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Bulk without boundaries

An empirical study of bulk vessel speeds absent of contractual constraints

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We hope this thesis will be interesting for its readers and that it can serve as basis for further research in the field of speed optimization. In addition we hope it can prove relevant for market participants and policy makers in the shipping industry.

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Abstract

Classical maritime theory suggests that vessel operators optimize speed based on prevailing market conditions. However, numerous academic contributions have failed to provide supportive empirical evidence of real life speed optimization and many believe that contractual limitations constitutes the hurdle for the theory being practiced.

In this thesis we empirically test the effect of contractual constraints on speed optimization. More specifically, we test whether speed choice and the extent of observable speed optimization differentiates before and after a vessel has entered into a contract. In addition, we test whether an estimate for revenue expectations is a better predictor for speed than current spot market rates. Using geospatial (AIS) data for ballasting Capesize vessels and corresponding freight market indices, we find that vessels increase speed after entering into a contract. This implies that the contract structure might affect speed decisions. When testing the effect from exogenous market conditions, such as freight rate levels and fuel prices, we get ambiguous results. Surprisingly, we cannot detect any trustworthy indicators for vessel speed optimization whilst vessels are free of contractual constraints. On the contrary, we find that operators are more responsive to shifts in market conditions after having entered into a contract. These effects are however only marginal compared to what is suggested by theory. Overall we conclude that it is questionable whether or not speed optimization theory is adequate to describe speed optimization in practice. As we can not find evidence that the contracting state constitutes a significant hurdle for speed optimization, we believe earlier literature tend to overemphasize the importance of contractual barriers.

Keywords – Speed optimization, Energy efficiency, Forward Freight Agreements, Dry bulk shipping

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1 Introduction

Speed optimization has long been a hot topic within maritime economic literature, primarily due to its vast implication for fuel costs, the dominant cost driver. During times of poor freight rates, reductions in speed in order to cut cost, often referred to as slow steaming, have been named as a potential remedy for lost revenuesb (Maloni et al., 2013). In later years, the increasing awareness of climate change and the acute need for emission cuts has further drawn attention towards fuel efficiency. At a global level, the shipping industry is responsible for about 2.5% of all greenhouse gas emissions, which under a business-as-usual scenario could increase by 50-250% in 2050 (IMO, 2014). In 2011 The Marine Environment Protection Committee (MEPC) of the UN International Maritime Organization (IMO) adopted measures for a mandatory greenhouse gas reduction regime for international shipping, thus introducing the first ever emission cut regime for an international industry sector (Hussein et al, 2015). Some of these measures have however been criticized for being ineffective (Devanney, 2010b).

The potential benefits from speed optimization are large due to the non-linear relationship between speed and fuel consumption, which in short terms implies that a unit change in speed will affect fuel consumption by one unit cubed (Manning, 1956). Under a voyage charter, the dominating contractual structure in the different shipping markets, the vessel operator is paid a fixed amount to transport a cargo from a load port to a discharge port. The operator remains in commercial control of the vessel, and accounts for all costs associated with the voyage. Developing the profit function for a vessel operator, this relationship implies that optimal speed is given by the point where marginal fuel cost savings equates the marginal cost of lost revenues due to fewer tonne-miles[1] (Ronen, 1982). This is given the assumption that freight markets are perfectly competitive, meaning that ship owners are categorized as price takers, both for freight rates and fuel (Ronen, 1982) (Strandenes, 1981). Furthermore, as profits depends on the sum of revenues and costs, it is not the freight rate or fuel price alone that sets the optimal speed, but the ratio between them[2] (Beenstock &Vergottis, 1989)(Assman et al., 2015)(Adland & Jia, 2016).

[1]Tonne-mile is a productivity measure in the shipping industry which denotes the amount of cargo multiplied by the distance moved

[2]In the following referred to as "market conditions"

Although the importance of speed optimization has been broadly recognized in academia, the lack of data has made it troublesome to verify. In the wake of the introduction of Automated Information System (AIS), access to micro-level ship data and empirical testing has been made possible, leading to numerous contributions within the field of speed optimization. Some of these are challenging the accuracy of classical maritime economic theory as it is ambiguous whether or not operators adjust vessel speeds to market conditions (Adland & Jia, 2018b).

A suggested reason for the discrepancy between theory and empirical findings is that contractual constraints are prevailing, prior or subsequent to the loading of cargo (Adland & Jia, 2018a). Before the cargo is loaded, it has been shown that standard voyage charters create unwanted economic incentives for the parties, inducing vessel operators to speed up immediately upon having entered into a contract (Lindholm, 2014). Such incentives surge from specific contractual clauses concerning concepts like laycan, lay-time and demurrage. The term laycan refers to a certain period of time in which the vessel must present itself to the charterer for the contract to be valid. When the vessel arrives the operator tenders notice of readiness (NOR) to the charterer, informing that the vessel has arrived at port and is ready to load. The vessel may choose when to arrive within the laycan, but if arriving after, the charterer has the option to cancel the charter. After NOR is accepted by the charterer, the lay-time starts running, which is the time allowed for cargo handling operations set out in the contract. The charterer is not obligated to start loading the vessel immediately; however, he/she must pay demurrage (a fee pre-agreed upon in the contract) for each day the vessel is at port excessive of the lay-time. In particular, contractual clauses on demurrage has potential to alter the profit function of a vessel operator, ultimately making it rational to steam at higher speeds than what is suggested as optimal by classical theory (Adland Jia, 2018a).

Furthermore, after the cargo is loaded, the standard obligation of “due dispatch” becomes prevalent. This is a contractual clause included in most charter parties, demanding the vessel to sail at “utmost speed” (Jia et al., 2017). Thus, a due dispatch clause implies that an operator that optimizes speed with respect to market conditions when the vessel is laden, could be in breach with the terms of the charter party, essentially making it undesirable (Lindholm, 2014).

The loading condition's effect on speed optimization has been investigated, showing that market conditions have a marginal influence only when vessels are ballasting. Hence, this suggests that the clause of due dispatch is hampering speed optimization (Adland Jia, 2016). Behavior of early arrival, both to load port and discharge port, is broadly acknowledged as inefficient, leading to higher fuel consumption, and excessive emission of pollutants(Johnson & Styhre, 2014). Consequently, new contractual clauses such as Virtual Arrival (VA) have emerged to address this, by granting economic incentives to both operator and charterer for slow steaming, whenever known delays occur (BIMCO, 2013) (OCIMF, 2011). Such policies are however yet to be widely implemented, as asymmetric information, principal-agent problems and other market failures still are dominating (Rehmatulla Smith, 2015).

