed. The second group is (ii) vessel specific variables, of which cargo weight, design speed and fuel consumption at design speed already are included. The last two groups are (iii) operational variables and (iv) other variables. The variables are only relevant for the leg where an expected coefficient sign is listed.

3.3.1 Adding Vessel Specific Variables (ii)

Hull design

The hull design and the size of the wetted area affect the resistance and thus how much power needed to move a vessel. This again affects the fuel consumption at a given speed (see *Table 3*). Presumably some of these effects should be reflected through "design speed" and "fuel consumption at design speed"[28], but due to severe uncertainty in the measurement and viability of these factors we introduce a set of alternative variables as proxies for the resistance[29]:

- **Block coefficient** $\left(C_B = \frac{\nabla}{(L_{WL}*B_{WL}*D)}\right)$ – This factor gives us the ratio between displacement volume ∇ and the volume of a box (L_{WL}*B_{WL}*D). WL refers to measures at the waterline. A higher ratio implies that the vessel design is squarer. Hence, the smaller the ratio the less resistance of the vessel, resulting in possibility of achieving higher speeds. We will thus expect a negative coefficient (MAN Diesel & Turbo, 2013a)
- **Length / Beam** – Increasing this ratio tends to reduce wave-making resistance, all other dimensions held constant. Thus we would expect to see that longer and narrower vessels steam at higher speeds (ABS, 2013)
- **Beam / Draught** – Reducing this coefficient reduces wetted surface and thus frictional resistance. Consequently, we expect to observe a negative coefficient (ABS, 2013)

In addition to the above-mentioned effects of hull design there are two further remarks that we should address. First, having a more efficient hull can give the additional benefit of using a larger propeller, amplifying the fuel saving effect (ABS, 2013). Secondly, since hull shape is likely to be optimized around the design draft (laden), we should pay attention to whether these factors influence the laden- and the ballast leg differently.

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[28] In theory, the design speed and the fuel consumption at design speed should take into account the specifications of the vessels

[29] We will be observant to potential multicollinearity between the hull efficiency variables and the design speed and fuel consumption in our analysis

Fuel efficiency

The IMO MEPC[30] introduced the Energy Efficiency Design Index (EEDI) a measure for CO_2 emissions for new vessels built after 1 January 2013 (IMO). The EEDI index is a measure of grams of CO_2 per tonne nautical mile, calculated using characteristics of the ship at build, incorporating factors such as engine power, ship capacity and fuel consumption. As this index only applies to new vessels RightShip introduced the Existing Vessel Design Index (EVDI) to address the existing fleet. Since CO_2 emissions are highly correlated with a vessel's fuel consumption we will test this index as a proxy for fuel efficiency for the individual vessels. The EVDI index is supposedly capturing the effects of a wide range of vessel specific variables. In order to avoid multicollinearity problems, we should therefore be careful to combine this index with other factors assumed to affect fuel-efficiency.

In addition to the EVDI index, we will add a dummy for ECO-vessels. Since the initial incentive for ECO-vessels is to offer low fuel consumption when slow steaming (Mitsubishi, 2014), we expect ECO vessels to steam slower.

Lastly, we introduce a dummy for vessels built before 2000. As they were built before sliding fuel-valves were introduced, a feature substantially improving the low-load/slow steaming performance (MAN Diesel & Turbo, 2013b), we expect these vessels to operate at higher speeds on average.

Biological fouling – Dry-docking

The potential speed of a vessel is dependent on its hull resistance, in which frictional resistance accounts for a major proportion (see *Table 3*). For a VLCC newbuild, or a vessel fresh out of dry-docking, the design hull specifications are the determinant of hull friction. However, from the time the vessel is launched, the wetted surfaces of the hull start accumulating microorganisms, algae, sea grass, barnacles and other biological particles (MAN Diesel & Turbo, 2013a). This biological fouling increases the friction, and the deterioration process continues until the hull is cleaned at dry-docking every five years[31]. For a given engine output the increased resistance from biological fouling will lead to lower speeds, and previous analysis' show an average speed loss of about 5.9%[32] during the five

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[30] International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC)

[31] SOLAS regulations require dry-docking every 5 years

[32] Analysis conducted by researchers, suppliers of measurement equipment and Jotun for various shipping segments

year period from one dry-docking to another (Kjølberg, 2015). Hence, we would expect that vessels with more biological fouling go slower on average.

3.3.2 Adding Operational Variables (iii)

Japan

According to EIA[33] (2015) Japan is both the third largest consumer (petroleum products) and importer of crude oil, relying almost entirely on crude import through the use of VLCCs to meet its needs. Several patterns suggest that the general spot assumption applied to traditional theoretical speed models do not hold for the Japanese VLCC trade. Firstly, the government maintain control over oil stocks to hedge against supply interruptions, and as of October 2014 they held 73% of the nations strategic crude oil stocks. Secondly, the government have agreements with oil producing countries in the Middle East such as Saudi Arabia and UAE, giving Japan priority of purchasing oil in events of serious supply disruptions through leasing of crude oil storage[34] (EIA, 2015). Thirdly, Japan has a tradition of large conglomerates where cross-ownership between refineries and shipping companies must be considered likely, with tankers being part of the logistical chain.

The sum of these characteristics makes it reasonable to assume that a major portion of vessels going to Japan operate on a shuttle basis. In addition, Assmann (2015) presents facts that suggest that most VLCC trade to Japan are likely to be operated through oil majors and time charter agreements. To analyse this potential effect we include a variable for vessels that we assume to operate on a time-chartered shuttle basis between MEG and Japan. Since there are reasons to believe that the vessels have more emphasis on scheduling than the costs of transportation, we expect to see them go faster with less respond to changes in fundamentals.

Part of a larger internal logistical chain

The schematic nature of crude transportation for vessels being part of a larger logistical chain could potentially affect the incentives and thus the speed decision. This dummy variable, hereafter referred to as “logistical chain” or “LogChain”, includes three categories we believe are likely to operate more as a shuttle, due to the focus of the owner. The first

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[33] U.S. Energy Information Administration
[34] They have an agreement to store 6.3 million barrels for each of the producers

group consists of vessels (i) part of an internal logistics chain, with the main purpose to source crude for internal use. The second group is (ii) state oil company owned vessels. The last group comprises vessels owned by (iii) private oil companies and refineries. For privately and state owned Oil-companies and refineries, the long term crude sourcing strategy may alter the priorities in favour of security of supply at the expense of short term profit maximization for each vessel.

Part of a large operational fleet

There are reasons to believe that being a part of a large pool[35] or operated by an owner with a large fleet could affect the observed speed of vessels. First of all, a large fleet introduces more flexibility when determining on which contracts to bid on. Operators with many vessels can make bids on the most favourable contracts and assign the ship located in the most beneficial position relative to the relevant port, with regards to bunker costs and laycan[36]. Further, the bidding for the movement of a cargo is organized as an auction controlled by the cargo owner. Consequently, shipowners are at information disadvantage (Euronav, 2015). Being a large owner or part of a large pool can increase the market visibility through better information on which vessels are available in the market for the next cargo movements, and what cargoes that need to be moved. Since operators with fewer vessels have less flexibility in regards to which vessels to assign to beneficial contracts and less information on future cargo moves, they might be likely to secure fixtures earlier in the ballast leg resulting in higher speeds in order to reach the laycan.

Secondly, when operating a larger fleet you could get more bargaining power over charterers. Hence, it is reasonable to assume that large operators can have more power to embed the trip specific optimal speed in the "minimum speed" requirement in the charter clause.

Based on our reasoning, we expect vessels managed by large owners or pools to steam slower in both the laden and ballast leg.

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[35] This is an operational collaboration between different shipowners to benefit from large scale operation (Euronav, 2015)
[36] Laycan is short for layday and cancelling, stating at which time a ship must be presented to the charterer

3.3.3 Adding Other Variables (iv)

Contango

Following the plunge in the crude oil price the last quarter of 2014, the forward curve changed from backwardation to contango[37]. This implies that the price for crude oil with delivery in the future is trading at a premium to that in the spot market. Contango is driven by expectations of the crude market going forward and the fact that investors may be interested in paying a premium to have the crude delivered on a later date, instead of purchasing the crude spot and pay for the cost of carry[38]. Periods of contango are often evident in times with oversupply of crude oil, high inventories and a weakening crude price, leading to increasing storage costs. If storage capacity runs out, the "cost-of-carry" relationship can break down and lead to a "supercontango" (Adland, 2014). In such a scenario the contango curve can get steep enough for it to be profitable to buy crude oil with immediate delivery, store, and sell off with future delivery. For this to be profitable the crude oil price premium needs to exceed the storage cost, i.e. VLCC TC rates in the case where floating storage is used as storing facility, and financing cost of the cargo value.

In late February 2015 Euronav said on a DNB Conference that around 20 vessels had been booked for storage by oil traders. Due to our minimum speed requirements in the data cleaning, VLCC vessels that are anchoring would not be included in our analysis (see section 4.1.2). However, as the owners of the cargo (charterer for a VC) could have incentives to slow down to take advantage of a steep forward curve, we expect that operators steam somewhat slower than implied by freight rates and bunkers prices in times of supercontango.

Cyclone

While macro economic variables have intricate effects on the daily speed of VLCCs, the relationship between rough weather and average daily speed is more straightforward. Higher waves, currents and windy conditions lead to higher air and residual resistance, which again could force vessels to steam at slower speeds than what is optimal at design conditions. Even though the relationship is easily comprehendible, it is not possible with today's data

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[37] If the forward curve is downward sloping the crude price is in backwardation, while an upward sloping curve is defined as contango

[38] Includes financial cost and storage cost

collection technology to link the local weather conditions[39] for each day to each vessel. Hence, observable weather conditions have to be allocated to each vessel in retrospect using longitude and latitude data. One such observable variable is the seasonal climate changes in the tropical wet equatorial regions surrounding the Indian Ocean. As the Indian Ocean is used as passage for all voyages going out of MEG[40] a significant portion of all VLCCs operate in waters where heavy wind, tropical storms and cyclones are factors to be considered by vessel owners and operators in large parts of the year.

The empirical model

The variables of choice described in this section leave us with the final empirical model for the laden leg and the ballast leg:

$$\ln \mathrm{V}_{it} = \beta_0 + \sum_j \beta_j M_{tj} + \sum_k \theta_k V_{ik} + \sum_l \omega_l O_{il} + \sum_m \gamma_m Q_{itm} + \alpha_i + u_{it} \qquad (20)$$

Where V is the observed speed per vessel i at time t. M_{tj} is the set of j macro-variables, V_{ik} is the set of k vessel specific variables, O_{il} is the set of l operational variables and Q_{im} is the set of m other variables[41], listed in *Table 4* above. Before proceeding to the empirical results we will present our dataset and describe the data we have used for each variable.

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[39] Wave size, currents & local wind conditions

[40] Northern Indian Ocean to East Asia and Southeast Asia, South-West Indian Ocean to U.S Gulf

[41] Of which the contango variable only varies across time, while cyclone varies across vessels and time

4. Data

In this chapter we will firstly describe our dataset and the cleaning process we have conducted in order to arrive on our final dataset of speed observations. Secondly, we will describe the data we have used for each of the explanatory variables and the data collecting process. In the data summary section we will argue why we use average weekly speed data instead of daily speed data, before summarizing the numerical data.

4.1 The Dataset

4.1.1 Original State

Being a part of the GREENSHIPRISK project, we were given access to a panel dataset consisting of daily data on the complete fleet of VLCCs from 31.12.2012 to 22.02.2015. The original dataset was collected and structured by Genscape Vesseltracker and Marinetraffic.

In its original state the dataset was divided into three parts based on the daily loading condition of each vessel: laden, ballast and unknown. All three parts were structured equally, providing daily data points on move[42] draught, max draught, latitude, longitude, move speed and average daily speed for vessels identified through Vessel ID, as well as MMSI number, IMO number and vessel name.

4.1.2 The Cleaning Process

Data points on average daily speed that could potentially lead to biased results and conclusions should be kept out of the regressions. In order to remove unwanted data points we have followed a 9-step cleaning process. See Appendix B for detailed information and excel calculations on the cleaning process.

1) Allocation of unknown to ballast and laden

First, we determined which data points in the unknown dataset we could allocate to the laden and ballast datasets, and hence put to use in our analysis. We removed data points with move draught registered as zero and with undefined max draught, before allocating the remaining

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[42] “Move” is generally referring to a dynamic measurement of a variable in the dataset at a single point in time

data to ballast and laden using a ratio of move draught over maximum draught[43] (draught ratio). The draught ratio limit for ballast was set to <66%, in line with the definitions of the loading conditions for the original datasets..

2) Removal of extraordinary low average speeds at start and end of data series

Structuring the average daily speed data in a matrix with vessels and dates in the axis's allowed us to identify data points presumably being part of one voyage[44]. It became evident that average daily speeds that were assumed to be in the beginning and end of each voyage were often considerably lower than for the rest of the voyage. This can be explained by the fact that vessels reduce speeds going in/out of ports, or that the vessels are very close to the shore. Because these observations are of no relevance to the optimal speed analysis they were be removed from the dataset.

3) Removal of lone values

Data points with no other data point within a +/- seven days range were removed from the dataset.

4) Removal of double counts

Throughout the dataset (both laden and ballast), average daily speed values were sometimes registered more than once a day. No robust explanation was to be found and as seen in *Figure 2*, particularly two dates were prone to double counts. The first data point registered for a given vessel at a given day was kept, the rest were removed.

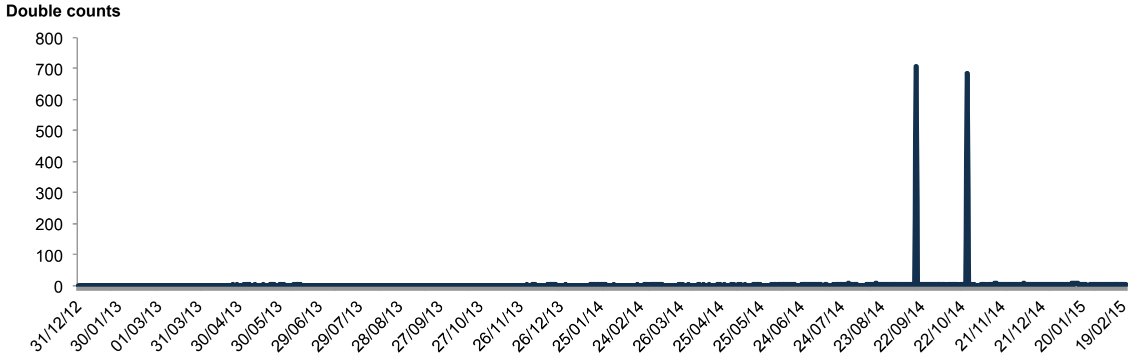

Figure 2: Number of observed double counts by date

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[43] Maximum draught specified in the original data set

[44] This method did, however, not allow us to identify voyages correctly through a formula because of the many blank fields

5) Removal of vessels only registered with either laden or ballast data

15 vessels were only registered with either ballast or laden data[45]. With data on only one leg, it is not known if the vessels were used actively for carrying crude in the period. Hence, the average speed could potentially be driven by other factors than for the active VLCC fleet in the dataset. All these vessels and the corresponding speed data were removed.

6) Defining new laden and ballast data points based on Draught Ratio

The distribution in *Figure 3* shows that 93% of the data is registered either with a ratio in the 46%-56% range or 84%-100% range, implying little variation in loading conditions.

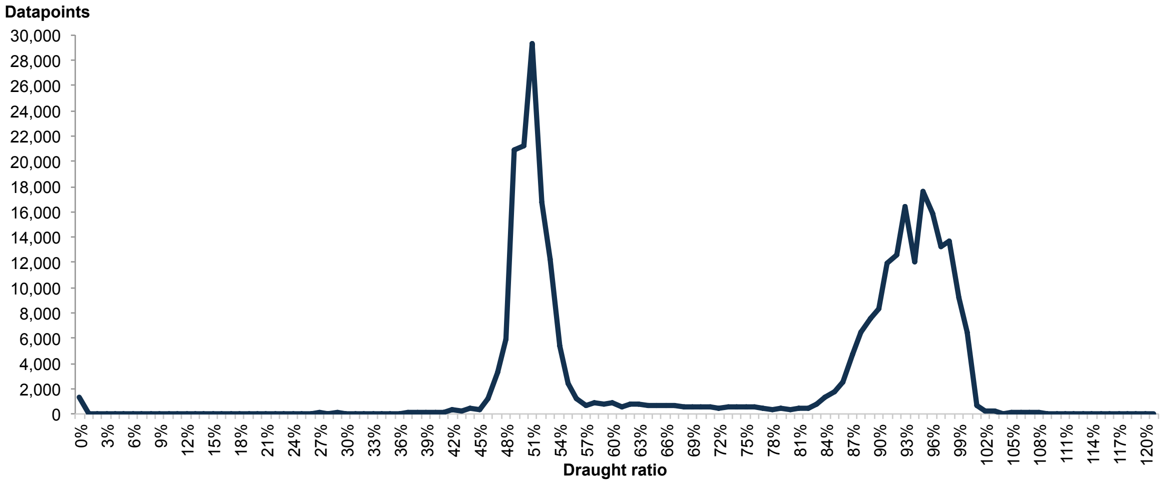

Figure 3: Draught ratio by number of observations for the complete dataset

In order to mitigate the risk of mixing laden and ballast data, new definitions were set for laden and ballast (*Table 5*), and data points not included in the reviewed defined range were removed.

Condition	Default		Reviewed	
	Definition	Count	Definition	Count
Laden	>66%	173552	80%-100%	163539
Ballast	<66%	130215	25%-64%	128544
Total		303767		292083

Table 5: Reviewed ballast and laden definitions

Ballast water is essential to un-laden VLCCs as it provides balance and stability to the vessels, reduces stress on the hull, and improves propulsion and manoeuvrability (IMO). Minimum draught ratio was set to 25% to reflect that data points with ratios below this are

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[45] 11 vessels with only Ballast data, 2 vessels with only Laden data, 2 vessels with 1 registered data point

either miscalculated or the vessel was about to go into dry dock at that time[46]. Data points where the reported move draught was higher than the max draught (more than 100% Draught Ratio) were also removed.

7) Removal of data points with lower average speed than minimum speed

The absolute minimum speed of a vessel depends on its ability to manoeuvre and navigate at low speeds, which again is dependent on hull design and engine specifications. However, IMO provide guidance criteria's for the manoeuvrability of vessels and operates with an approximate minimum speed of 8 knots (IMO, 2011), a minimum speed supported by Gray et al. (2001) for direct-drive diesel ships. This implies that if a data point is registered with an average daily speed below 8 knots it should be removed from the dataset because it alters the fact that no vessel would operate at speeds lower than their minimum speed. However, by studying the dataset it becomes evident that several observed vessels steam at lower speeds in some periods. In fact, 7528 data points or about 2.5% or the initial dataset are observed with average speed between 7 and 8 knots. Lower speeds than 7 knots are observed less frequently and setting the minimum speed to 7 knots reduces the amount of removed data points to 815. This suggests that shipowners allow their vessels to steam at speeds lower than what IMO characterizes as minimum speed, but not much lower than 7 knots.

8) Removal of data points with higher average speed than maximum speed

While the maximum speed of VLCCs differs depending on factors mentioned in *Table 3*, the highest maximum speed described in reliable sources are 18 knots (Ligtertingen & Velsink, 2012). 18 data points with recorded speeds higher than 18 knots were removed.

9) Removal of data points with no vessel data in Clarksons

One vessel was not included in the Clarksons database. Since no vessel specific information was available, the vessel and the 439 corresponding data points were excluded from the dataset.

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[46] When dry docking the vessels are emptied for ballast water and can be observed steaming with draught ratios less than 25%.

4.1.3 Cleaning Summary

The cleaning process, summarized in *Figure 4*, reduced the initial dataset with 7%, removing in total 21,549 data points. Total vessels were reduced from 624 to 607.

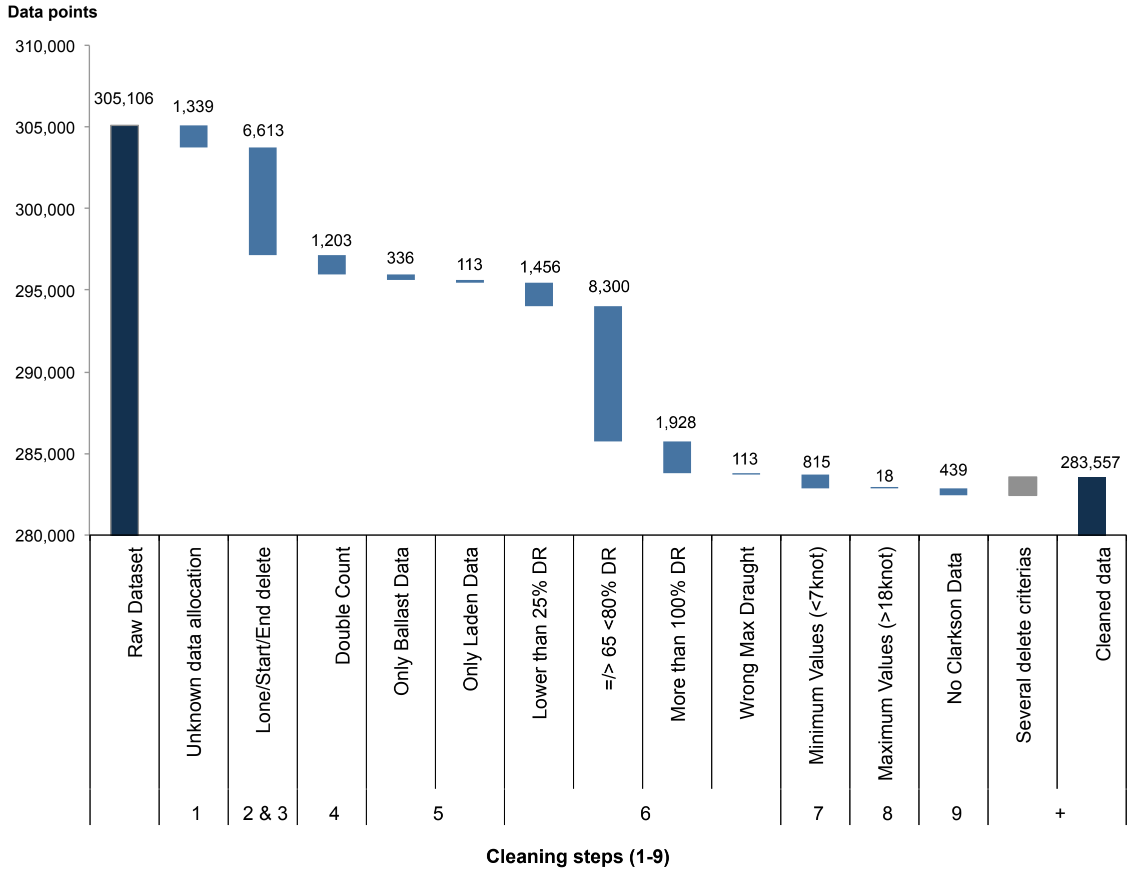

Figure 4: Cleaning process showing number of deleted data points for each step

4.3 Data Collection – Explanatory Variables

4.3.1 Macro Variables Data (i)

Freight rates

Routes	Loading			Discharge	
	Region	Country	Location	Country	Location
BDTI TD1	Middle East Gulf	Saudi Arabia	Ras Tanura	USA	LOOP
BDTI TD2	Middle East Gulf	Saudi Arabia	Ras Tanura	Singapore	Singapore
BDTI TD3	Middle East Gulf	Saudi Arabia	Ras Tanura	Japan	Chiba
BDTI TD4	West Africa	Nigeria	Offshore Bonny	USA	LOOP
BDTI TD15	West Africa	Nigeria/Equatorial Guine	Offshore Bonny / Serpentina	China	Ningpo

Table 6: VLCC routes in the Baltic Dirty Tanker Index (BDTI)
Source: Baltic Exchange (2015) and Kavussanos & Visvikis (2006)

Out of the five VLCC routes in the BDTI presented in *Table 6*, the Tanker Dirty 3 (TD3) route from Ras Tanura, Saudi Arabia, to Chiba, Japan, is the most commonly traded (Kiesel, Scherer, & Zagst, 2010).

	TD1	TD2	TD3	TD4	TD15	Sum
TD1	1.00	0.92	0.92	0.86	0.90	**4.59**
TD2	0.92	1.00	1.00	0.92	0.98	**4.82**
TD3	0.92	1.00	1.00	0.92	0.98	**4.82**
TD4	0.86	0.92	0.92	1.00	0.96	**4.66**
TD15	0.90	0.98	0.98	0.96	1.00	**4.82**

Table 7: Correlation in freight rates for different routes over relevant time period
Source: Own calculations based on Clarkson's SIN (2015)

Given the high correlation between the routes, as seen in *Table 7*, daily Worldscale[47] rates for TD3, converted to $/tonnes, is used as a proxy for freight rates for all routes. As we do not know the contracted route for each data point in our dataset, this simplification allows us to still analyse the broad effects of freight rates on speed.

To check if expected future spot rates can have more impact on the speed choice than the spot rate, or the lagged spot rate, we have also collected data for forward freight agreement (FFA) for TD3.

Opportunity cost – Ballast leg

To find a proxy for the opportunity cost of a vessel we will use a time-charter equivalent (TCE) for a trip from Middle East Gulf to Japan. In our view this is a good proxy for what a

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[47] Worldscale is a method to measure spot freight rates relative to an index, the flat rate, which for a defined standard vessel gives the TCE of 12,000$/day on any global tanker route. The worldscale is quoted as a percentage of this flat rate, such that WS50 is flat rate*0.5 for that route

vessel alternatively can generate in profit if they speed up, under our assumption that all vessels are operating in the spot market.

In some periods the TCE can be negative. This is often a result of the TCE being calculated based on a fixed speed for the different legs, not accounting for the fact that vessels will slow steam in poor market conditions. However, if the TCE is truly negative or at least very low, owners should consider laying up their vessel. In any case a negative TCE should reduce the speed, so we have not taken the possibility to lay up into the consideration. The TCE for BDTI TD3 is extracted from Clarksons Shipping Intelligence Network (SIN) (2015) database on a weekly basis. As some values are negative we are not able to do a log transformation and thus keep it as it is.

Bunkers

Since we were unable with our data to estimate routes we have used the prices for Fujairah 380cst as the cost of bunker fuel oil, extracted from Clarksons SIN (2015). We believe this is a good proxy for the bunkers cost, as it is both from the Arabian Gulf and also the cheapest alternative in the area in the relevant period (Clarksons Shipping Intelligence Network, 2015).

For the laden leg it is reasonable to assume that the vessels bunker up in the Arabian Gulf before the beginning of each trip. Given that sailing time one way is around 4 weeks we find it sensible to use two-week lagging bunkers. For the ballast leg the question is a bit less straightforward. A ship could choose to carry smaller amounts of bunker fuel in exchange for more space for cargo, in cases where the constraint is cargo weight and not the volume of cargo (Ronen, 1982). Hence, it might be beneficial to refill in the discharge port. For the sake of our analysis we have ignored this possible issue, as the effect of this increased cargo is marginal, dependent on the operators refuelling policy, and neither does it always exist. Further, our approach is supported by the fact that the 380cst fuel oil price in Japan in the relevant period had a correlation of 0.99 with the Fujairah, and traded at an average premium of 8.1%. Hence, it is likely that it is more beneficial to bunker up for the whole round-trip in the Arabian Gulf. Given the sailing time one way of around 4 weeks and assuming bunkering in the Arabian Gulf, a vessel has bunkered fuel between 4 and 8 weeks ago depending on where in the ballast leg it is, thus we find it most reasonable to use a 6-week lagging bunkers for the ballast leg.

4.3.2 Vessel Specific Variables Data (ii)

Design speed

The Clarksons World Fleet Register (2015) has been used as a starting point to find design speed for the individual vessels. The database had missing values for 88 of the vessels and in addition some values registered were clear outliers. To estimate the missing values and replace the outliers we have used a three-step approach, described in detail in Appendix C.

Fuel consumption at design speed

The Clarksons World Fleet Register (2015) includes a fuel consumption variable[48] measured in tonnes per day (tpd), but it lacks data on 277 vessels. In addition, among the vessels where tpd is given, there are large variations in fuel consumption that is seemingly unrelated to engine and hull specifications. This questions the credibility of the Clarksons tpd database and makes it necessary to compute our own proxy's for fuel consumption at design speed in order to analyse the effects on average daily speed.

To form a tpd measure of fuel consumption at design speed we create a relationship between the specified maximum continous rate (SMCR) and total generated power (TGP), both variables reported in the Clarksons database on a per vessel basis. SMCR is the maximum RPM rating required by the yard or owner for continuous operation of the engine (MAN). TGP is measured in kilowatt (kW) and is the corresponding power output of the engine when running at SMCR. We are hereby not trying to establish a fuel consumption regression applicable to all speed levels, but rather form a relationship between engine speeds (RPM), mean effective pressure (kW) and fuel consumption at design speed at design conditions.

See Appendix D for a comprehensive process on how fuel consumption at design speed is estimated.

We acknowledge that the method used has its pro's and con's.

Pros

- Captures that large engines in terms of total power output consumes more fuel at design speed than smaller engines
- Small total difference to reported Clarksons data

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[48] Assumed to be at Clarksons defined design speed

- Captures general differences in engine tuning

Cons

- Does not capture the technological differences between engines from different manufacturers
- Does not account for other engine specific factors affecting fuel consumption than RPM and total power output
- The engine allocation follows simple principles regarding SMCR and the engines may not be accurately allocated to the three Wartsila engine performance charts. However, the differences between the fuel multiplication factors are not major so this problem should not distort the results to a large extent.
- Assumes that all variables related to hull resistance are captured in the design speed.

Draught ratio and cargo weight

The draught ratio is measured as *weekly average* move draught[49] over max draught, where we have used the data from the original dataset. This is used as a measure of resistance in the ballast leg. For the laden leg we have used two different approaches:

1. Combining draught ratio with a *fixed cargo weight*. The latter is estimated as DWT*0.95 with intention to pick up speed differences *between* vessels due to persistent differences in carrying capacity. The draught ratio will pick up resistance and the variation in cargo *within* a vessel over time.
2. *Floating cargo weight* – measured as draught ratio * DWT as a measure of both differences in carrying capacity, loading degree and resistance

Hull shape

- **Block coefficient** – since we do not have all the exact data, we must approximate the coefficient after best effort. All data are extracted from Clarksons World Fleet Register (2015).
    a. *Displacement volume* – since we lack data on light displacement, we can use the MAN Diesel & Turbo (2013a) suggestion of a displacement/DWT ratio of 1.17 for tankers. To convert from tonne to volume we divide by 1.025 t/m^3, which is the normal mass density of seawater.

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[49] Calculated as weekly average given the loading condition (laden and ballast)

b. *Length at waterline (L_{WL})* – what we have is length between perpendiculars[50] (L_{PP}), which often is used instead of L_{WL}. Only difference is that L_{PP} is a bit smaller, so the coefficient is somewhat larger.
c. *Beam* – we use regular beam, as we do not have the waterline beam
d. *Depth* – we use max draught from the original dataset. Based on the laden draught ratio of 93.5% on average it seems to coincide pretty well with what we would expect from design draught. Relative differences in max draught should anyhow be approximately the same as differences in design draught.

→ Gives us the coefficient: $C_B = \frac{\text{DWT}*1.17/1.025}{(L_{PP}*B*D)}$

- **Length / Beam** – we use L_{PP} and regular beam
- **Beam / Draught** – also here we will use max draught

Fuel efficiency

Based on engine data from Clarksons we identified seven vessels with a main engine specified as ECO from the manufacturer MAN B. & W. The EVDI index was provided by RightShip.

Biological fouling – Dry-docking

We include a dummy variable for vessels that are assumed to be in their fourth year out of dry-docking and zero for the ones that are assumed to be in their first year. The assumption behind the variables is that the vessels are dry-docked every five years, starting five years after year built.

	Year built	**1**	**2**	**3**	**4**	**Dry-docking**
Count Formula	0	1	2	3	4	0
Dummy variables	-	0	-	-	1	-

Table 8: Method for adding dry-dock dummy

The count formula in *Table 8* is based on years after dry-dock. This means that every fifth year a vessel is assumed to dry-dock, resetting the count. If the vessel is dry-docked sometime during year 5, the year before (4) is the best proxy we have for when the hull of a vessel is heavily affected by fouling. Year 1 should be the best proxy for the cleanest hull. All other data points from years other than +1 and +4 after dry-dock are removed from the

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[50] The distance between rudder shaft and the point where bow stem enters water, at design draft

dataset, enabling us to single out the fouling effect. This comes at the expense of reducing the number of data points considerably. We acknowledge that market conditions might result in off-cycle dry-docking, but as such data are hard to obtain our approach is the best approximation to account for fouling of the hull.