In this paper we do not further examine in depth where contractual constraints derive from, instead we analyze its aggregate effect on speed optimization during the ballast leg of the voyage. As former academic contributions argue against the existence of speed optimization; entirely when laden, and vaguely when ballasting, we do not expect to find evidence of speed optimization subsequently to a fixture. However, if contractual constraints truly are a barrier to speed optimization, we expect to find a substantial change in behavior during the transition between the period prior- and subsequent to a contracting decision, with speed optimization happening to a larger extent prior. Although there are studies on speed optimization addressing contractual constraints through the means of loading condition, there exists to the authors' knowledge no published studies on vessel behavior completely free of contractual constraints.

If the contracting decision has no effect on vessel speed optimization, this could contribute to the ongoing policy development aimed at reducing greenhouse gas emissions. Independent of result, it should serve as yet another contribution to the empirical testing of classical maritime economic theory, which thus far appears to overestimate the effect from market conditions on vessel speeds.

The remainder of this thesis is structured as follows. In section 2, we outline the fundamental literature covering the classical theory and empirical testing of vessel speed optimization. In section 3, we provide some descriptive statistics for vessel data, bunker fuel prices and freight indices. In section 4, we present the theoretical framework utilized in order to derive our econometric models. Then, we present how we have modeled our data in order to create reliable variables for empirical testing. A detailed approach is to be found in section 5. In section 6, we run our regression models and illustrate how vessel speed optimization is affected by contractual constraints and market conditions. Finally, we presents our concluding remarks in section 7.

2 Literature Review

Academic literature on speed optimization has been around since the transition from sail to mechanical propulsion engines, presenting captains with the possibility to determine speed. Manning (1956) was the first to study the relationship between speed and fuel consumption, establishing that these are linked through a cubic relationship. This relationship is expressed as $F = BV^{\epsilon}$, where B and ϵ are a vessel specific constant.

Freight markets, and in particular bulk shipping, are highly competitive. Hence, one should expect operators to adjust speeds in order to maximize profits and to be competitive (Strandenes, 1981). Using a vessel specific constant $\epsilon = 3$, Ronen (1982) show that optimal vessel speed in bulk shipping depends on the ratio between freight rate levels and the price of bunkers (term for marine fuel). He derives the profit function for vessels when laden (sailing with cargo), arguing that the optimal speed can be found by maximizing the daily profits (freight earnings) with respect to speed. Similarly, when ballast (sailing without cargo), the optimal speed can be found by minimizing daily losses with respect to speed, where daily losses are considered as the alternative cost associated with lost freight revenues implied by a lesser number of voyages and units shipped. For both legs this implies that the optimal speed is given by the point where marginal fuel cost savings equates the marginal cost of lost revenues. Demand is further assumed to be inelastic with respect to freight rates in the short run, hence freight rates are subject to exogenous pricing. The work of Ronen (1982), has to a large extent served as reference in the academic field of speed optimization and in general shipping literature (see for example Stopford (2009)).

Beenstock & Vergottis (1989) are the first to empirically test the relationship between the freight rates/fuel price ratio and speeds in the tanker market, finding that these positively correlate. However, as their analysis is done with aggregate (annual) data, freight rates and fuel prices correlate strongly, and they are not able to test for separate effects (i.e. what effect freight rates and fuel prices account for separately). In their study on dry bulk carriers trading on inland waterways, Jonkeren et al. (2012) find that vessels speed increase when freight rates increase, and decrease when fuel prices increase, however with more minuscule coefficients than what is expected *a priori*.

In an updated theoretical application, Devanney (2010) show that the shape of the supply curve is fluctuating with the cost of fuel, suggesting that market supply becomes less sensitive to freight rate changes when fuel prices are high and *vice versa*. He also states that vessels in the spot- and time charter market is facing the same optimization problem with relation to speed, as any time-chartered vessel may enter the spot market (ie. a charterer could re-let a time-chartered vessel). Hence, they should adapt to the same speeds. Speed should also be determined considering the round-trip voyage, and not the separate legs. Most importantly, the owner's freight rate expectations should be used when theoretically determining optimal speed, and not the rate at which the current voyage was fixed, as this revenue is secured given that the vessel meet laycan and other contractual provisions.

Seaborne freight accounts for the transportation of around 90% of all goods traded, and is one of the most efficient in terms of emissions per unit shipped (ICS, 2020) (OECD Observer, 2008). Nevertheless, the industry has a substantial carbon footprint, accounting for about 2,5% of all global GHG emitted on average between 2007 and 2014 (IMO, 2014). Hence, the shipping industry are considered essential in order to achieve the established long-term temperature goals in the Paris Agreement of 2015 (United Nations, 2015). In April 2018 the International Maritime Organisation (IMO) announced a target of cutting greenhouse gas emissions (GHG), by 50%, compared to 2008 levels, by 2050 (Parry et al., 2018). Among the suggested strategies are market-based mechanisms, more specifically a carbon tax or fuel levy, which has revitalized the debate around speed optimization and fuel efficiency. Adland et al. (2018) discuss the effects of hull cleaning on fuel consumption whilst Bouman et al. (2017) review numerous technologies for improving energy efficiency in shipping, including renewable energy sources, using fuel with lower carbon content and using emission reduction technologies. On the topic of speed optimization, Jia et al. (2017) estimates the potential reductions in fuel consumption and emissions from virtual arrival policy, under which reduction in average speed can be achieved at the cost of unproductive waiting time.

Along with the introduction of the Automatic Identification System (AIS) for vessel tracking came the ability to analyze micro-level data for vessel speeds. This has led to numerous contributions in the field of speed optimization. Assman et al. (2015)

analyses AIS-data for VLCCs[3] and find support for the theory developed by Ronen (1982), however with elasticities of smaller magnitude than expected. Adland & Jia (2016) uses weekly aggregated data for VLCCs, and finds that speeds are mainly effected by whether the operator also owns the cargo (i.e. oil companies that have contracted vessel on a time-charter basis). In the same study they do find that freight rates and fuel prices have a significant effect on speed, but to a minor extent and only when vessels are ballasting.

Adland & Jia (2018) later became the first to conduct a similar study for dry bulk carriers. Based on multiple regression analysis of approximately 18.000 voyages performed by Capesize vessels, they argue that ship owners do not adjust sailing speed based upon freight market conditions and fuel price. However, Adland & Jia acknowledges that there may be factors outside their models, such as bad weather conditions and contractual limitations, that affects the results. There are multiple studies which addresses such factors. For example, while Prpic-Orsic et al, (2014) address wind, sea, currents and other meteorological factors' effect on actual vessel speed. Adland & Jia (2018) demonstrates the economic effect of demurrage on vessel earnings and therefore optimal speed. Furthermore, Jia et al. (2017) show that there are large economic and environmental benefits to speed optimization, given that contracts assures aligned incentives for the operator and charterer.