4.3.3 Operational Variables Data (iii)

From a statistical point of view vessels should only be included in one of the three ownership categories to not cause problems in the model. Since we would expect the speed effect of shuttling to Japan to be present regardless of the vessel being part of a larger internal logistical chain or part of a large operational fleet, Japan have first priority out of the operational variables. In the same way, being part of a larger internal logistical chain is arguably more important for the speed incentives than being part of a large operational fleet.

Japan

We have estimated which vessels that are most likely to shuttle MEG-Japan (Td3) by looking at the share of observations (days) in Japanese waters (Appendix E)[51]. In *Table 9*, three routes from Saudi Arabia to Japan are presented, with Port of Kagoshima being the closest to Ras Tanura. Chiba is the port located in the middle, while Tomakomai represents the longest sailing distance for VLCCs. In *Table 9* we have presented the expected minimum days in Japanese waters for different round trips, and the corresponding share of total days in the round trip.

Route	Nautical Miles	Days at sea @ 12 knots	Minimum days in Japanese waters (Excl. Port time)	% of total route
Ras Tanura - Kagoshima - Ras Tanura	14600	51	2	4%
Ras Tanura - Chiba - Ras Tanura	16006	56	6	11%
Ras Tanura - Tomakomai - Ras Tanura	16914	59	9	15%

Table 9: Routes from Ras Tanura to three different ports in Japan based on distance
Source: Own analysis based on route descriptions from Ports.com

From the table it is evident that vessels shuttling MEG-Japan should at least have 4% of all observations in Japanese waters. However, on the basis that Ras Tanura to Chiba is the main discharging port in Japan we have set the limit for inclusion in the Japan variable at 8%.

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[51] This is not territorial Japanese waters, but defined by several longitude and latitude squares to capture areas close to the Japanese shore. This is to exclude the effects of vessels going to South Korea. See Appendix E for detailed definition of longitude/latitude for Japan.

Hence, a Japan Dummy is added to all vessels with 8% or more observations in Japanese waters. This totals 62 vessels, or about 10% of all vessels included in the analysis.

Part of a larger internal logistical chain

We have removed two vessels that fell under the category "Japan" manually. The identification of vessels part of a larger internal logistical chain is based on a manual review of the owner companies and their web sites. A vessel is assigned a dummy if it falls into one of the three categories defining this variable, specified in section 3.3.2.

Part of a large operational fleet

To estimate a dummy variable for vessels that we define as operated by a large pool or owner, we have used input from Clarksons World Fleet Register (2015) and company web sites. Firstly, we define and count vessels that are in a pool. Secondly, vessels *not* part of a pool is grouped and counted based on the manager, which can either be a shipowner or a pure ship manager with no ownership. Then we select those vessels that are operated by a pool or a manager/owner with more than a total of 15 VLCCs. In accordance with our previous discussion and as seen from *Table 10,* we have excluded vessels that are in the category "Japan" and the vessels from NIOC, being a state owned oil company. In the table underneath we observe 8 different operational fleets making up a total of 180 vessels or 29% of the total fleet.

Pool/Owner	Count	Dummy	Description
Japan	55	0	TC to Japan - *excluded*
Tankers Intl	37	1	Pool
NIOC	33	0	State OilCo owned - *excluded*
Bahri	31	1	Owner
Angelicoussis Group	22	1	Owner
VL8 Pool	21	1	Pool
V. Ships	19	1	Manager
SK Shipmngt.	18	1	Owner
Assoc. M/time (H.K.)	16	1	Manager and owner
Mitsui O.S.K. Lines	16	1	Owner
Count included vessels	**180**		
Market share	**29%**		

Table 10: Operational fleets including pools, managers and owners

4.3.4 Other Variables Data (iv)

Cyclone

To estimate a dummy variable for cyclones we have identified all data points registered in the North Indian Ocean throughout the period (see Appendix F), totalling 25.6% of all data points. Depressions, tropical storms and tropical cyclones[52] in the North Indian Ocean, potentially affecting crude trade[53], for the period from Jan 2013 to Feb 2015 are summarised in *Figure 5*.

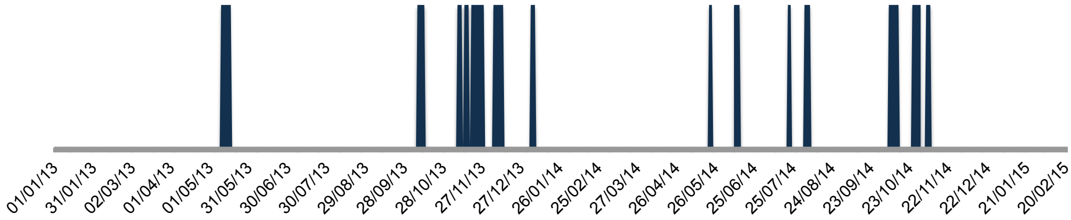

Figure 5: Depressions, tropical storms and tropical cyclones observed in the North Indian Ocean (except Bay of Bengal, an area with little vessel traffic)
Source: Various warnings and reports from India Metrological Department (IMD) and Joint Typhoon Warning Center (JTWC)

As weekly average speed is used for the regression analysis, dummies are only applied to weeks with four or more days of recorded bad weather[54]. In this way we are able to analyse if the fact that vessels are located in the North Indian Ocean in times of especially bad weather affect the average weekly speed.

Contango

To determine the contango dummy we have extracted historical futures curves for ICE Brent on a weekly basis from Bloomberg. In order to compare the steepness, curves are indexed and normalized with regards to months to delivery. We have also made a qualitative assessment bearing in mind that at the middle of the month, first delivery will switch to the subsequent month. Hence, in contango the short-term futures curve should be steepest the 16th and the least steep at the 15th in a month. As it is hard to determine an absolute cut-off point for where the contango trading pattern applies, as discussed in section 3.3.3, we choose a conservative approach and choose only January and the first two weeks of February for our

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[52] India Meteorological Department (IMD) operates with 6 weather categories, From Tropical Depression (51km/h-62km/h) to Very Intense Tropical Cyclone (>212km/h)

[53] Depressions in the northern parts of the Bay of Bengal are excluded from the analysis.

[54] A specific vessel is only assigned a cyclone dummy for a week in which the vessel finds itself in a specific cyclone, for more than 50% of the registered data points within that week

dummy variable. As illustrated in *Figure 6*, these are the weeks with the steepest futures curves. We acknowledge that the steepness of the futures curves alone is not enough to analyse the profitability of a contango trade. However, the weeks included by choosing the ones with the steepest curves correspond to the fact that various articles in specialized press addressed the contango play in this period.

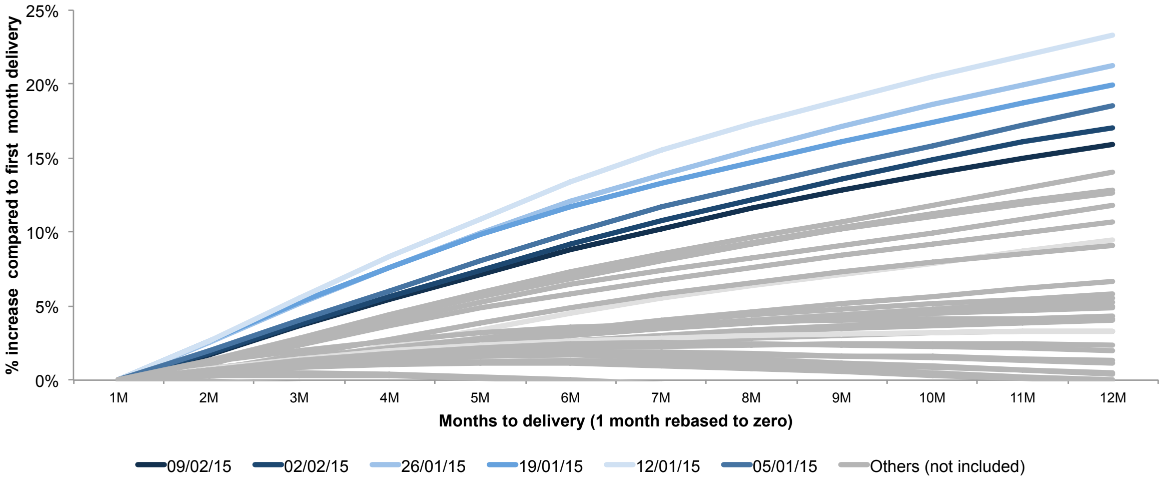

Figure 6: ICE Brent future contracts for different dates by delivery month and % premium
Source: Bloomberg (2015)

4.4 Summarizing Data

When conducting the analysis we have used the average speed per vessel per week instead of average daily speeds per vessel. This is done for the following reasons:

1. We observe that daily speeds vary quite considerably from day to day for a vessel. A large part of this variation is likely to be caused by unobservable noise such as wind, waves and currents. This noise can be reduce by averaging over weeks
2. In our opinion it is not likely that the speed decision is micro-managed on a daily basis, a view supported Euronav (2015). If this is true, the daily movements in freight rates and bunkers cannot explain the daily speed variations, and it makes more sense to use weekly data to capture the broader fluctuations in fundamentals.
3. We only have weekly data for bunkers, and based on the previous argument we use weekly freight as well. Consequently, it would not be meaningful to let speed vary per day while the explanatory variables vary over weeks.

When averaging over weeks we use only one observation per week for a vessel. The alternative would be to use the weekly averages on a daily level. However, the latter would result in the standard errors of the estimators being artificially small[55]. We acknowledge that one issue with the chosen approach is that a week with only one observation is weighted just as much as a week with seven observations. Ideally, we would weigh our regression with number of observations the weekly average is based on, but such an operation is not allowed for panel data (StataCorp, 2015a). This approach increases the importance of cleaning the dataset for observations not representative of the true speed decision of operators. We will check the robustness of our approach by performing the empirical analysis when removing weeks with less than X number of observations, as outlined in section 5.1.4.

Our approach results in that averages and standard deviations of dependent and independent variables will deviate somewhat from what can be found if we had used daily data. We end up with a dataset of 33,147 weekly speed observations for the laden leg and 28,713 for the ballast leg, spread on 607 vessels. In *Table 11* we have presented the descriptive statistics for our variables by leg. A more comprehensive descriptive statistics with standard deviations, min- and max observations both within and between vessels are presented in Appendix G.

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[55] Stata would calculate the estimators as if the dependent variable varied much less than what it actually does

	Laden Leg					Ballast Leg				
	Average	Std. Dev.	Min	Max	No.obs	Average	Std. Dev.	Min	Max	No.obs
Independent Variable										
Speed	12.08	1.41	7.00	17.29	33 147	11.83	1.95	7.00	17.80	28 713
Macro Variables										
TCE						22 350	23 422	-7 108	90 140	28 713
FFA+1M	12.63	2.16	9.63	17.68	33 147	12.57	2.16	9.63	17.68	28 713
Freight	13.02	3.28	9.07	21.10	33 147	12.96	3.28	9.07	21.10	28 713
Bunkers*	569.4	93.1	282.5	663.0	33 147	586.1	71.4	282.5	663.0	28 713
FreightBunkers*	0.025	0.013	0.014	0.071	33 147	0.023	0.010	0.014	0.060	28 713
FFA1M/Bunkers	0.024	0.010	0.015	0.061	33 147					
Vessel Specific Variables										
DraughtRatio	0.935	0.039	0.795	1.005	33 147	0.511	0.034	0.253	0.645	28 713
CargoConstant	291 869	9 671	246 999	420 347	33 147					
CargoFloating	287 125	12 911	206 817	391 423	33 147					
dSpeed	15.77	0.52	13.50	17.40	33 147	15.74	0.50	13.50	17.40	28 713
FuelCons	100.4	11.5	56.0	130.4	33 147	99.8	11.2	56.0	130.4	28 713
Consumption/dSpeed	6.37	0.70	3.59	8.23	33 147	6.34	0.68	3.59	8.23	28 713
BlockCoefficient	0.84	0.02	0.78	0.93	32 902	0.84	0.02	0.78	0.98	28 448
Length/Beam	5.58	0.11	4.76	6.09	32 962	5.58	0.11	4.76	6.09	28 505
Beam/Draught	2.73	0.13	2.49	3.68	32 962	2.74	0.13	2.49	3.68	28 505
Built2000_D	14.4%				33 147	17.0%				28 713
EVDI	2.48	0.15	1.99	2.95	33 147	2.47	0.15	1.99	2.95	28 713
Drydock_D	50.2%				13 397	51.9%				11 589
ECO_D	0.6%				33 147	0.6%				28 713
Operational Specific Variables										
Japan_D	10.6%				33 147	10.3%				28 713
LogChain_D	8.7%				33 147	9.7%				28 713
LpOw_D	44.0%				33 147	38.7%				28 713
Other Variables										
Contango_D	4.6%				33 147					
Cyclone_D	1.8%				33 147	2.3%				28 713

** For the laden leg we use spot bunkers, and for the ballast leg we use 6-week lagging bunkers*

Table 11: Descriptive data summary

First of all we should emphasize that much of the variation between the two legs are a result of the differing distribution of observations over the time period and across vessels for the two legs. An interesting observation is that vessels on average seem to sail faster in the laden leg than in the ballast leg, and that there are larger variations in speed for the ballast leg both across vessels and per vessel (Appendix G). The average between the fixed and the floating cargo weight is quite similar, but not surprisingly the floating cargo has a larger standard deviation, as it varies over time in addition to vary across vessels. We also observe that vessels in a large pool or part of a large fleet are relatively overrepresented in the dataset, especially in the laden leg, as they only constitutes 29% of the fleet but 44.0% and 38.7% of the observations. Japan is slightly overrepresented with vessels constituting 9.1% of the fleet, and LogChain is slightly underrepresented, as these vessels make up 10.9%[56] of the fleet.

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[56] There are 66 vessels in the category LogChain, and 55 vessels operating to Japan

5. Analysis & Discussion

In this chapter we will first present the statistical tests we have performed during our analysis, before presenting the empirical results for the laden leg and ballast leg. We will follow up with a critical discussion of main findings, before presenting suggestions for further research on this topic.

5.1 Tests

5.1.1 Hausman Test for Model Choice

We perform the Hausman test for each model specification in *Table 12* and *Table 13*. This test indicates whether the random effects model is acceptable. It tests the null hypothesis that the individual unobservable effects are uncorrelated with the time-varying regressors[57], the key assumption of the RE model. So if we do not reject the null, we can apply the RE-model. If the p-value from the Hausman test is less than 5% we reject the null and either we must use the FE-model, or we need to improve the model specification in order to make the RE-model acceptable. For the models where the main focus is on the time-varying variables, we apply the FE-model if the Hausman test dictates so. In the model specifications where the inclusion of time-constant variables is of importance, we keep the model as a RE-model and rather try to improve the model specification. This is done because the FE-model will omit the important time-constant variables. For the laden leg, the RE-model was not acceptable for model specification (4), (5), (6), (11) and (12). We applied the FE-model for specification (4), and tried to improve the model for the remaining. For the ballast leg, the only model specification not feasible with the RE-model was (12), which is re-estimated with the FE-model in specification (13).

5.1.2 Obtaining Robust Standard Errors

One potential issue in our dataset is heteroscedasticity, which implies that the variance is dependent on some of the regressors, thus not constant as we assume. This would not cause biased estimators, but it would cause our standard errors to be wrong (Wooldridge, 2010).

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[57] Mathematically this implies that $Cov(x_{it}, \alpha_i)=0$. Under this assumption both RE and FE are consistent, but only RE is efficient.

To deal with this potential issue we use cluster-robust standard errors to make the standard errors robust against serial correlation, heteroscedasticity, non-normality and/or outliers. This is the same as specifying the Huber/White sandwich estimator[58]. Firstly, it relaxes the assumption that standard errors need to be identically distributed; hence they are robust against heteroscedasticity. Secondly, the standard errors are clustered on panels, relaxing the assumption of independence of the observations. Consequently, observations only need to be independent across the clusters (vessels), while allowing for serial correlation within panels. The coefficient estimates will be the same but standard errors and t-stats will change. The Huber/White sandwich estimator produces “correct” standard errors, even if the observations are correlated and not identically distributed, in the sense that we can make valid statistical inference about the coefficients (StataCorp, 2015b).

One advantage for us is that we have a large panel, and increasing the number of panel’s increases the likelihood of fulfilling the assumptions behind the model. It also reduces the time-series properties of the regression (Wooldridge, 2012).