In the above mentioned literature, the proxy for the contractual state of a vessel has been its loading condition, which does not account for that vessels can be under contract – also when ballast. To our knowledge, there are no empirical studies that test classical speed optimization theory in the ballast leg when also distinguishing between observations made before and after a contract is entered. As suggested by Devanney (2010), speed optimization theory should also be tested in light of freight rate expectations rather than current rates. The contributions in this master thesis are therefore threefold; (i) we seek to discover any behavioral change happening at the time vessels are being fixed, (ii) we seek to test classical maritime theory on vessels free from contractual limitations, and (iii) we seek to do so whilst accounting for the unique (time-dependent) market conditions each vessel is facing through the use of Forward Freight Agreements (FFA).

[3]Very Large Crude Carrier

3 Data

To address the effect from contractual constraints during the ballast leg, it becomes necessary to isolate the vessel behavior preceding and subsequent to the moment of fixture (MOF). MOF refers to the time at which the vessel operator and charterer agree to a voyage charter. Long deep-sea shipping routes are adequate for this analysis, as most short-sea charter parties are confirmed before discharging the previous contract, thus not leaving the operator any interval free of contractual constraints. The iron ore trade between Brazil and North East Asia is suitable for such analysis, as it is one of the longest routes frequented. Although a large portion of the trade is conducted on Valemax vessels sailing on long-running Contracts of Affreightment[4] (COA) for Brazilian miner company Vale, there is a considerable spot market for Capesize vessels. The major route for this segment is between Western Australia and China but occurring freight rate differentials (e.g. due to seasonality) can attract spot players to deviate towards Brazil. Here they may run cargo back to Asia, referred to as a front-haul (FH) voyage, or perform a trans-Atlantic contract, typically a voyage from South-America to one of the major ports in Europe. Capesize vessels are also recognized as homogeneous, most being between 170,000-180,000 deadweight tonnage (dwt), and almost exclusively carrying either iron ore or coal.

3.1 Data collection

The data is essentially reported spot fixtures in the Capesize segment which are matched with AIS-data. The contracts are extracted from Clarksons database of Capesize fixtures, a leading brokerage firm and provider of shipping intelligence services (Clarksons, 2020b). The AIS-data is provided by Centre of Shipping and Logistics at Norwegian School of Economics and originates from Vesseltracker.com. AIS is an automated tracking system used on ships and by Vessel Tracking Services (VTS), such as MarineTraffic. The information is exchanged electronically with shore-based receivers or other nearby vessels. The International Maritime Organization (IMO) requires, through their standards for health and safety, that all vessels with a gross tonnage of 300 or more has to be equipped with AIS. This also includes all passanger ships, which must be equipped with

[4] A Contract of Affreightment is an agreement to transport a defined amount of cargo within a fixed time-period at an agreed freight rate. (Clarksons, 2020a)

AIS regardless of size.

As the IMO number (a unique vessel identifier used globally) is not included in the fixture report from Clarksons, these are matched with the AIS-data based on vessel name with an additional requirement on size (dwt). In the case where a ship has performed more than one contract in the period, we separate these based on the charterer. As vessel name is only included in half of the reported fixtures for the time period, our sample gets substantially reduced. Some vessels could also have changed names between the fixture and the extraction of AIS-data, which makes it impossible to match the contract to the vessel as the AIS-data reports the currently held name only.

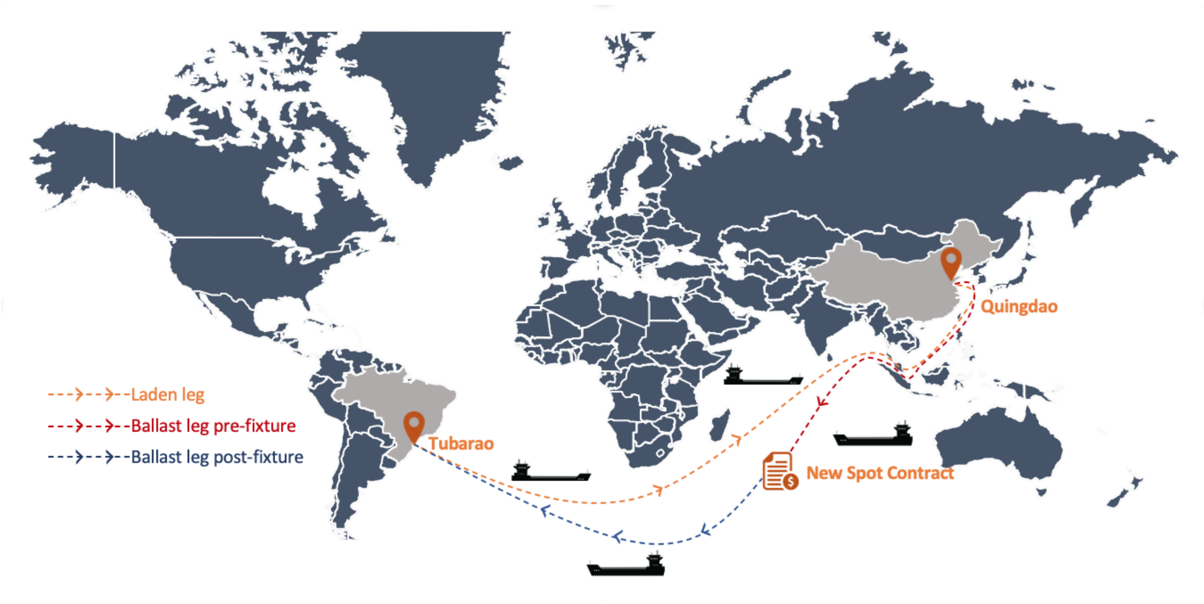
In order to determine whether or not the AIS-data can be combined with the fixture data, we need to verify the completion of the fixture. This is done by controlling that the vessel appears in the reported loading area, as specified in the contract, within the laycan window. To allow for broadly defined geographical loading areas (e.g. BRAZIL), and early- or late arrival relative to laycan, deviations are tolerated by $\pm$ 3 degrees of latitude/longitude, and ± 7 days, respectively.

All data series are categorized as follows: before fixture (pre-fixture), between fixture and arrival (post-fixture), and the laden leg (laden). Pre-fixture is 30 days prior to the reported day of fixture. The reported day of fixture is the first day of post-fixture. We note that this could be a source of error as the reporting day could be subsequent to the day of agreement between charterer and vessel operator. The transition from post-fixture to laden occurs when vessels have arrived at load port. A vessel is considered to have arrived when 1) it appears in loading area ($\pm$ 3 degrees of longitude/latitude), within laycan (± 7 days), and 2) speed is below 3 knots. These conditions are often met in anchorage awaiting loading. The laden category therefore includes transfer from anchorage to terminal, loading and finally the laden voyage (up to 30 days after last day of laycan). We note that in this thesis we do not analyze vessel behavior when laden. See figure 3.1 in the bottom of this section for a illustration of the division in the data series, using a typical voyage charter going east, from Tubarao in Brazil to Quingdao, China.

All distances are calculated using a simplified model of the world – assuming that it is a perfect sphere. Hence, the vessel speeds are calculated based on the distance traveled from point to point.Compared to more precise geodetic models, this method has neglectable differences and works well (Adland & Prochazka, 2019). Draught levels are reported in the AIS-data and included with no further adjustments. The current draught is divided by the specific design draught for each vessel. This ratio gives an approximation to hull displacement and an indication of whether the vessel is laden (around 1) or ballast (0.5-0.7) (Farbrot & Kalvik, 2019). Other ship specifications, such as vessel dimensions and design speed, come from Clarksons World Fleet Register (Clarksons, 2020c).

Before pre-processing, our sample data consist of 506 voyages performed by 323 unique Capesize vessels between 2015 and 2019. These are compiled in a panel data set.

Figure 3.1: Breakdown of the ballast leg

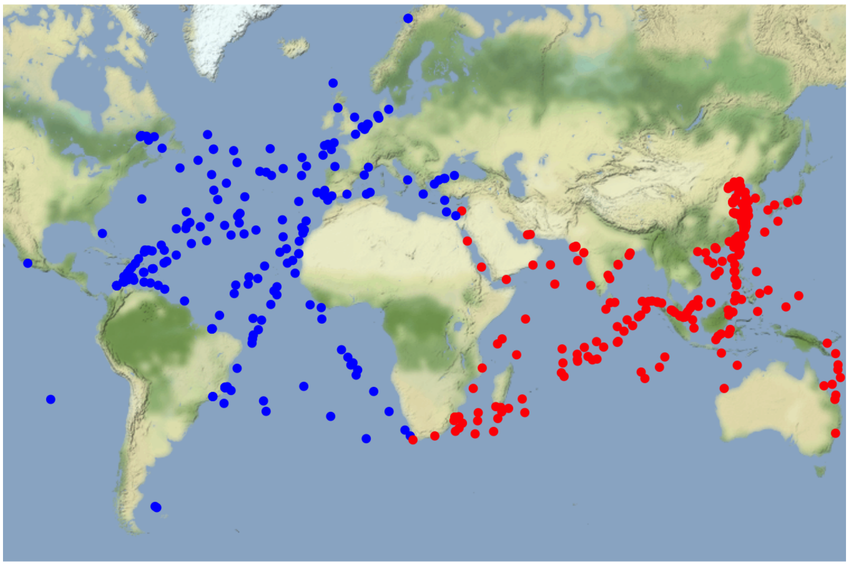


3.2 Data pre-processing

As the AIS-data is reported at different hours, multiple times a day, they are converted into daily average speeds for each vessel. Further, only days where the average speed is higher than 6 knots, and lower than 16 knots, are considered. Speeds lower than 6 knots typically represents port calls, while speeds higher than 16 knots are considered unrepresentative as this requires tail wind in addition to full steam and perfect sailing conditions (Adland & Jia, 2016). As observations of a vessel commence 30 days prior to the relevant fixture, we have to verify that vessels are not performing on additional contracts within this time frame. Therefore, we eliminate observations that at any given time reports a draught ratio >0.7 for the remainder of the voyage. Hence, if a given vessel in either pre-fixture or post-fixture loads a cargo, all observations until unloading of that cargo, are discarded. After this pre-processing step we are left with 472 voyages performed by 308 unique vessels.

As we seek to analyze vessel behavior prior to the loading of cargo, and in particular long-haul voyages absent of contractual constraints, we are interested in where vessels are coming from rather than where they are headed. As previously argued, we find that vessels sailing from North-East Asia to a large extent meet these conditions. We therefore use the reported longitude and latitude in the time series and include only voyages starting east of the Cape of Good Hope (South-Africa) or the Suez canal (ie. coming from the Indian Ocean or beyond). These are 237 voyages performed by 198 unique vessels, and will serve as basis for the remainder of this thesis. The majority of the observations excluded are trans-Atlantic fixtures. This was expected, as many of these vessels are performing several contracts of this type before returning to North-East Asia. As a control measure we note that 91% of the remaining voyages report a west-bound direction in the pre-fixture leg. The starting position for all voyages is presented in figure 3.2. Voyages marked as blue are eliminated.

Figure 3.2: Illustration showing starting position for each vessel.



3.3 Descriptive statistics

Vessel and voyage summary statistics are presented in table 3.1 and 3.2, respectively. Interestingly, we note that the average speed is higher for post-fixture, indicating that

Table 3.1: Summary vessel specifics

Statistic	Year built	DWT	Lenght	Beam	Design Draught	Design Speed
N	198	198	198	198	198	189
Mean	2,010.4	180,226.9	291.7	45.4	18.2	14.7
St. Dev.	4.0	8,557.2	2.8	1.3	0.2	0.8
Min	1,995	168,404	283	45	17.6	11.2
Pctl(25)	2,010	175,825.2	290.2	45	18.1	14.5
Pctl(75)	2,012	180,840.5	292	45	18.3	15.0
Max	2,017	209,243	300	50	18.5	17.9

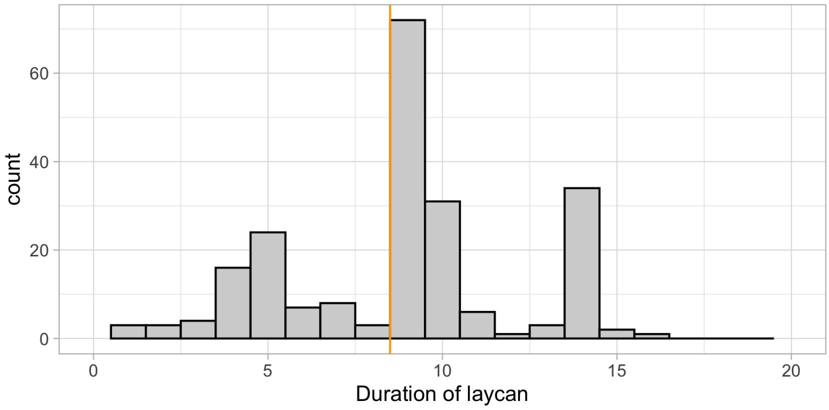
Table 3.2: Summary speed

Statistic	Overall	Pre-fixture	Post-fixture
N	8,257	3,816	4,441
Mean	11.26	10.97	11.51
St. Dev.	1.72	1.73	1.67
Min	6.00	6.00	6.01
Pctl(25)	10.11	9.85	10.39
Pctl(75)	12.52	12.25	12.71
Max	15.95	15.95	15.73

the contracting decision might have an effect on vessel speed. It is also curious that the average speeds differs substantially from the fleet average design speed. Further, we note that speeds overall have dropped over time, when compared to a sample of ballasting Capesizes from 2011 and 2012, where reported average ballasting speed were 11.58 knots (Adland & Jia, 2018). This is also in line with the reported Bulkcarrier Average Speed Index, which has dropped by around 6% between January 2012 (index start) and the timeframe for our sample data (2015-2018).