5.1.3 Dealing with Multicollinearity

There are no applicable formal multicollinearity tests in Stata for the random effects model. Therefore we have made piece-wise checks between variables to check for multicollinearity between these, and let this affect which variables we include in the same model specifications (StataCorp, 2015a). Throughout the analysis we have commented on present and potential multicollinearity problems where relevant.

5.1.4 Robustness Check

As previously discussed a weekly data point could be based on the average of 7 daily observations or on one daily observation. As we are not able to weigh the observations, there will be more uncertainty for weekly observations that are averaged from fewer daily observations. To check that our results are robust to this issue we will perform the empirical estimation of the model after removing weekly observations that are calculated from less or equal to 1, 2 and 3 daily observations, respectively. An important reason to do this is because there is no guarantee that we have been able to remove all observations that are not

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[58] In Stata this can be done by specifying either ”robust”, ”vce(robust)” or ”vce(cluster *panelvar*)”, using vessels as panel variable, always being the case in random-effects models

representative. Some weeks with few observations might be biased by entry and exits into ports, unusual weather and so on. The results are presented in Appendix H and will be commented in the following section.

5.2 Empirical Results

In *Table 12* and *Table 13* in the following sections, we have presented the results of the estimation of various model specifications for respectively the laden leg and the ballast leg. The models are specified with the natural logarithm of weekly average speeds as the dependent variable. Similar models for both legs were tested with a level model for speed and macro variables, and with daily speed data, but they showed less efficient results. Variables starting with "l" are on logarithmic form, and those ending with "_D" are dummy variables.

The "R^2 overall" tells us how much of the variation in observed speeds that our model are able to explain. The "R^2 within" is the models ability to explain changes in speeds over time, for a given vessel. "R^2 between" tells how much of the speed variations across vessels the model is able to explain. Numbers in parenthesis is the p-value of the estimates.We use a significance level of 5% and p-values above this is marked in red. The variables coefficient is red if excluded from the model.

5.2.1 Laden Leg

In the following table we have presented the results of the empirical analysis for the laden leg. For space reasons we have left out a few tests and variables from the table, which we will comment on in the text. With regards to our *a priori* expectations based on theoretical models, the results correspond badly.

	(1)	(2)	(3)	(4)-FE*	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	Reason dropped
Macro Variables																	
IFFA+1M		-0.0273															Counter-intuitive
		(0.000)															
IFreight	0.0038				0.0041	0.0041	0.0041	0.0041	0.0035	0.0030	0.0029	0.0030	0.0032	0.0162	0.0033	0.0032	**Kept**
	(0.333)				(0.309)	(0.307)	(0.309)	(0.309)	(0.379)	(0.454)	(0.465)	(0.458)	(0.416)	(0.010)	(0.414)	(0.416)	
IBunkers	0.0070	-0.0091			0.0070	0.0069	0.0070	0.0069	0.0105	0.0057	0.0057	0.0057	0.0064	0.0096	0.0061	0.0039	**Kept**
	(0.183)	(0.073)			(0.186)	(0.187)	(0.180)	(0.186)	(0.130)	(0.282)	(0.281)	(0.283)	(0.225)	(0.282)	(0.248)	(0.465)	
IFreightBunkers			-0.0010														Insignificant and counter-intuitive
			(0.670)														
IFFA1MBunkers				-0.0072													Counter-intuitive
				(0.000)													
Vessel Specific Variables																	
IDraughtRatio					0.0753												Better alternative
					(0.006)												
ICargoConstant					0.1438												Insignificant
					(0.108)												
ICargoFloating						0.0776	0.0741	0.0756	0.0767	0.0678	0.0728	0.0751	0.0730	0.0501	0.0767	0.0771	**Kept**
						(0.005)	(0.007)	(0.006)	(0.005)	(0.014)	(0.008)	(0.006)	(0.008)	(0.225)	(0.005)	(0.005)	
IdSpeed							0.2128		0.2533	0.2805	0.2220	0.2287	0.1213	0.1389	0.136	0.1356	**Kept**
							(0.006)		(0.001)	(0.000)	(0.004)	(0.002)	(0.122)	(0.105)	(0.032)	(0.033)	
IFuelCons							0.0408										Insignificant and multicollinear
							(0.108)										
IConsumptionDSpeed								0.0403									Insignificant
								(0.115)									
BlockCoefficient										0.6244							Counter-intuitive
										(0.000)							
Length/Beam											-0.0320						Counter-intuitive
											(0.142)						
Beam/Draught												0.0862					Counter-intuitive
												(0.000)					
Built2000_D													-0.0150				Multicollinearity
													(0.026)				
EVDI													0.0827	0.0764	0.0538	0.0540	**Kept**
													(0.000)	(0.000)	(0.000)	(0.000)	
Drydock_D														-0.0118			
														(0.047)			
ECO_D													0.0904				Too small sample
													(0.000)				
Operational Specific Variables																	
Japan_D															0.1017		**Kept**
															(0.000)		
LogChain_D															0.0461		**Kept**
															(0.000)		
Ibunkers:Japan_D																0.0161	**Kept**
																(0.000)	
Ibunkers:LogChain_D																0.0072	**Kept**
																(0.000)	
LpOw_D															0.0215	0.0215	**Kept**
															(0.000)	(0.000)	
Other Variables																	
Contango_D									0.0056								Insignificant
									(0.268)								
Cyclone_D									0.0112	0.0102	0.0106	0.0106	0.0110	0.0077	0.0108	0.0108	**Kept**
									(0.008)	(0.015)	(0.011)	(0.012)	(0.009)	(0.186)	(0.010)	(0.010)	
Constant	2.4253	2.6055	2.4755	2.4571	0.6205	1.4501	0.7199	1.4008	0.7411	0.2836	1.0879	0.6261	0.9757	1.1858	0.9379	0.9477	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.581)	(0.000)	(0.067)	(0.000)	(0.059)	(0.487)	(0.013)	(0.117)	(0.015)	(0.032)	(0.012)	(0.011)	
R^2 Overall	*0.0001*	0.0008	0.0000	0.0004	0.0050	0.0050	0.0102	0.0054	0.0090	0.0202	0.0082	0.0163	0.0210	0.0186	0.1003	**0.1003**	
R^2 Within	***0.0001***	***0.0013***	***0.0000***	***0.0005***	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0009*	*0.0007*	*0.0007*	*0.0007*	*0.0008*	*0.0017*	*0.0008*	*0.0009*	
R^2 Between	0.0065	*0.0037*	*0.0080*	*0.0092*	***0.0099***	***0.0163***	***0.0278***	***0.0140***	***0.0239***	***0.0459***	***0.0273***	***0.0540***	***0.0783***	***0.0455***	***0.3228***	*0.3226*	
Hausman test (p-value)	**0.1543**	**0.1053**	**0.0855**	**0.0335**	**0.0246**	**0.0325**	**0.2912**	**0.0848**	**0.0520**	**0.2500**	**0.0477**	**0.0251**	**0.2769**	**0.1108**	**0.0671**	**0.1810**	
No of observations	33 147	33 147	33 147	33 147	33 147	33 147	33 147	33 147	33 147	32 902	32 962	32 962	33 147	13 397	33 147	33 147	

** Estimated using the fixed effects (FE) model*

Table 12: Empirical results laden leg

From model specification (1) to (4)[59] the macro variables either do not have any explanatory power on the speed choice, or their interpretation is counter-intuitive. We have tested multiple combinations for freight and bunkers, with varying lagging length as well as moving averages, all showing disappointing results. For freight and bunkers we only find a significant positive relationship for freight when we combined a two-week lagging freight and bunkers cost. However, the explanatory power was negligible only explaining 0,03% of the within variation and 0.01% overall. With virtually no sensible relationships to be found with speed, freight and bunkers, we keep the spot rate for both. For freight rate it can both be

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[59] Model specification (4) is estimated with the fixed effects (FE) model, as suggested by the Hausman test

argued that the relevant rate is future spot rates and the actual rate obtained for a voyage. We are under the opinion that spot is the most appropriate. For bunkers costs we argued for using a two-week lagging bunkers, but as we will discuss, the results indicates that the speed might be affected by the value of cargo, not only fuel costs. Due to the very high correlation between crude price and bunkers price it is hard to split these two effects, but the spot bunkers price should pick up both. Further, since we wanted to test interaction dummies for Japan and Logistics Chain in model (16) it is more meaningful to use spot bunkers, as this variable to a larger extent probably reflect value of cargo for these vessels.

In specification (5) to (13) we have included vessel specific and other variables. Firstly, in model (5) and (6) we examine which of the two approaches for measuring cargo weight and draught that is best. There are no significant speed differences between vessels with different carrying capacity, while higher draught ratio results in faster sailing speeds, as can be seen from model (5). Using floating cargo weight (6) is a better measure, being able to explain one percent of the speed differences between vessels. This indicates that more cargo generates more income, resulting in higher speeds. This implies that the increased income from more cargo outweighs the effect of increased resistance. Beyond saying that speed increases with cargo carried, it is hard to interpret the magnitude of this coefficient as it absorbs both variations within and between vessels.

When including design speed and fuel consumption at design speed (7), the latter is not significant. We should however be careful to interpret these variables on a stand-alone basis because vessels with high design speed often also will have high fuel consumption at design speed. This is backed by the strong correlation between consumption and design speed of 27.39%, which causes multicollinearity problems in the model. To deal with this issue we include the ratio between these two, measuring consumption per unit of design speed. This is a proxy for fuel efficiency, but it still showed insignificant (8). This is not that surprising, bearing in mind that the ratio is based on a static relationship not changing with speed. Anyhow, design speed is significant and included in our model. A one percent increase in design speed results in approximately 0.29%[60] faster sailing speeds on average. From model to model we should be somewhat careful of the interpretation as the design speed is correlated with a few other variables, evident from the changing coefficient. We have also

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[60] The exact coefficients are calculated in the following way throughout this analysis: $\frac{\partial V}{\partial dspeed} = e^{0.2533} - 1 = 0.2883$

tested RightShips design speed database, showing negative and not sensible coefficients. This questions the quality of the RightShips design speed data.

When including contango and cyclones in model (9), we find no support of our hypothesis that vessels steam slower in times with a substantial forward premium in the crude price. One explanation might be that the period of contango was in a period with a spike in the freight rates from late 2014. A falling crude price stimulating transportation demand, combined with vessels withdrawn from the market to be used for floating storage, contributed to pushing up freight rates, and with that speed incentives for shipowners. This speed increase should be reflected through the freight rate variable, but as the freight variable showed insignificant in our regression, the contango variable is possibly picking up some of this effect contributing to the positive effect on average speed[61].

Conversely to our *a priori* belief, if a vessel finds itself in a cyclone it sails on average 1.1% faster, not slower. This questions the accuracy of the variable and/or suggests that vessels sometimes speed up in order to not get caught in a cyclone as well.

In model specification (10)-(12) hull efficiency variables are included, all being counter-intuitive. An interesting observation is that the counter-intuitive speed relationships of the block coefficient and the beam-draught ratio both have significant explanatory power. As DWT is a part of both floating cargo and the block coefficient, the correlation of 26% causes multicollinearity problems in model (10). However, excluding floating cargo weight only increases the positive magnitude of the block coefficient, thus not being source to the puzzling relationship with speed. What we know is that the larger these two hull efficiency measures are, the more the hull is shaped like a box. It might suggest that the increased income from having a hull with a design more focused on efficiency in terms of carrying capacity, as opposed to hull resistance, have a larger effect on speed. However, as the floating cargo weight should pick up differences in carrying capacity and as the freight rates do not show a significant effect on speeds, these findings are puzzling and hard to explain.

When adding the EVDI-index and dummies for ECO-vessels and ships built before 2000 in model (13) the explanatory power of our model increases substantially, but at the same time, design speed gets insignificant as a result of multicollinearity. Vessels built before 2000

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[61] Interestingly, we did not find any more promising results when we added an interaction dummy for contango and freight rates

seem to go somewhat slower (1.5%), rather than faster. However, the coefficient might reflect other factors already accounted for in the model, such as having less carrying capacity and a lower design speed[62]. As this variable contributes to less explanatory power (0.18%) than what is the case for floating cargo and design speed (0.86%), we exclude this dummy[63]. The EEDI/EVDI index contributes with more than 1% of the overall R^2, explaining 3% of the difference between vessels. What is surprising is that the sign of the coefficient is positive. This indicates that a vessel steams faster the lower the fuel efficiency, which is counter-intuitive from an economical point of view. One possible explanation is that vessels designed for higher speeds also have higher emissions, resulting in both higher emissions and observed speeds. This is supported by a correlation of 23.5% between EVDI and design speed. Despite that EVDI and design speed have some multicollinearity issues we keep both as they contribute to the overall explanatory power. We should, however, keep this in mind when interpreting the coefficients. The ECO-vessels surprisingly showed a positive coefficient, but due to very limited data (only 7 vessels) this can be coincidental with other factors, and thus we exclude this variable[64].

Model specification (14) should be considered separately as our construction of the dry-dock dummy results in that we only keep 40% of the observations in the laden dataset (see section 4.3.2). In line with our expectations, vessels that are subject to fouling sail slower (1.2%) on average. What is interesting is that freight rate becomes significant when accounting for hull fouling, even though the magnitude of the response is small. Regardless, this can suggest that fouling creates noise in the analysis making freight rates insignificant, when this is not accounted for.

The factors that contribute the most to the explanatory power of the model are the operational specific variables. By including these three, the overall explanatory power increases from 1.8%[65] to 10%, with the model explaining 32% of the variation between vessels. From model (15) we see that vessels operating to Japan sail nearly 11% faster, equivalent to 1.3 knots. Vessels that are part of a larger internal supply chain sail 4.7% faster, or 0.57 knots.

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[62] This is evident from a negative correlation of 25% and 22% for design speed and floating cargo weight respectively

[63] This is based on a model with only macroeconomic factors and the respective variables included

[64] We have checked for whether these vessels fell within the operational variables. Only one of them were part of the logistical chain variable, which can contribute somewhat to the positive coefficient

[65] When using model specification (13) and omitting vessels built before 2000 and ECO-vessels

To examine this finding further we included interaction dummies for “Japan” and “LogChain”, testing different combinations with freight, bunkers as well as a level dummy. Model specification (16) shows the results from the best combination, where the interaction dummy with freight is removed as it was insignificant. From this model specification we find evidence that the changes in bunkers price is actually what is fuelling the higher speeds for these vessels. We will discuss this thoroughly in the critical discussion. Lastly, we observe that vessels being part of a large pool or operated by a large owner goes faster, rather than slower, contradicting our *a priori* expectations.

As mentioned in the *Tests* section (5.1) we have performed a robustness check of our analysis, presented in Appendix H. As we remove the weeks with averages based on only 1, 2 and 3 daily observations we observe that certain variables turn insignificant. When we only include weeks with two or more daily observations design speed turns insignificant on a 5% significance level[66], and floating cargo turns highly insignificant. This casts doubt to whether these variables truly have an effect on speed, and we need to be careful with our conclusion and interpretation of these coefficients. Further, the cyclone dummy is only positive when all weeks are included. Consequently, there is very limited evidence that vessels sail faster when located in a cyclone. Surprisingly, bunkers turn positive when we only include weeks with four or more observations. This observation supports the hypothesis that cargo value plays a role in the speed decision. The remaining coefficients are largely unaffected while the models R^2 increases slightly.

5.2.2 Ballast Leg

For space reasons we have left out a few tests and variables from the results, which we will comment on in the text. For the bunker fuel costs we have also tested spot price and two week lagging, but in line with our expectations we found that 6 weeks lagged bunkers gave the best estimates. This is supportive of our assumption that vessels do bunker up fuel for both legs in the Arabian Gulf. As for the laden leg, design speed data supplied from RightShip was also tested, without showing more promising results than the data from Clarksons.

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[66] Still significant on a 10% level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13) - FE*	(14)	(15)	Reason dropped
Macro Variables																
TCE	4.7E-07 (0.000)															Better alternative
IFFA+1M		0.0203 (0.019)														Better alternative
IFreight			0.0459 (0.000)		0.0454 (0.000)	0.0459 (0.000)	0.0464 (0.000)	0.0463 (0.000)	0.0463 (0.000)	0.0459 (0.000)	0.0459 (0.000)	0.0510 (0.000)	0.0520 (0.000)	0.0458 (0.000)	0.0542 (0.000)	**Kept**
l6wBunkers	-0.0393 (0.000)	-0.0771 (0.000)	-0.0489 (0.000)		-0.0494 (0.000)	-0.0489 (0.000)	-0.0499 (0.000)	-0.0500 (0.000)	-0.0500 (0.000)	-0.0488 (0.000)	-0.0489 (0.000)	-0.0296 (0.077)	0.0064 (0.715)	-0.0491 (0.000)	-0.0575 (0.000)	**Kept**
IFreight6wBunkers				0.0470 (0.000)												Better alternative
Vessel Specific Variables																
IDraughtRatio					0.0719 (0.000)											Counter-intuitive
IdSpeed					0.1791 (0.212)											Insignificant
IFuelCons					0.0294 (0.473)											Insignificant
IConsumptionDSpeed						0.0248 (0.545)										Insignificant
BlockCoefficient							1.3263 (0.000)									Counter-intuitive
Length/Beam								-0.1015 (0.005)								Counter-intuitive
Beam/Draught									0.2261 (0.000)							Counter-intuitive
Built2000_D										-0.0160 (0.170)						Insignificant
EVDI											0.0999 (0.000)	0.0685 (0.027)	(omitted)	0.0492 (0.047)	0.0493 (0.041)	**Kept**
Drydock_D												-0.0085 (0.366)	-0.0279 (0.013)			
ECO_D										0.1413 (0.000)						Too small sample
Operational Specific Variables																
Japan_D														0.1895 (0.000)		**Kept**
Ifreight:Japan_D															-0.0387 (0.000)	**Kept**
l6wBunkers:Japan_D															0.0452 (0.000)	**Kept**
LogChain_D														0.1254 (0.000)		**Kept**
Ifreight:LogChain_D															-0.0440 (0.001)	**Kept**
l6wBunkers:LogChain_D															0.0373 (0.000)	**Kept**
LpOw_D														0.0304 (0.000)	0.0304 (0.000)	**Kept**
Other Variables																
Cyclone_D					0.0042 (0.394)											Insignificant
Constant	2.6933 (0.000)	2.8937 (0.000)	2.6490 (0.000)	2.6339 (0.000)	2.0733 (0.000)	2.6034 (0.000)	1.5349 (0.000)	3.2199 (0.000)	2.0359 (0.000)	2.6502 (0.000)	2.4017 (0.000)	2.5137 (0.000)	2.3007 (0.000)	2.4850 (0.000)	2.5169 (0.000)	
R^2 Overall	*0.0091*	0.0070	0.0097	0.0097	0.0135	0.0098	0.0304	0.0151	0.0473	0.0156	0.0187	0.0179	0.0068	**0.1730**	**0.1744**	
R^2 Within	***0.0150***	***0.0115***	***0.0164***	***0.0164***	*0.0175*	*0.0164*	*0.0169*	*0.0168*	*0.0168*	*0.0164*	*0.0164*	*0.0124*	*0.0128*	*0.0164*	*0.0185*	
R^2 Between	0.0036	*0.0040*	*0.0027*	*0.0026*	***0.0108***	***0.0032***	***0.0412***	***0.0120***	***0.0668***	***0.0178***	***0.0208***	***0.0469***	***0.0072***	*0.3609*	*0.3613*	
Hausman test (p-value)	0.3117	0.4550	0.4695	0.5903	0.1747	0.4666	0.4083	0.4935	0.5698	0.6895	0.4220	**0.0002**	**FE-model**	0.2786	0.7144	
No of observations	28 713	28 713	28 713	28 713	28 713	28 713	28 448	28 505	28 505	28 713	28 713	11 589	11 589	28 713	28 713	

** Estimated using the fixed effects (FE) model*

Table 13: Empirical results ballast leg

The results somewhat corresponds to our *a priori* expectations. Regarding the macro variables (model specification (1) to (4)) we observe that freight rate was the most meaningful measure of income/opportunity cost of the vessel. As the bunkers price is a part of the calculated TCE the two are highly correlated, making bunkers less significant. The FFA+1M did not show significant at 5 percent level. From the results we observe that speed are increasing with freight rates and decreasing with bunkers prices, in line with our expectations. However, based on the theoretical optimal speed model for the ballast leg (*Equation 18*) we would expect coefficients of around -0.33 for bunkers and 0.33 for the opportunity cost, while we only observe coefficients of -0.049 for bunker prices and 0.046

for freight rate. Still, a smaller coefficient for freight rate might be reasonable. The reason is that the coefficient in the theoretical model is based on the alternative value of the vessel, which is a profit element (freight minus voyage costs), while freight rate is an income element. Furthermore, we see that the macro factors have low explanatory power explaining 1.56% of the variations over time. Even though macro factors are explaining less of the variations in speed than what we would expect, it is encouraging that we find meaningful functional relationships with speed for these variables, as opposed to what is the case for the laden leg.

We clearly observe from model specification (5) to (13) that the explanatory power of the vessel specific variables fell short of our expectations. Both design speed and fuel consumption at design speed show insignificant, and so did the consumption-speed ratio. It is puzzling that design speed is significant for the laden leg, but not for the ballast leg.

As opposed to in the laden condition, whether a vessel has been in a cyclone does not seem to affect the speed (5). This can be consistent with the theory that vessels might speed up in order not to get caught in a cyclone. It can also be sensible that the coefficient is less positive in the ballast leg. Since vessels have more contractual obligations to maintain a certain speed in the laden leg, they could have higher incentives to speed up to not get caught in a cyclone.

In model specification (7) to (10) we find that the variables supposed to explain differences in the efficiency of the hull design were counter-intuitive for the ballast leg as well. We argued for the laden model that higher speeds for a vessel with a more square hull might be driven by higher carrying capacity. This explanation is difficult to support for a leg without any cargo. One could argue that higher cargo capacity increases the alternative value of the vessel also for the empty positioning leg. However, it is reasonable to believe that the hull efficiency in terms of resistance plays a more important role. That carrying capacity is not important is supported by the fact that DWT did not show significant when we included it in the model. Thus, we do not have any good explanations for these puzzling findings.

Whether a vessel was built before year 2000 did not have a significant effect on the speed chosen. The EEDI/EVDI index shows significant results and contributes to the overall R^2 with 0.9%, explaining 1.8% of the differences between vessels. Our argument that higher emission is correlated with higher design speed resulting in the positive relationship between speed and EVDI is weakened, as the design speed is insignificant in the ballast model.

Lastly, we observe that more fouling on the hull leads to ships steaming almost 3% slower, when applying the FE-model as proposed by the Hausman test.

As for the laden leg, the operational specific variables are the ones that contribute the most to the explanatory power of the model. Including these three increases the R^2 considerably to 17%, with the model being able to explain 36% of the variations between vessels. The vessels that are operating to Japan seems to steam approximately 21% faster, while vessels being part of a larger internal logistical chain sail on average 13% faster. In a level model this corresponds to approximately 2.3 and 1.5 knots. The variable for vessels being a part of a large pool or operated by a large owner shows a counter-intuitive coefficient, consistent with the findings for the laden leg.

Including interaction dummies combining the two macro variables with Japan and LogChain shows that the speed seems to be inversely related with freight rates and bunkers costs. However, we feel less confident about these interaction dummies than for the laden leg as they contradict the correlation coefficients between speed, bunkers and freight shown in *Table 14*. It is also puzzling why operators would respond negative to changes in freight rates, even though showing a positive correlation in *Table 14*. We can be certain that vessels being part of these two categories steam faster, but we are somewhat uncertain with regards to the interpretation of the interaction dummies, other than not being in line with optimal speed theory.

The robustness check is encouraging with regards to our findings as all coefficients stays highly significant and the explanatory power of the model increases. Both the freight and bunkers elasticities increase slightly in magnitude, and the same applies for the rest of our variables. The within R^2 increases from 1.64% to 2.34% both indicating that some noise is present in our model, but also ensuring that freight and bunkers do affect speed in a sensible manner over time. The robustness check for both legs seem to slightly improve the model, suggesting that there is some noise connected to weekly speeds based on few daily observations. However, as our conclusions are quite robust, this indicates both that our approach is acceptable and that we can be quite confident in our data cleaning process.

5.3 Discussion of Main Results

In order to set the agenda for our discussion we can outline the main findings from the empirical results.

1. In the laden leg, we find no evidence that the relationship between speed, freight and bunkers is in line with what theory suggests
2. For the ballast leg the macro-coefficients are sensible and significant, but less in magnitude than expected
3. Vessel specific factors presumed to affect speed mainly showed insignificant or counter-intuitive for both legs. Design speed and floating cargo weight were exceptions for the laden leg at first, but turned insignificant in our robustness check
4. The operational variables plays an important part of the differences in observed speeds across vessels, but the large pool or owner is counter-intuitive
5. We find some evidence that difficult observable variables affect the speed, indicating that this is a source to noise in the regression

There are of course several possible explanations for each of these findings. First of all, the quality of our input data is of great essence to the viability of our model. So is the specification of our model. The automatically registered average speeds of Genscape Vesseltracker and Marinetraffic in combination with a nine-step cleaning process makes us confident on the quality of the data. However, even though the data quality can be considered to be high, there are still unobservable noise and assumptions regarding the variables that can influence the performance of the model substantially. For the sake of this discussion we can divide variables that have an affect on speed into three categories; (i) observable variables, (ii) difficult/hardly observable variables and (iii) non-/unobservable variables. It is especially the two latter groups that can cause substantial noise in our regression. Obvious examples of unobservable variables are local weather and currents, but we also have more intricate factors such as port congestion, piracy attacks and mini markets affecting the local supply and demand balance. As for the hardly observable variables, some are included in the regression, but behind the computation of these variables lays assumptions that can make them unreliable. Examples here are the cyclone and dry-dock dummies. The fact that we cannot be certain that the hardly observable explanatory variables captures only the intended effects leads to a vaguer analysis where we are cautious not to make bold statements on the causality between the variables and speed. The argument that the hardly observable variable can cause noise in the empirical model is supported by the fact that freight rates turns significantly positive for the laden leg when the dry-dock dummy is included. This is also evident from the robustness check where both the model and the macro variables are improved when we exclude the noisiest and most uncertain data points from the regression.

In the following we will discuss main drivers and structural reasons that can explain our findings. The non-observable variables will be included throughout the chapter as a factor for why we may see deviations between theoretical- and observed effects of explanatory variables on speed.

5.3.1 Lack of Response to Freight and Bunkers for the Laden Leg

The lack of speed responsiveness to changes in freight and bunkers for the laden leg is supported by the low variance in average speed for this leg, as observed in *Figure 7*. While average monthly speeds for laden shows a negative correlation with freight/bunkers of -0.12, the ballast speed is more in line with theory showing a correlation of 0.49.[67]

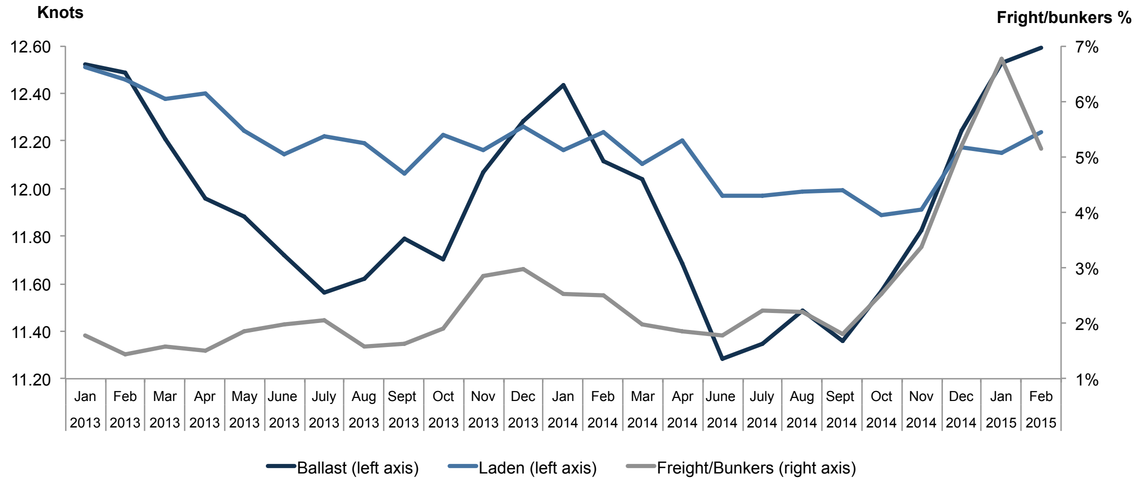

Figure 7: Average monthly ballast and laden speeds and freight/bunkers
Source: Based on data from Genscape Vesseltracker, Marinetraffic and Clarksons

One reason for the low variation in speed for the laden leg can be explained by looking further into the *usage problem* addressed by Rehmatulla et al. (2013), and the way fuel costs

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[67] Removing vessels assumed to shuttle Japan-Meg and vessels owned by oil companies and refineries makes the relationship even clearer. Laden with correlation of -0.03 with freight/bunkers, ballast with a correlation of 0.56.

are distributed between charterer and shipowner for VC contracts. This was previously discussed in section 2.2. The charterer of a vessel is most likely to be the owner of the cargo. Hence, the lower the speed of a vessel, the more days at sea and the higher the financing cost for the charterer. Shipowners however, would like to steam at speeds that maximize profits when taking into account the trade-off between bunkers cost and freight rate. So while cargo owners would like to minimize days at sea, shipowners may want to slow steam in order to conserve fuel. This can cause split incentives between the charterer and shipowner regarding the speed decision. This relation is illustrated in *Figure 8* for crude oil prices at 80$/barrel, and a 20% lower bunkers price to reflect the historical crude/HFO-spread[68]. *Figure 8* is a simplistic exercise based on heavy assumptions regarding the steepness of the fuel consumption curve and the financing cost (See Appendix I for details) and should therefore only be used for illustration purposes.

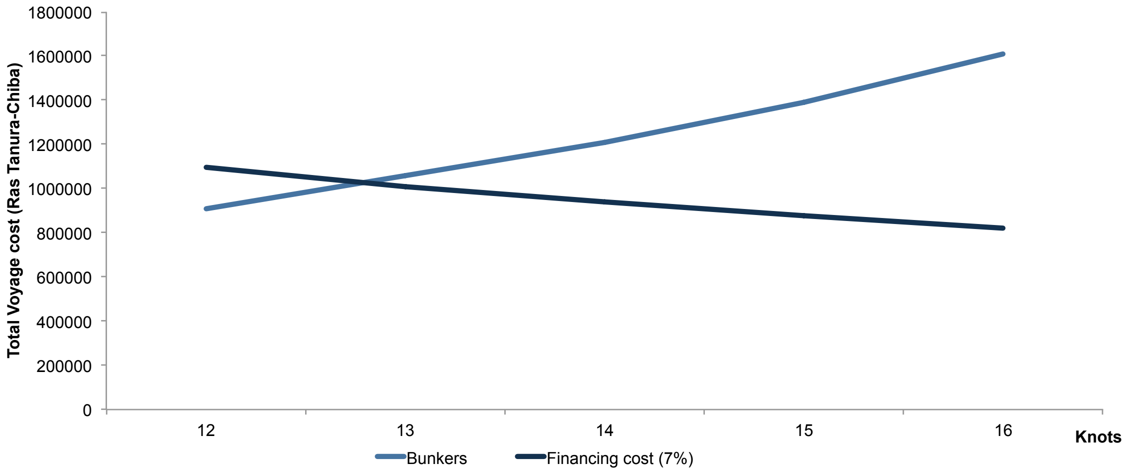

Figure 8: Total financing cost in $ for chartering a 305,000 dwt VLCC at 95% utilization from Ras Tanura to Chiba (TD3) for different speeds vs. Total bunkers cost
Source: Own calculations based on Devanney (2011)

The different speed preferences between charterers and owners create a demand for minimum speed clauses from charterers[69]. This is a contractual agreement between the charterer and the shipowner setting the minimum average speed allowed for a voyage. The use of minimum speed clauses for VCs can explain why we do not see much variation in the average speed in the laden leg. For the ballast leg the charterer has no say in the speed decision, making it easier for the shipowner to adapt a speed more in line with theoretical optimal speed. The fact that we also observe higher speeds for the laden leg than for the

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[68] Based on own calculations of the spread in the relevant period
[69] See for example BIMCO minimum speed clauses for voyage charters

ballast leg could suggest that the bargaining power of the shipowners in the contract negotiations is somewhat limited, and that the speed in the laden leg mainly is determined in favour of the charterer. This supports the view of Rehmatulla (2013) that split-incentive problems related to the specific structure of the shipping market cause vessels to steam at speeds that are not only suboptimal for the shipowner, but also for the environment. Modelling performed by Rehmatulla (2013) in relation to the efficiency problem of TC contracts shows that in those cases where the shipowner gets 100% payback on his investment in energy efficient equipment, greater measures are taken. Using the same type of argument for VC contracts, the incentives for shipowners and charterers regarding the speed decision could be more aligned if the fuel costs to a larger extent were passed back to the charterer.