Adland & Jia (2018) show that the time of arrival relative to the laycan, might be indicative of an operator's risk aversion. More specifically its shown that in a low freight rate environment, it is optimal to arrive on the first day of laycan, following from the potential triggering of demurrage. In figure 3.2 we see the distribution of duration of laycan. Average duration is 8.5 days. We note that a few vessels have outlined very short laycans in their contracts.

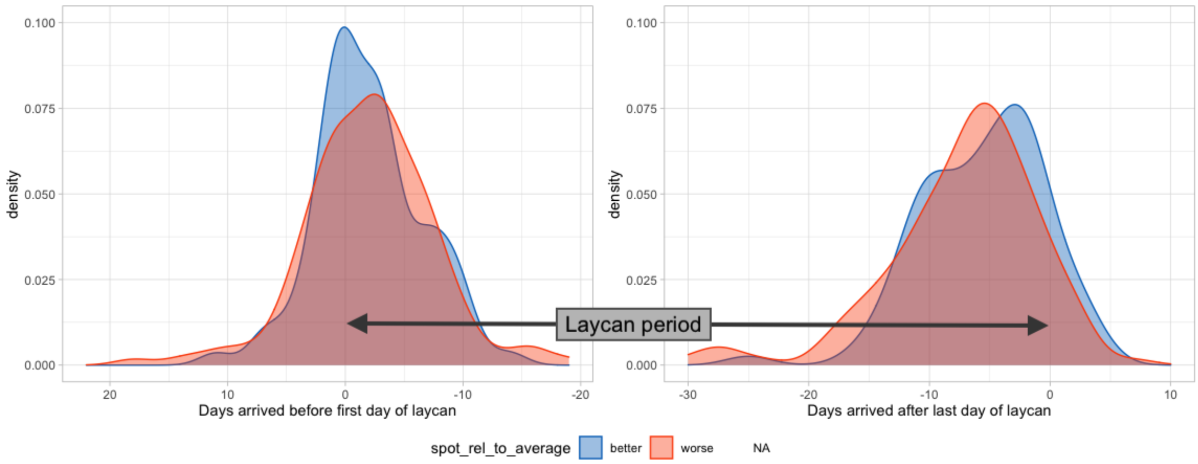
Figure 3.3: Distribution of laycan duration



In figure 3.3 it is illustrated the distribution of arrival day relative to the first and last day of laycan. For the purpose of controlling for market dependent behavior, the fixtures are grouped by freight rate level; "better" holds vessels that have outlined a \$/tonne freight rate above the average spot rate through the sample period, and "worse", those that achieved a lower rate.

In relatively worse freight markets vessel arrivals are slightly more spread, with no indication of vessels arriving earlier than in relatively better markets. Furthermore, we note that irrespective of freight rate level, a large proportion of our sample arrive before or at the first day of laycan. This could be due to that freight rates are, from a historical perspective, poor for the entire sampled period, independent of grouping (The Baltic Exchange). This could suggest that the contract structure indeed provide an unwanted incentive to arrive early, and that the laycan outlined in the contract is the objective function when optimizing speed in the post-fixture leg (Lindholm, 2014) (Adland & Jia, 2018). Lastly, it is important to note that laycan dates might have been re-negotiated after the reporting of fixture.

Figure 3.4: Real arrival day relative to laycan.
NB: note that horizontal axis in left diagram is inverted



Another characteristic of contracting behavior is that of vessel position in moment of fixture. Using spot fixture reports from the VLCC-tanker market and AIS-data, Prochazka et. al (2019) show that market conditions affect fixture location, with high freight rates inducing charterers to secure tonnage earlier, meaning a longer period prior to the arrival. In figure 3.3 we present a map indicating the geographical position of each vessel when contracted. Whereas in in figure 3.4 we present the distribution of days fixed prior to arrival, with the same grouping as above, to indicate the vessels' position in time when contracted.

Figure 3.5: Position of vessels the day of reported fixture

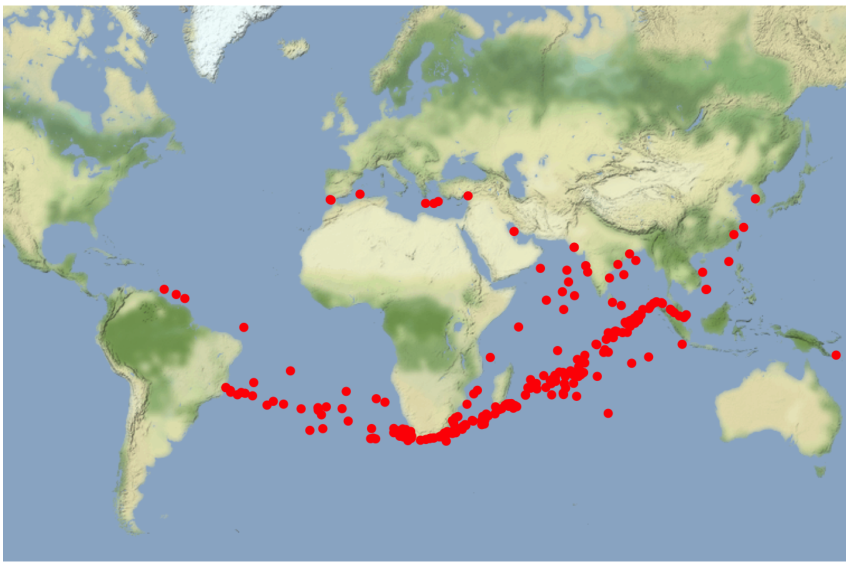
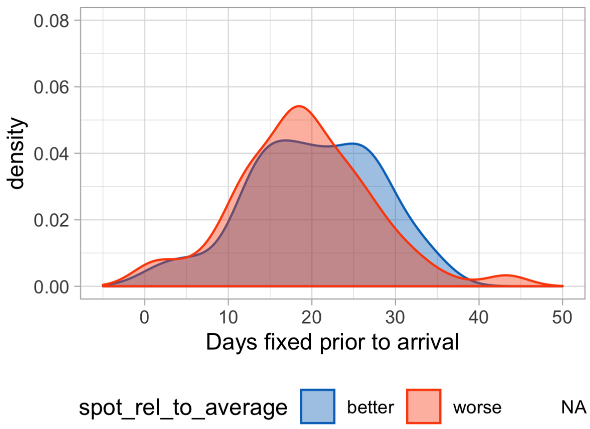


Figure 3.6: Number of days prior to real arrival that vessels are fixed



We observe some indications of vessels being fixed earlier in better markets, but the trend is too weak to conclude. We note that most vessels are fixed well ahead of arrival, and that the geographical position at which they are fixed indicate that most vessels are steaming west out of North East Asia. Lastly, we note that the sampled vessels have an average sailing time of 35 days (at required speed and without cargo). Average sailing time pre-fixture is 16 days, leaving 19 days on average for the post-fixture leg. The distribution of sailing times is presented below.

Table 3.3: Summary voyage durations

Statistic	Overall	Pre-fixture	Post-fixture
N	237	237	237
Mean	34.8	16.1	18.7
St. Dev.	8.1	9.1	8.4
Median	36	16	19
Min	11	0	0
Max	52	30	44

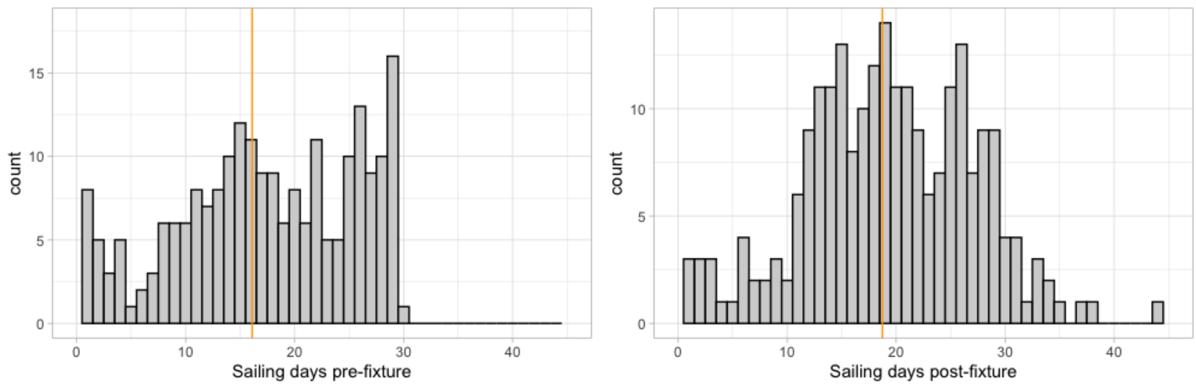
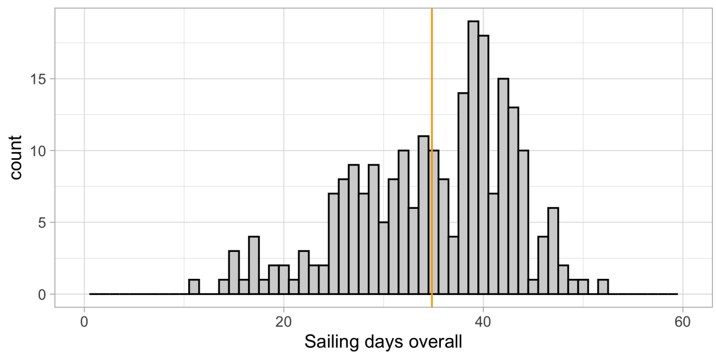


Figure 3.7: Distribution of sailing days in the two contractual states and total. Line depict averages.



3.4 Freight market indices

As freight rate indicators we use foward freight- and spot-rates reported by the Baltic Exchange, the dominating benchmark for settling freight related products. The exchange publishes daily indices, compiled of reported freight rates obtained by a vessel type on a specific route that day. The Baltic Capesize Index (BCI), contains such route specific information for Capesizes and is collected from Clarksons Shipping Intelligence Network (SIN)(Clarksons, 2020b). The exchange also produces daily assessments of Forward Freight Agreement (FFA) rates, called Baltic Forward Assessments (BFA), which have been extracted directly from the exchange (Baltic Exchange, 2019). These are compiled of reported bid-ask spreads submitted by a panel of forward brokerage firms (Alizadeh & Nomikos, 2009). FFAs are Contracts-of-Difference traded over the counter (OTC) between a seller and a buyer with the purpose of settling a freight rate for a specified trade route and cargo type. FFAs are all settled against the average of its underlying Baltic Index, for the duration of the contract (usually a month), meaning that it is not the index level on the day of settlement which defines the outcome of an FFA, but rather the average level over a fixed time period.

FFAs have become popular for risk management and hedging purposes within the industry. In OTC derivatives markets each party accepts counterparty credit risk, however, after the financial crisis in 2008, counterparty risk aversion has increased and today almost all FFA trades are centrally cleared through a clearing house (Alizadeh et al. 2015). This assures a more correct position value, as it requires a daily realization of P&L for the holder and seller of a contract (due to mark-to-market). A cleared contract is therefore closer to the "true" market value of a contract as it is quoted free from any potential counter-party risk (Alizadeh et al. 2015).

Theoretically, a forward price is equal to the expected spot price at maturity, provided that there is no risk premium and rational use of information (Kavussanos & Visvikis, 2009). However, as FFAs trade the expected value of a non-storable service, its pricing is not linked through arbitrage as in other commodity futures markets, but rather the expectations of market agents regarding the average spot price in the defined period before the contracts maturity (Alizadeh & Nomikos, 2009). The existence of such a pricing relationship, also called the "unbiasedness hypothesis" determines whether FFA prices can be utilized for price discovery purposes, adequate for this thesis. Kavussanos et al. (2004) investigate this relationship and find that FFAs trading one and two months before maturity are unbiased predictors of the realized spot rates within the Panamax segment (mid-size vessel). However, the results are dependent on the characteristics of the underlying market. Conversly, Ishizaka et al. (2007) finds that there exists risk premiums (and therefore biases) under all market conditions for a VLCC[5] route going from the Arabian Gulf to Japan.

Whether an FFA price is an unbiased predictor of future spot rates could also be affected by the liquidity in the instrument, with higher volumes leading to lower transaction costs and a more effective price discovery function (Alizadeh et al. 2015). The Capesize time-charter basket average is considered as the most liquid FFA on the freight derivatives market (Kavussanos & Visvikis, 2016). This could be due to the fact that in terms of cargo types and trade routes the options are limited, and therefore hedging effectiveness is high (Athanassiou, 2017). It is also the most volatile segment of dry bulk shipping, thus

[5]Very Large Crude Carrier

market participants can find it more attractive to hedge. However, none of the underlying routes for Capesize FFAs are particularly liquid, which for this thesis can be a source of error as it weakens the price discovery function (Kavussanos & Visvikis, 2016)(Alizadeh et al. 2015).