5.3.2 The True Supply-Demand Balance – A Mini Market Around Each Crude Move

One of the reasons for the discrepancies between theoretical and observed speeds could be that the true supply-demand balance of the market is overlooked. The issue is seldom addressed in theory and hard to account for through empirical research. On DNB Markets annual Oil, Offshore and Shipping conference in Oslo, Paddy Rogers, chief executive in Euronav, raised the issue that the analysis of vessel speeds usually is way to generic:

"…the reality is that we don't work in a market of statistics. We work in very small micro-markets around each crude move, so every time a cargo has to move, they make a little market around it about the ships in the area, the owners that are acceptable to that move and you end up with a little auction process around that crude move" (Tradewinds, 2015)

In a note to shareholders, Euronav (2015) further elaborates on how this mini auction around each crude move makes the volatility in the true freight rates received by owners' way larger than in the average market rates. Thus, despite a market average of say $100,000 per day, vessels can be fixed at $200,000 and $7-80,000, because the supply-demand balance varies for each crude move. **For the laden leg**, the important insight is that the true freight rate can deviate severely from the average market rate we use. Thus, there may be considerable error in the income generating part of the optimal speed equation, creating noise and reducing the observed relationship between speed and freight rates in the model. Still, on aggregate we must add that it makes sense that vessels should go faster when the overall freight market picks up. Deviations between true and average market rates will also affect the alternative value of the vessel, thus the ballast leg. Paddy Rogers elaborates on what is truly of relevance in this leg:

"If we discharge a cargo in China, our attitude would be on ***bunker costs management****. We don't know what we are going to do next. We go eco-speed to Singapore. On the way, the chartering desk is trying to find the next fixture and they can either look at an early window date, if there is a good opportunity, but if they see 10 or 15 people bidding in on an early cargo that you would reach at 15 knots, then they would say no. Price-wise, it makes more sense to do nine knots and come in a later window to cargo where there is less competition"* (Tradewinds, 2015)

This suggests that the **ballast leg** can be divided into two parts with differing speed drivers: before and after securing the next fixture. In the positioning part of this leg, what is truly relevant for the optimal speed decision is the spot rates resulting from the mini market around those crude moves that the vessel realistically can compete on, combined with bunkers cost management. Once the owner has secured the next fixture, what makes sense from an economical point of view is to make the laycan just in time but with a sufficient margin so that the risk of cancellation is adequately reduced. Hence, the objective to make the laycan is the main driver in the speed decision. Bunker costs and opportunity cost (spot rate) should from this point have very low explanatory power of speed. This can contribute in explaining why the observed speed relationship with freight and bunkers are less in magnitude than the theoretical model suggests.

5.3.3 Type of Charter Contract and Operational Strategy Matters in Practice

The results of the empirical analysis, backed by monthly average speed data (*Figure 9*), show that vessels assumed to shuttle between the MEG and Japan steams at significantly higher speeds than the rest of the fleet. The same applies for vessels being part of a larger internal logistical chain, only less in magnitude. The differences are especially large for the ballast leg.

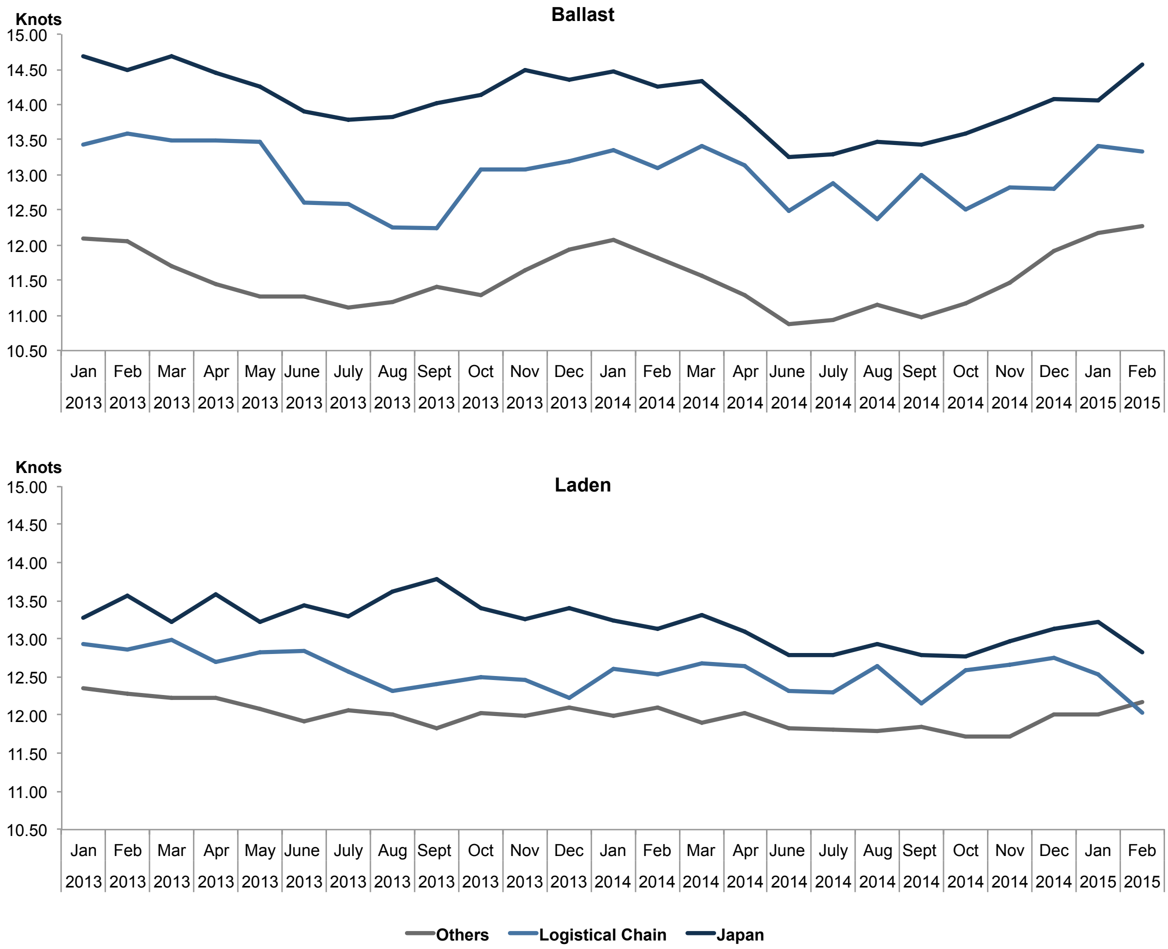

Figure 9: Average monthly speeds for different vessel categories, for the laden and the ballast leg
Source: Based on data from Genscape Vesseltracker and Marinetraffic

Additionally, when examining interaction effects of these two vessel categories with freight and bunkers, the only finding for the laden leg was a positive relation with bunkers. Again, the effect was strongest for Japan vessels. For the ballast leg we found inverse relationships for both freight and bunkers relative to the suggestions of optimal speed theory. However, as we will discuss, we are more uncertain regarding the interpretation of these. Correlation coefficients between the average speed of vessels from different categories and freight and bunkers are presented in *Table 14*.

Vessel Condition	Observed data points	Freight	Bunkers	Freight/Bunkers
Ballast	Logistical Chain	0.16	-0.03	0.16
	Japan	0.18	0.02	0.12
	All excl. Logistical Chain & Japan	0.56	-0.40	0.56
Laden	Logistical Chain	-0.28	0.22	-0.23
	Japan	-0.24	0.33	-0.24
	All excl. Logistical Chain & Japan	-0.07	0.13	-0.03

Table 14: Bunkers (380) and freight rates (TD3) correlation with speed for different vessel categories
Source: Based on data from Genscape Vesseltracker, Marinetraffic and Clarksons

We will now argue that the observed results could be explained by financing cost and the crude sourcing strategy of the operators in control of the vessels.

Vessels shuttling to Japan delivering crude oil to Japanese refineries have highly predictable sourcing patterns, as previously discussed in section 3.3.2. This makes these vessels more likely to be chartered on fixed long-term contracts, with properties more similar to TC than VC contracts. In practice there are two key differences between TC and VC contracts that could make a difference in the speed decision of the operators. **Firstly**, the fact that TC rates are treated as a periodically fixed cost for a time chartered vessel implies that it is irrelevant for the speed decision. **Secondly**, for TC contracts the operator of the vessel is also usually the owner of the cargo. These two characteristics are also present for vessels that are part of a larger logistical chain, even though for a slightly different reason. With the owner and charterer being part of the same organization, freight rates should be irrelevant in the speed decision for these vessels. As for the Japan vessels, it could also be assumed that these vessels own the cargo themselves.

Financing cost of the value of cargo is not accounted for in the theory of Devanney (2009) and we regard this as a main explanatory factor for why we observe a positive relationship between bunkers and speed for vessels assumed to be operated by cargo owners. As opposed to the owners discussed by Devanney (2009) that have no economical interest in the cargo value, cargo owners will need to take into account the financing cost in their speed decision. When choosing speed, they must weigh the saved fuel costs of slow steaming against the increased financing cost of arriving later. As previously discussed, the bunkers cost variable will absorb both of these contradicting effects. The positive coefficient implies that the positive effect on speed of increased cargo value outweigh the negative effect of increased bunkers cost. The findings are opposing to what traditional optimal speed theory suggests, but in line with the alternative theoretical model presented in section 3.1.3, which accounts for the financing cost effect in the laden leg. For the ballast leg the empirical analysis shows positive response to bunkers, but we are uncertain about whether this is due to cargo value. This is based on 6-week lagged bunkers, which is not a good proxy for changes in value of cargo. Further, when looking at the correlation between speed and spot bunkers in *Table 14* there seems to be no correlation, casting doubt to whether the speed in the ballast leg is affected by the cargo value.

So far in this section we have argued that **lack of exposure to freight rates** and **the value of cargo** might explain why we do not see any response in speed for changes in freight rates, and the positive relationship between bunkers and speed, for Japan-MEG and LogChain vessels. Hereby, it remains to address the observation that both vessel categories steam consistently higher than other vessels.

One could argue that long-term crude sourcing strategies allow the parties to perform bunkers hedging in a greater extent than what is feasible for short term VCs and that this pushes down the bunkers cost, fuelling incentives to speed up. However, bunkers hedging is a speculative risk reducing measure and should not consistently give a lower bunkers price than buying bunkers spot. We must therefore assume that the operators of these vessels are exposed to the same fuel prices as others. An argument in favour of higher speeds for both legs is related to the schematic sourcing plan of Japan and LogChain vessels. In order to ensure consistency in supply, it could be beneficial to steam faster with less focus on macro variables.

The last observation is that the speed differences between these two categories and the rest of the fleet are larger for the ballast leg than the laden leg. One reason could be that for the laden leg, minimum speed clauses present in VC contracts push up the speed above optimal for the remaining fleet (shipowners). In the ballast leg however, vessels on VC contracts have no contractual obligations and can maintain a larger focus on bunkers costs until the next fixture is secured.

The arguments discussed in this section are relevant to both Japan and LogChain vessels. However, the results imply that the effects related to crude sourcing strategy and/or value of cargo is even more present for Japan vessels than for vessels part of a logistical chain. A reason for this could be that some of the vessels included in LogChain are re-let and are actually trading at VC contracts.

5.3.4 Conclusive Remarks on Vessel Specific Variables

As one of the main contributions of this thesis is to analyse how vessel specific variables affect speed in practice, we will devote some space to summarize and conclude on our findings. The main result from the empirical analysis is that most of these variables prove insignificant and/or counter-intuitive for both legs. In this section we will address some explanations for why this is the case.

The floating cargo variable is at first sight in line with theory, suggesting that more cargo results in higher freight income and thus a higher optimal speed. However, it turned insignificant in our robustness check. This does not necessarily mean that the variable lacks explanatory power, but rather that it could be distorted by three noise factors we have identified. Firstly, as previously discussed, the frictional resistance pulls the coefficient in two opposite directions. Secondly, in light of our discussion on the importance of value of cargo, cargo weight might also partially reflect that a larger cargo volume also implies a higher financing cost for the cargo owner, increasing his speed incentives as well. Thirdly, this ratio might reflect that loading degree might be lower in bear markets with lower freight rates and speeds. This might cause both multicollinearity issues in the model and the speed effect might already be picked up by the freight rate variable. However, from the table in Appendix J we observe no such sensible relationship, but rather a negative correlation between draught ratio and freight rates.

From the speed and consumption variables we found that design speed were only significant for the laden leg and not for the ballast leg. It is hard to find an explanation for this, but one possibility is that the design speed is considered when determining the minimum speed requirement in the charter clause. However, this is a very speculative inference to draw. As for the speed-consumption ratio an issue with the variable is that it only takes into account the fuel efficiency when the vessel steam at design speed. Hence, it does not capture that the fuel efficiency of a vessel varies depending on the engine's rate of speed.

The reason for the counter-intuitive hull efficiency measures could be inaccuracy between which effects they are intended to capture and what is truly reflected. One obvious example is that a having a square hull does not only capture the intended effect of higher resistance, but also a higher carrying capacity. The other reason we can think of is the biological fouling on the wetted surface of the vessel. The fact that the empirical results show that fouling reduces speed makes us more certain that fouling creates noise for both hull- and fuel efficiency measures, causing deviation between theoretical and actual hull resistance.

It could also be that speed determining market participants do not act according to the theoretical model of Ronen (1982), which states that vessels with higher design speed or lower fuel consumption at design speed will have a higher optimal speed, ceteris paribus. Even though we recognize the limitations of our vessel specific variables, the lack of significant and meaningful coefficients could suggest that vessels are treated more homogeneous than theory suggest and that owners can benefit from a larger extent of vessel specific speed optimization. The positive relationship between EVDI and speed, even though counter-intuitive, might suggest that it is premature to conclude that fuel efficiency has no impact on speed. It should be noted that our finding on EVDI is contrary to the findings of Rehmatulla (2013) for the dry-bulk market. He finds that vessels with lower EEDI (higher fuel efficiency) steams faster than average.

5.3.5 Other Discussion

The effect of TC vessels present in the dataset

As thoroughly discussed, our analysis suggests that vessels on contracts with characteristics similar to TC go faster and are not responding to the macro variables in line with our *a priori* beliefs. We have identified vessels that are likely to sail on such contracts through the Japan and LogChain variables. Still there are vessels on TC contracts in the dataset that we have not been able to identify. From model specification (15) in the ballast leg (*Table 13*) we observe that when taking out Japan and LogChain vessels from the macro variable coefficients, by letting them interact with these factors, the magnitude of both freight and bunker increases. Hence, this suggests that the speed response to changes in freight and bunkers is stronger for vessels on VC than the empirical analysis suggest, implying that the true coefficients probably are closer to the coefficients in the theoretical models. Some of the same findings could also be applicable to the laden leg. It is evident that the inability to identify TC vessels is creating noise when analysing the vessels on VC.

Large Pool or operator

We have previously argued for why we would expect a negative coefficient for vessels included in this variable. However, the fact is that we observe a slightly positive and significant coefficient. We have identified two factors that might contribute to this observation. Firstly, having a lot of bargaining power might after closer considerations also result in higher achieved freight rates, which might be just as an important focus as reducing the minimum speed in the charter clause. This can contribute to the true freight rates being higher for this group, increasing the optimal speed. Secondly, the increased visibility and information about the upcoming cargo moves might result in that this group is better to position the vessels for movements with less supply and better rates. This can result in both higher and slower speeds, and not solely slower speed.

5.4 Limitations and Suggestions for Further Research

The main drawback of the dataset used in this thesis is the lack of route descriptions, making it infeasible to compare the average speed of one route to another. It also means that we have to make assumptions regarding freight rates and where the vessels bunker up, in which we have done by using TD3 rates and 380cst Fujairah for all vessels. Since the correlations between the different freight rates and between different types of bunkers are high, the empirical model analysing **changes** in speed for changes in explanatory variables would not be affected by the assumptions to any large extent. However, even though the strong correlation between freight rates justifies the use of TD3 as a proxy for the received freight rate for a given day, the rate may not reflect the true freight rate received by shipowners at various locations. This may also have implications for the observed speed levels between different routes. Future analysis should try to capture if /why some vessels steam consistently faster than others due to different sailing routes.