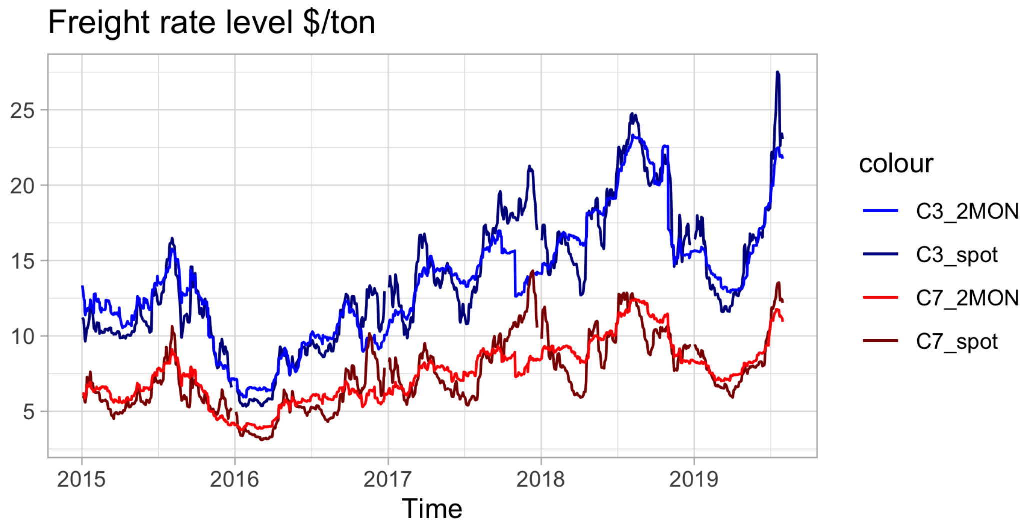
For east-bound, or "front haul" contracts (Atlantic to the Far East), we use the BCI and BFA prices for route C3 Tubaraou-Beilun and Baoshan. As a large portion of the sampled front haul contracts are for similar routes, we assume it to be a good indicator. This is also the relatively speaking most liquid FFA (Athanassiou, 2017). For trans-Atlantic contracts, typically from South-America to Europe, we use the index for route C7 Puerto Bolivar-Rotterdam. This is a less frequently traded route for our sampled contracts, however we still assume it to be a good indicator for the trans-Atlantic freight rate level.

Table 3.4: Baltic indices summary

	Spot	CURMON	+1MON	+2MON
C3				
N	1,146	1,158	1,158	1,158
Mean	13.77	13.64	13.67	13.60
St. Dev.	4.49	4.28	4.17	4.00
Min	5.33	5.58	5.58	5.93
Pctl(25)	10.46	10.74	10.99	11.03
Pctl(75)	16.75	16.53	16.19	15.70
Max	27.52	23.77	23.30	23.33
C7				
N	1,146	1,158	1,158	1,158
Mean	7.48	7.49	7.54	7.54
St. Dev.	2.37	2.19	2.06	2.00
Min	3.10	3.28	3.47	3.76
Pctl(25)	5.72	5.91	6.15	6.12
Pctl(75)	9.03	8.97	8.92	8.72
Max	14.32	13.05	12.19	12.42

Where:
Spot is the spot rate
CURMON is the FFA for the current month
+1MON is the FFA for the next month
+2MON is the FFA for month after next month
All FFAs are rolled over at settlement (end of period).

Figure 3.8: Spot freight rate and forward rate as reported by BCI and BFA



We note that volatility is decreasing with time to maturity for both routes. In figure 3.7 it can also seem like the spot rates are fluctuating around the +2MON FFAs, which are relatively more stable. Although a short time-frame, this is in line with the common assumption that freight rates are mean-reverting in the long run (Koekbakker et al., 2006)(Anestad & Abrahamsen, 2019).

3.5 IFO380 and Brent oil

IFO380 (high-sulfur marine fuel), quoted at Singapore ha been chosen as indicator for fuel cost. Over the sampled period it was the commonly used fuel for Capesizes, while Singapore is the natural bunkering port for the voyages analyzed. In addition, daily quotes for Brent crude prices have been extracted from Clarkson SIN (Clarksons, 2020c).

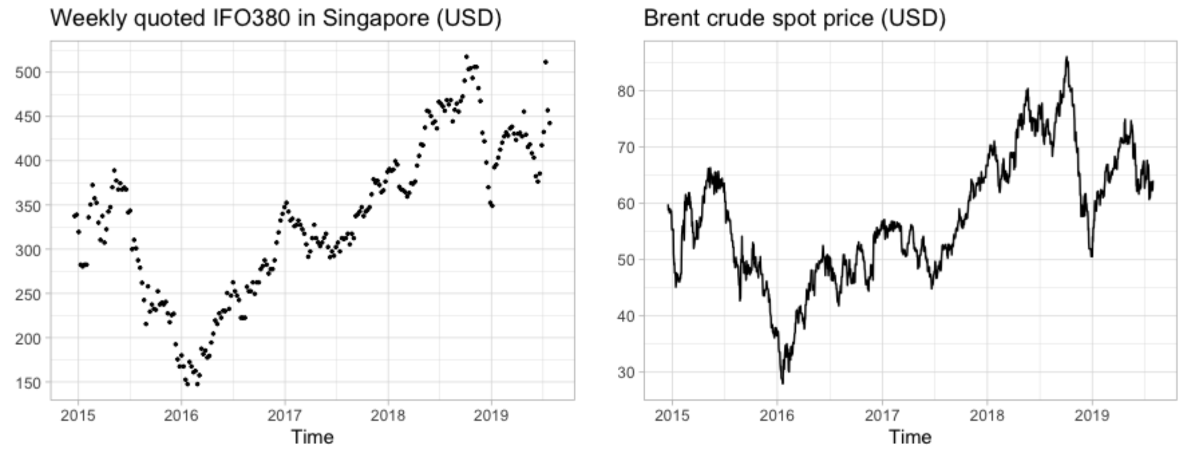


Figure 3.9: Weekly quoted IFO380 and daily quoted Brent oil

Visual assessment of the charts give the impression that international oil prices correlate well with bunker prices. Formal testing results in a Pearson's R of 0.937, confirming that the two are strongly correlated, at least in the sampled period. The authors note that for intervals exceeding the sampled period, the correlation is lower. Further, with the introduction of new bunker fuel regulations, and the altered demand for this type of fuel, the relationship between the oil price and IFO380 might have been changed on permanent basis.