An additional limitation of this thesis is that we do not take into account the various fuel strategies of shipowners, potentially neglecting hedging strategies and other factors with effects on the volatility of the speed. However, factors related to mini markets and owner specific strategies are hard to overcome and adjust for through any empirical study of the shipping market and we must therefore add a portion of uncertainty to the studies.

Another topic for further research could be examination of whether there are any differences in speed in the beginning and the end of the ballast trip, or how freight and bunkers affect the speed differently in these two parts. If the speed of a vessel is primarily driven by the laycan in the time after a new fixture is agreed upon with the charterer, one would expect to observe a weaker relationship between macro factors and speed in the last part of the leg.

The findings in this thesis suggest that the financing cost has explanatory effects on speed in the laden leg. Even though some theoretical models try to account for this factor, it is hard to conduct an analysis of this in practice due to the high correlation with bunkers costs. The incentive for cargo owners to speed up when the value of cargo is high (being the charterer in a VC) puts pressure on shipowners, which may have other speed preferences. Future research should further analyse the relationship between the incentives of cargo owners vs. shipowners when the value of cargo changes (either by size of vessels or by changes in crude oil price). More sophisticated models incorporating finance cost could reveal relationships that in current theoretical optimal speed literature remains unexplained. When analysing the effect of cargo value, one should also include storage capacity and costs, as discussed in our alternative theoretical speed model.

6. Conclusion

In this thesis we have utilized panel data to analyse how the speed of VLCCs respond to changes in explanatory variables and compared the results to what theory suggests. Theoretical optimal speed models are generally based on the view that the speed of vessels are positively related with freight rates and negatively related with bunkers price. The results of the empirical model find support for the theory for the ballast leg, even though to a less extent than theoretical models suggest. However, no such relationship could be found for the laden leg. In hindsight, the laden results are not that surprising. Behind the theory stating that speed should increase with freight rate and decrease with bunkers lies the assumption that shipowners are the only party in the speed decision. This means that for changes in the bunkers price, traditional theoretical speed models only take into consideration the changes in speed incentives for a shipowner. What they fail to recognize is that for a change in bunkers price there will be a simultaneous change in the crude oil price, effectively driving the value of cargo up or down. For VC contracts the charterers are usually the cargo owners. When the speed of a voyage is settled, their incentives to speed up because of the financing cost may be conflicting to the optimal speed of a shipowner. Hence, the observed results for the laden leg may be explained by split-incentive problems for voyage charters, or that a larger share of the observed VLCC fleet is time chartered than originally anticipated. In either case the value of cargo is a decisive element in the speed settling decision. Our adjusted theoretical model, which takes into account the value of cargo and implicitly the speed incentives of cargo owners, supports the results in the laden leg.

Somewhat surprisingly, the empirical analysis studying the effects of vessels specific variables on speed mainly proved to be insignificant or counter-intuitive. The results imply that speed determining market participants look past the individual specifications of the vessels, treating the fleet more homogenously than we expected. However, the fact that we do find a relationship between EVDI and speed, even though contra-intuitive, suggests that it may be premature to conclude that vessel specific variables are irrelevant in the speed settling decision. The fact that we find some evidence that design speed and cargo size affect the speed in a meaningful matter for the laden leg supports the argument that vessel specific variables may matter in the speed decision but that the effects are difficult to capture through an empirical analysis.

The daily longitude and latitude data provided in the dataset allowed us to identify which vessels that are most likely to shuttle between MEG and Japan. These vessels, as well as vessels part of a larger internal logistical chain, were found to steam at consistently higher speeds than the average vessel. One reason might be that these vessels operate on a more shuttle-like basis with emphasis on consistency in crude sourcing rather than market fundamentals. In addition, these vessels showed no meaningful response to freight rates for either leg. The empirical model also revealed that for an increase in fuel prices, these vessels tended to speed up, a finding contrary to what theory suggests. Again, introducing the value of cargo shed light on the rationality of the observed relationship. As these vessels are more likely to be operated by cargo owners, a higher fuel price implies higher value of cargo. This drives up the financing cost and thus also the speed incentives.

We acknowledge that unobservable variables and assumptions regarding the explanatory variables can influence the performance of the model substantially. Local weather, port congestions, piracy attacks and mini markets affecting the local supply and demand balance are all unobservable variables that may affect the speed of a vessel in the short term. When including hardly observable variables as hull fouling and cyclones, as well as reducing noise through robustness checks, these measures both improve the models as well as the magnitude and explanatory power of the macro variables. Hence, these effects should not be underestimated and further research should strive to reduce this noise.

In order to reduce GHG emissions, market regulators may want to enforce reduced speeds in the shipping industry. In this thesis we have showed that the cost distribution relative to the charterer’s control of the vessel in combination with the financing cost could lead to split-incentive problems in the speed settling decision for VC contracts. In order not to induce unintended effects or an unnecessary burden on the shipping industry, regulating authorities should fully understand the intricate relationship between various market participants that are part of the speed settling decision before undertaking any market-based measures.

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8. Appendix

8.1 Appendix A – Theoretical Fuel Consumption Formula

According to MAN Diesel & Turbo (2013a) the fuel consumption for a vessel can be determined through the admiralty coefficient. This coefficient is constant for a given hull, i.e. for a given vessel with a certain design speed, and it gives the approximate relationship between propulsion power (P), speed (V) and displacement (∇). Since the coefficient should be constant for any speed, propulsion power and displacement, we can write:

$$A = \frac{\nabla^{\frac{2}{3}} * V^3}{P} = \frac{\nabla_d^{\frac{2}{3}} * V_d^3}{P_d}$$

Where *d* denotes design characteristics. The power needed to generate a certain speed can be given by

$$P = \frac{\nabla^{\frac{2}{3}} * V^3 * P_d}{\nabla_d^{\frac{2}{3}} * V_d^3} = \left(\frac{V}{V_d}\right)^3 \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}} P_d$$

We see that the displacement scale the relationship between power and speed. If we further assume that relationship between propulsion power and fuel consumption is proportional for any given speed, we can in the next step say that fuel consumption is scaled by displacement in an equivalent way. Daily fuel consumption can thus be written as a function of constant displacement and speed

$$F = \left(\frac{V}{V_d}\right)^3 \left(\frac{\nabla}{\nabla_d}\right)^{\frac{2}{3}} F_d$$

In accordance with MAN Diesel & Turbo (2013) the draught ratio might be given instead of the displacement ratio as an approximation[70]. The speed-consumption relationship is scaled to the power of three in MAN, but since this is vessel specific and not certain we do not account for this in our formula. Thus

$$F = \left(\frac{V}{V_d}\right)^{\varepsilon} \left(\frac{\mathrm{D}}{\mathrm{D}_d}\right)^{\frac{2}{3}} F_d$$

---

[70] To be exact it should be scaled by the block coefficient relative to the design block coefficient

8.2 Appendix B - Detailed Data Cleaning

The laden, ballast and unknown files consisted of respectively 173,552, 130,215 and 6,151 average daily speed observations, totaling 305,106.

1) Allocation of Unknown to Ballast and Laden

Allowed us to ad 1,890 and 2,922 data points to the Ballast and Laden data sets, respectively, but reducing the total amount of data points to 303,767.

2) Removal of extraordinary low average speeds at the start and the end of voyages

Using the same matrix with vessels and dates in the axis's as basis, the following IF statement was run for each vessel, for each day, in order to remove the unwanted start values:

- IF the previous two data points are blank
- AND the data point is 30% lower than the average daily speed of the next 10 days
- Then the data point should be removed from the data set.

The same method was used for removing end-values. By following this procedure, 2,740 data points were removed from the data set with an average speed of 7.6 knots[71].

3) Removal of lone values

1,213 datapoint were removed using a IF statement:

- IF no other values registered the next 7 days or previous 7 days for the vessel

4) Removal of double counts

On the 18th of September 2014 and 26th of October 2014, 356 and 344 vessels, respectively, were registered with double, triple or quadruple counts, with 223 vessels encountering double counting both dates.

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[71] **Laden Start/End delete**: 1332 datapoints, average 7.3 knots
Ballast Start/End delete: 1408 datapoints, average 7.8 knots

By keeping only the first data point registered for a given vessel at a given day, 1201 data points were removed.

5) Removal of vessels only registered with either laden or ballast

In total, 449 data points were removed as a result of removing vessels with only ballast or laden data.

6) Defining new laden and ballast data points based on draught ratio

For the few vessels where the maximum draught was set to zero or had unrealistic values, maximum draught was collected from Clarksons. The reviewed definitions of ballast and laden excludes 11,684 data points in total.

7) Removal of data points with lower average speed than minimum speed

In the final dataset, after all cleaning steps are performed, there are still 5909 data points observed with speeds between 7 and 8 knots. This supports our theory that shipowners allow vessels to steam at speeds as low as 7 knots, and not that the observations are caused by other factors.

8.3 Appendix C – Estimation of missing design speed

A comparison between vessels with the same engine has been conducted based primarily on engine power (kW), RPM and DWT. Secondarily we have looked at age of the vessel and other determinants of size, such as displacement. To determine the missing values of design speed, we have employed the subsequent rules, in the listed order:

1. If a vessel exactly match another vessels characteristics, employ the same design speed
2. For each engine type we calculate an average design speed. If this average is based on more than 5 vessels (values) and the standard deviation in design speed is less than 0.5 knots, we employ this average to vessels with missing design speed for that engine type
3. If none of the above are feasible, we manually insert design speed based on the specified characteristics after best estimation

Eight outliers with speed of 12.5 and 21.5 have been set to the adjusted average speed[72] for that engine type, as they had very similar characteristics as the other vessels with the same engines. Lastly, the seven ECO-vessels with missing values have been assigned speeds based on speed-consumption curves supplied by DNB Markets for the relevant engines. A total of 97 values were added or adjusted, of which 37 were hard typed based on qualitative assessment.

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[72] The adjusted average is the average per engine type excluding the outliers

8.4 Appendix D – Detailed Calculation of Fuel Consumption at Design Speed

The design speed of a vessel is assumed to capture the effects of variability in hull resistance and engine power among vessels when the engine is running at Maximum Continuous Rating (MCR). Hence, when design speed is reported, the fuel consumption at design speed should only be dependent on the total power output at MCR (effective break power).

MCR, commonly set to 85% of the SMCR, and the corresponding power generation at this rate form the engine's effective brake power at which the design speed is calculated from. In *Table 15* RPM, kW, Brake Specific Fuel Consumption (BSFC)[73] and fuel consumption in tonnes per day are presented for different levels of engine speed for three Wartsila engines at standard SMCR tuning.[74]

Wartsila Engine Model	Cylinders	kW @ SMCR	RPM @ SMCR		Power (%CMCR) at Design conditions						
					70%	75%	80%	MCR	90%	SMCR	110%
Flex82C	7	31640	102	**RPM**	90.6	92.7	94.7	96.6	98.5	102	105.3
				kW	22 148	23 730	25 312	26 894	28 476	31 640	34 804
				BSFC	168.7	168.9	169.4	170.4	171.3	174	175
				tpd	**89.7**	**96.2**	**102.9**	**110.0**	**117.1**	**132.1**	**146.2**
Flex82T-A	7	31640	80	**RPM**	71.0	72.7	74.3	75.8	77.2	80.0	82.6
				kW	22 148	23 730	25 312	26 894	28 476	31 640	34 804
				BSFC	163.7	163.9	164.4	165.4	166.3	169.0	170.0
				tpd	**87.0**	**93.3**	**99.9**	**106.8**	**113.7**	**128.3**	**142.0**
Flex84T	7	29400	76	**RPM**	67.5	69.1	70.6	72.0	73.4	76.0	78.5
				kW	20 580	22 050	23 520	24 990	26 460	29 400	32 340
				BSFC	168.7	168.9	169.4	170.4	171.3	174.0	175.0
				tpd	**83.3**	**89.4**	**95.6**	**102.2**	**108.8**	**122.8**	**135.8**

Table 15: Engine power output, fuel efficiency and fuel consumption for three main Wartsila engines at standard SMCR tuning for different engine speeds (in % of SMCR and RPM)
Source: Wartsila (2015)

These three engines are used as basis when calculating fuel consumption at design speed for all vessels except for ECO-vessels. Engines are coupled with one of the three engines based on reported SMCR and TGP. Hence, we assume that there are no technological differences among the various engine manufacturers.

Engines can be tuned in terms of SMCR, so that the BSFC curve matches the operational strategy of the owner or operator (*Figure 10*)[75]. In that relation, two otherwise identical engines have different fuel consumption at design speed dependent on the RPM tuning.

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[73] Brake specific fuel consumption (BSFC) is a measure of fuel efficiency and is defined as g/kWh)

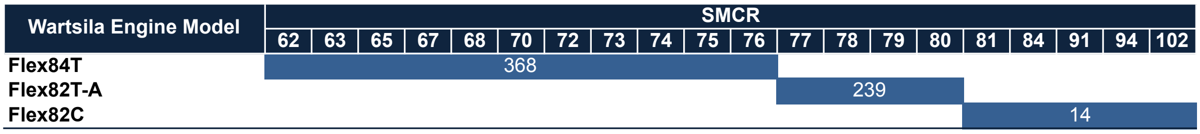
[74] All data collected from Wartsila engine program, except for tpd, which is own calculations, based BSFC and kW.

[75] An engine can be tuned to be most fuel effective at high or low speeds. In general, a higher SMCR makes the engine relatively more fuel effective working at higher RPMs.

Wartsila Engine Model	SMCR Range
Flex84T	61-76
Flex82T-A	68-80
Flex82C	87-102

Figure 10: SMCR tuning possibilities for three main Wartsila engines
Source: Wartsila (2015)

The chosen engine allocation is presented in *Figure 11*. All engines reported with SMCR between 62-76 (except for ECO-vessels) are assumed to have the engine characterization of a Wartsila Flex84-T engine. RPM at SMCR in the range 77 to 80 correspond to a Flex82T-A, while all engines above 80 are allocated to the Flex82C engine performance chart.



Wartsila Engine Model	SMCR																			
	62	63	65	67	68	70	72	73	74	75	76	77	78	79	80	81	84	91	94	102
Flex84T	368																			
Flex82T-A												239								
Flex82C																14				

Figure 11: Allocation of VLCC engines to the three Wartsila engine characterizations based on Clarkson specified SMCR for each vessel
Source: Wartsila (2015)

An engine's power output, for a given SMCR, can be viewed as a linear function of engine size (number of cylinders) (Wärstilä)[76]. Therefore we can normalize the engine data to correspond to 1kW and then multiply the tpd data at 85% (MCR) with the reported kW of all vessels with reported SMCR of a given RPM. The normalized multipliers for fuel consumption at design speed (85% of SMCR) in tpd for each engine, and for different RPM tunings, are presented in *Table 16*. As we see from the multiplication factors they are very similar when looking at a 1kW level, implying that the total kW output of an engine is the main driver of fuel consumption[77].

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[76] For a Wartsila flex84-T engine with 76 RPM at SMCR, each cylinder is equivalent to a power output of 4200 kW at SMCR (29400kW/7 cylinders)

[77] The multiplication factors are computed using data for different SMRC tuning possibilities from Wartsilas online tuning program. We acknowledge that in practice there might be differences between the engines, but the low (and none) observed differences in tpd per 1kw suggests that wartsila do not emphasize the engine variations to a large extent.

Reported SMCR	Wartsila Engine Model	TPD @ 1kW @ MCR
>80	Flex82C	0.003476
80	Flex82T-A	0.003374
79	Flex82T-A	0.003384
78	Flex82T-A	0.003395
77	Flex82T-A	0.003405
<77	Flex84T	0.003476

Table 16: Fuel consumption in tonnes per day (tpd) equivalent to 1kW engine output for MCR (85% of SMCR) for three main Wartsila engines
Source: Own calculations based on Wartsila (2015)

A vessel with reported SMCR of 77 and Total Power of 29,000kW is computed to have fuel consumption at design speed of 101 tpd (29,000*0.00347616), while a vessel employing an engine with the same reported SMCR, but with a total power output of only 25,000kW (implying fever cylinders), only will have tpd of 87 at design speed (25,000*0.00347616). As we see, the engine characteristics of Flex82c and Flex84T are the same when looking at tpd per 1kW of power output. In practice, however, differences in fuel consumption at design speed are seen through the fact that Flex82C usually generate higher kW (as seen *Table 15*).

8.5 Appendix E – Definition of Japanese Waters

To approximate when a vessel was entering Japanese waters we had to utilize the daily longitude/latitude data provided in the panel data set. When defining an area using long/lat it needs to be square. Therefore, the following squares is defined to capture all vessels that steam in Japanese waters:

						Latitude		Longitude	
Country	**Region**	**LAT BASE**	**LON BASE**	**+/- LAT**	**+/- LON**	**Max**	**Min**	**Max**	**Min**
Japan	1	32	130.5	2	3	34.00	30.00	133.50	127.50
Japan	2	34	136	2	6	36.00	32.00	142.00	130.00
Japan	3	38	139	4	4	42.00	34.00	143.00	135.00
Japan	4	43	143	3	4	46.00	40.00	147.00	139.00

Table 17: Longitude and latitude definitions of Japanese waters
Source: Own estimations based on Globalenergyobservatory.org

To generate the Japan data, we used an IF statement. IF a vessel was located within one of the above-mentioned squares on a particular day, Japan was returned. If not, “blank” was returned.

8.6 Appendix F – Definition of Regions

We allocate data points to various regions using predefined latitude/longitude squares. To generate the region data, we used an IF statement. IF a vessel was located within one of the longitude/latitude squares defined in *Table 18* on a particular day, a region was returned (starting with Persian Gulf, ending with South Pacific Ocean). If not, “blank” was returned.

					Latitude		Longitude	
Region	**LAT BASE**	**LON BASE**	**+/- LAT**	**+/- LON**	**Max**	**Min**	**Max**	**Min**
Persian Gulf	26	57	9	10	35.00	17.00	67.00	47.00
South Asia	17	79	15	13	32.00	2.00	92.00	66.00
Southeast Asia	5	124	16	31	21.00	-11.00	155.00	93.00
East Asia	42	125	21	30	63.00	21.00	155.00	95.00
Red Sea	20	40	10	15	30.00	10.00	55.00	25.00
East Coast Africa	-8	42	18	15	10.00	-26.00	57.00	27.00
South Coast Africa	-38	27	10	20	-28.00	-48.00	47.00	7.00
West Coast Africa	1	-3	31	20	32.00	-30.00	17.00	-23.00
Australasia	-30	140	20	40	-10.00	-50.00	180.00	100.00
Mediterrean	38	12	8	25	46.00	30.00	37.00	-13.00
North Sea	60	-10	10	25	70.00	50.00	15.00	-35.00
Caribbean	18	-76	4	13	22.00	14.00	-63.00	-89.00
Caribbean	13	-71	2	13	15.00	11.00	-58.00	-84.00
West Coast Middle America	20	-111	12	13	32.00	8.00	-98.00	-124.00
West Coast Middle America	12	-99	5	10	17.00	7.00	-89.00	-109.00
West Coast Middle America	9	-94	5	10	14.00	4.00	-84.00	-104.00
West Coast Middle America	7	-88	2	10	9.00	5.00	-78.00	-98.00
Gulf Of Mexico	28	-91	10	9	38.00	18.00	-82.00	-100.00
U.S Atlantic Coast	39	-75	8	10	47.00	31.00	-65.00	-85.00
U.S West Coast	38.5	-125	10	12	48.50	28.50	-113.00	-137.00
East Coast Canada	57	-70	10	25	67.00	47.00	-45.00	-95.00
West Coast Canada	59	-130	10	20	69.00	49.00	-110.00	-150.00
East Coast South America	-25	-48	35	20	10.00	-60.00	-28.00	-68.00
West Coast South America	-30	-90	35	20	5.00	-65.00	-70.00	-110.00
South Atlantic Sea	-30	-10	30	40	0.00	-60.00	30.00	-50.00
North Atlantic Sea	30	-40	30	44	60.00	0.00	4.00	-84.00
Indian Ocean	-15	84	40	65	25.00	-55.00	149.00	19.00
North Pacific Ocean	30	150	30	30	60.00	0.00	180.00	120.00
North Pacific Ocean	30	-139	30	41	60.00	0.00	-98.00	-180.00
South Pacific Ocean	-30	-150	30	80	0.00	-60.00	-70.00	-230.00

Table 18: Regions defined by latitude/longitude squares

8.7 Appendix G – Descriptive Statistics, Comprehensive

		Laden Leg					Ballast Leg				
		Average	Std. Dev.	Min	Max	No.obs	Average	Std. Dev.	Min	Max	No.obs
Independent Variable											
Speed	*overall*	12.08	1.41	7.00	17.29	33 147	11.83	1.95	7.00	17.80	28 713
	between		0.78	8.76	14.25	607		1.35	8.98	15.18	607
	within		1.19	6.02	16.84			1.42	5.75	18.71	
Macro Variables											
TCE	*overall*						22 350	23 422	-7 108	90 140	28 713
	between							5 119	1 991	48 365	607
	within							23 042	-19 091	96 252	
FFA+1M	*overall*	12.63	2.16	9.63	17.68	33 147	12.57	2.16	9.63	17.68	28 713
	between		0.53	10.17	15.22	607		0.51	10.24	14.53	607
	within		2.13	8.27	18.39			2.12	8.71	18.51	
Freight	*overall*	13.02	3.28	9.07	21.10	33 147	12.96	3.28	9.07	21.10	28 713
	between		0.69	9.95	16.74	607		0.69	10.28	16.62	607
	within		3.25	5.50	22.17			3.23	7.22	22.17	
Bunkers*	*overall*	569.36	93.11	282.50	663.00	33 147	586.06	71.45	282.50	663.00	28 713
	between		23.62	404.15	637.25	607		15.82	477.23	624.90	607
	within		91.49	248.75	790.21			70.24	267.87	713.91	
FreightBunkers*	*overall*	0.025	0.013	0.014	0.071	33 147	0.023	0.010	0.014	0.060	28 713
	between		0.003	0.016	0.048	607		0.002	0.017	0.037	607
	within		0.013	-0.009	0.074			0.010	0.007	0.063	
FFA1M/Bunkers	*overall*	0.024	0.010	0.015	0.061	33 147					
	between		0.002	0.016	0.041	607					
	within		0.010	-0.001	0.063						
Vessel Specific Variables											
DraughtRatio	*overall*	0.93	0.04	0.80	1.00	33 147	0.51	0.03	0.25	0.64	28 713
	between		0.03	0.87	0.99	607		0.02	0.45	0.60	607
	within		0.03	0.75	1.04			0.03	0.25	0.67	
CargoConstant	*overall*	291 869	9 671	246 999	420 347	33 147					
	between		11 054	246 999	420 347	607					
	within		0	291 869	291 869						
CargoFloating	*overall*	287 125	12 911	206 817	391 423	33 147					
	between		9 810	247 581	391 047	607					
	within		9 382	234 962	319 420						
dSpeed	*overall*	15.77	0.52	13.50	17.40	33 147	15.74	0.50	13.50	17.40	28 713
	between		0.51	13.50	17.40	607		0.51	13.50	17.40	607
	within		0	15.77	15.77			0	15.74	15.74	
FuelCons	*overall*	100.40	11.46	56.02	130.35	33 147	99.77	11.21	56.02	130.35	28 713
	between		11.51	56.02	130.35	607		11.52	56.02	130.35	607
	within		0	100.40	100.40			0	99.77	99.77	
Consumption/dSpeed	*overall*	6.37	0.70	3.59	8.23	33 147	6.34	0.68	3.59	8.23	28 713
	between		0.70	3.59	8.23	607		0.70	3.59	8.23	607
	within		0	6.37	6.37			0	6.34	6.34	
BlockCoefficient	*overall*	0.84	0.02	0.78	0.93	32 902	0.84	0.02	0.78	0.98	28 448
	between		0.02	0.78	0.93	600		0.02	0.78	0.98	600
	within		0	0.87	0.87			0	0.87	0.87	
Length/Beam	*overall*	5.58	0.11	4.76	6.09	32 962	5.58	0.11	4.76	6.09	28 505
	between		0.11	4.76	6.09	601		0.11	4.76	6.09	601
	within		0	5.58	5.58			0	5.58	5.58	
Beam/Draught	*overall*	2.73	0.13	2.49	3.68	32 962	2.74	0.13	2.49	3.68	28 505
	between		0.13	2.49	3.68	601		0.13	2.49	3.68	601
	within		0	2.81	2.81			0	2.83	2.83	
Built2000_D	*overall*	14.4%				33 147	17.0%				28 713
	between					607					607
	within										
EVDI	*overall*	2.48	0.15	1.99	2.95	33 147	2.47	0.15	1.99	2.95	28 713
	between		0.16	1.99	2.95	607		0.16	1.99	2.95	607
	within		0	2.48	2.48			0	2.47	2.47	
Drydock_D	*overall*	50.2%				13 397	51.9%				11 589
	between					579					582
	within										
ECO_D	*overall*	0.6%				33 147	0.6%				28 713
	between					607					607
	within										
Operational Specific Variables											
Japan_D	*overall*	10.6%				33 147	10.3%				28 713
	between					607					607
	within										
LogChain_D	*overall*	8.7%				33 147	9.7%				28 713
	between					607					607
	within										
LpOw_D	*overall*	44.0%				33 147	38.7%				28 713
	between					607					607
	within										
Other Variables											
Contango_D	*overall*	4.6%				33 147					
	between					607					
	within										
Cyclone_D	*overall*	1.8%				33 147	2.3%				28 713
	between					607					607
	within										

** For the laden leg we use spot bunkers, and for the ballast leg we use 6-week lagging bunkers*

Table 19: Descriptive statistics

8.8 Appendix H – Robustness Check Empirical Analysis

Laden Leg Robustness Check				
Variable	**Include weeks with…**			
	All	**>1 daily obs.**	**>2 daily obs.**	**>3 daily obs.**
lFreight	0.0033	0.0011	-0.0009	-0.0025
	(0.414)	(0.782)	(0.830)	(0.527)
lBunkers	0.0061	0.0090	0.0102	0.0129
	(0.248)	(0.084)	(0.056)	(0.013)
lCargoFloating	0.0767	0.0624	0.0283	0.0124
	(0.005)	(0.024)	(0.315)	(0.654)
ldSpeed	0.1360	0.1263	0.1074	0.1094
	(0.032)	(0.042)	(0.090)	(0.079)
EVDI	0.0538	0.0552	0.0532	0.0584
	(0.000)	(0.000)	(0.000)	(0.000)
Japan_D	0.1017	0.0982	0.0959	0.0928
	(0.000)	(0.000)	(0.000)	(0.000)
LogChain_D	0.0461	0.0451	0.0454	0.0427
	(0.000)	(0.000)	(0.000)	(0.000)
LpOw_D	0.0215	0.0204	0.0206	0.0213
	(0.000)	(0.000)	(0.000)	(0.000)
Cyclone_D	0.0108	0.0076	0.0052	0.0069
	(0.010)	(0.074)	(0.226)	(0.113)
Constant	0.9379	1.1329	1.6197	1.7911
	(0.012)	(0.003)	(0.000)	(0.000)
R^2 Overall	**0.1003**	**0.1033**	**0.1051**	**0.1060**
R^2 Within	*0.0008*	*0.0008*	*0.0007*	*0.0013*
R^2 Between	*0.3228*	*0.3115*	*0.3028*	*0.3015*
Hausman test (p-value)	**0.0671**	**0.0694**	**0.2816**	**0.2005**
No of observations	33 147	29 595	25 897	22 533

Table 20: Robustness check, laden

Ballast Leg Robustness Check				
Variable	**Include weeks with…**			
	All	**>1 daily obs.**	**>2 daily obs.**	**>3 daily obs.**
lFreight	0.0458	0.0457	0.0490	0.0547
	(0.000)	(0.000)	(0.000)	(0.000)
l6wBunkers	-0.0491	-0.0511	-0.0515	-0.0501
	(0.000)	(0.000)	(0.000)	(0.000)
EVDI	0.0492	0.0566	0.0599	0.0602
	(0.047)	(0.024)	(0.021)	(0.027)
Japan_D	0.1895	0.1932	0.1962	0.2012
	(0.000)	(0.000)	(0.000)	(0.000)
LogChain_D	0.1254	0.1261	0.1277	0.1310
	(0.000)	(0.000)	(0.000)	(0.000)
LpOw_D	0.0304	0.0308	0.0307	0.0316
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	2.4850	2.4828	2.4715	2.4491
	(0.000)	(0.000)	(0.000)	(0.000)
R^2 Overall	**0.1730**	**0.1854**	**0.1953**	**0.2054**
R^2 Within	*0.0164*	*0.0182*	*0.0201*	*0.0234*
R^2 Between	*0.3609*	*0.3556*	*0.3433*	*0.3413*
Hausman test (p-value)	**0.2786**	**0.3822**	**0.4005**	**0.5744**
No of observations	28 713	24 930	20 810	17 202

Table 21: Robustness check, ballast

8.9 Appendix I – Financing Cost vs. Bunkers

In order to compare financing cost to bunkers cost we have to make assumptions on both sides of the equation. In *Table 22* we have estimated the total financing expenses and bunkers expenses for a vessels going from Ras Tanura to Chiba, a distance of 8005 nautical miles (Ports.com, 2015). The main takeaway from the two tables is that higher speed means fewer days on water thus lower financing cost, but higher bunkers cost. For illustration purposes we have used a financing rate of 7% for chartering a 305,000 dwt VLCC at 95% utilization. Fuel consumption is based on the fuel consumption curves of Devanney (2011). The average EVDI of the total vessel fleet was used when choosing the fuel curve.

Financing cost		Crude Price ($/Barrel)						
		50	**60**	**70**	**80**	**90**	**100**	**110**
Speed (knots)	**12**	$547 291	$656 750	$766 208	$875 666	$985 125	$1 094 583	$1 204 041
	13	$505 192	$606 230	$707 269	$808 307	$909 346	$1 010 384	$1 111 423
	14	$469 107	$562 928	$656 750	$750 571	$844 392	$938 214	$1 032 035
	15	$437 833	$525 400	$612 966	$700 533	$788 100	$875 666	$963 233
	16	$410 469	$492 562	$574 656	$656 750	$738 843	$820 937	$903 031

Bunkers cost		Crude Price ($/Barrel)						
		50	**60**	**70**	**80**	**90**	**100**	**110**
Speed (knots)	**12**	$454 422	$545 306	$636 191	$727 075	$817 960	$908 844	$999 728
	13	$528 565	$634 278	$739 991	$845 705	$951 418	$1 057 131	$1 162 844
	14	$604 343	$725 212	$846 081	$966 949	$1 087 818	$1 208 687	$1 329 555
	15	$696 509	$835 810	$975 112	$1 114 414	$1 253 716	$1 393 017	$1 532 319
	16	$805 427	$966 513	$1 127 598	$1 288 684	$1 449 769	$1 610 855	$1 771 940

Table 22: Illustrational example - Financing cost versus bunkers cost

8.10 Appendix J – Draught Ratio vs. Freight Bunkers

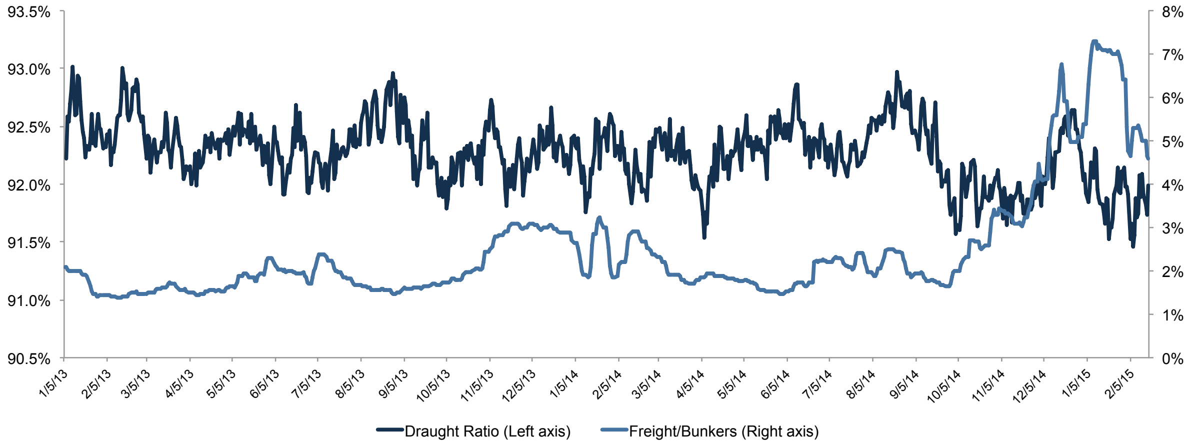

Figure 12: Draught ratio and freight/bunkers
Source: Clarkson's (2015), Genscape Vesseltracker and Marinetraffic (2015)

The draught ratio is calculated as a daily average of all vessels for the laden leg, using data points where draught ratio is above 80%.