4 Theoretical Framework

4.1 Speed Optimization Theory

The fundamental assumptions within maritime economic theory is that vessel operators are rational economic individuals seeking to maximize their freight revenues, while minimizing costs (Stopford, 2009). Due to the degree of fragmentation in the shipping industry, and the level of homogeneity of services performed within each segment, it is a reasonable and well adopted assumption that freight markets are highly competitive, hence vessel operators are price takers (Strandenes, 1981)(Beenstock & Vergottis, 1989). However, operators are not only price takers on freight rates (R) but also for unit voyage cost such as bunkers, port charges and crew cost. Price of bunkers (PB) is considered the most important unit cost due to its great magnitude relatively to other costs, averaging to about 50% of voyage related cost, with the possibility of being even higher for long-haul voyages (Alizadeh & Nomikos, 2009). Price of bunkers is also the only variable cost when analyzing voyages individually, as crewing and other operational costs in the short run are fixed. As a vessel is earning a unit freight revenue, the vessel speed (V) determines the amount of cargo delivered over a post-fixture period, or vessel productivity, which in turn defines total revenue (Stopford, 2009). Simultaneously, a vessel's speed impacts the voyage cost, due to change in fuel consumption, hence fuel cost. Based on the above, Beenstock and Vergottis (1989) define a vessel's profit function as:

$$\pi = VR - V^{\epsilon} P_B - OC \; s.t \; \epsilon > 1 \tag{4.1}$$

where V^{ϵ} denotes the hypothesized relationship between voyage cost and vessel speed, and OC denotes all other operational costs, independent of speed. By maximizing with respect to V, we derive the function for optimal vessel speed:

$$V = (\frac{R}{\epsilon P_B})^{\frac{1}{(\epsilon - 1)}} \tag{4.2}$$

Thus, optimal speed is given by the ratio of freight rates to fuel cost, independent of post-fixture costs. Given the optimal vessel speed, the following profit function is derived:

$$\pi = R^{\frac{1}{1-\epsilon}}\epsilon^{\frac{1}{1-\epsilon}}(1-\epsilon^{-1})P_B^{\frac{1}{1-\epsilon}} - OC \tag{4.3}$$

Beenstock & Vergottis model for optimal speed forms a basic understanding of the complex problem of speed optimization. However, a more realistic way of portraying speed optimization is by treating the ballast and laden leg separately (Ronen, 1982). Such as split was proposed by Adland & Jia (2016). We have included their model for the sole purpose of demonstrating how one might distinguish between the differences in trade-offs evaluated when deciding speeds during ballast and laden leg. The following variables are defined:

R - Spot freight rate (\$/tonne)
W - Cargo size (tonnes)
L - Leg distance (nautical miles)
d - days sailing
V - Vessel speed (knots)
V_d - Design speed (knots)
V_{min} - Minimum vessel speed (knots)
V_{max} - Maximum vessel speed (knots)
F - Daily fuel consumption (tonnes/day)
F_d - Fuel consumption at design speed V_d
P_B - Price of bunker fuel (\$/tonne)
$\bar{V}$ - Displacement of the ship (tonnes)
$\bar{V}_d$ - Displacement at design draught (tonnes)
D_d - Design draught of the ship
D - Draught of the ship (depth in the water, meters)

A vessels daily fuel consumption is determined by the sailing speed and the displacement ratio. Assuming that the displacement ratio can be approximated by the vessel's draught ratio (Man Diesel Turbo, 2012) we have the following expression for fuel consumption:

$$F = (\frac{V}{V_d})^{\epsilon} F_d (\frac{\bar{V}}{\bar{V}_d})^{\frac{2}{3}} \approx (\frac{V}{V_d})^{\epsilon} F_d (\frac{D}{D_d})^{\frac{2}{3}} \tag{4.4}$$

Psaraftis Kontovas (2013) suggests that $\epsilon = 3$ is a good approximation for bulk carriers and tankers. Thus, equation (4.4) provides a bottom-up approach to fuel consumption, as described by Jia et. al (2017). Based on equation (4.4), the daily profit π function can be expressed as following:

$$\frac{\pi}{d} = \frac{RW}{\frac{L}{24V}} - (\frac{V}{V_d})^{\epsilon}\ F_d (\frac{D}{D_d})^{\frac{2}{3}} \tag{4.5}$$

From here, we can derive the optimal speed during laden leg by taking the partial derivative of daily profits (4.5) with respect to V. By setting the partial derivative equal to zero, we arrive at the formula for optimal laden speed:

$$V_L^* = (\frac{24RWV_d^{\epsilon}}{\epsilon P_B L F_d \frac{D}{D_d}^{\frac{2}{3}}})^{\frac{1}{\epsilon-1}} \; s.t \; V_{min} \leq V_L \leq V_{max} \tag{4.6}$$

The theoretical optimal speed for the laden leg is increasing with the freight rate R, design speed Vd, the cargo size W, a potential decrease in fuel price PB, the trip distance L, fuel consumption at design speed Fd and the draught ratio D/D_d.

As the vessel is not transporting any cargo during a ballast leg, there are no revenues associated. Thus, it is natural to use the cost minimizing model presented by Ronen (1982). This equation introduces the alternative cost associated with extending the duration of the ballast voyage due to slow steaming. C_a represents the optional daily value of freight rate income that the vessel is giving up due to slow steaming. C_a might also be projected by the corresponding FFA, as it provides an estimate of potential earnings at the time when the vessel expects to reach port. Thus, the cost function will be depicted as follows:

$$C = \frac{L}{24V} C_A + (\frac{V}{V_d})^{\epsilon} F_d (\frac{D}{D_d}^{\frac{2}{3}}) P_B \frac{L}{24V} \tag{4.7}$$

From here, we can derive the theoretical optimal ballast speed by minimizing (4.5) with respect to the speed (V_B). Note that the ballast speed is bound to the same technical constraints of the propulsion system as explained in (4.6) (Adland Jia, 2016).

$$V_B^* = V_d (\frac{C_a}{(\epsilon - 1) F_d \frac{D}{D_d}^{\frac{2}{3}} P_B})^{\frac{1}{\epsilon-1}} \; s.t \; V_{min} \leq V_L \leq V_{max} \tag{4.8}$$

The theoretical optimal ballast speed is increasing with design speed V_d and the alternative income C_a. The speed decreases with bunker fuel price P_B, fuel consumption F_d and the draught ratio D/D_d.

4.2 Optimal speed under different contractual states when ballasting

In the pre-fixture state of the ballast leg, the possible speed interval is only restricted by the vessels propulsion system, accounting for a vessel's physical limitations. Thus, optimal speed for the pre-fixture leg does not differ from equation (4.8):

$$V^*_{B\,pre} = V_d(\frac{C_a}{(\epsilon-1)F_d\frac{D}{D_d}^{\frac{2}{3}}P_B})^{\frac{1}{\epsilon-1}}\ s.t\ V_{min} \leq V_L \leq V_{max} \tag{4.9}$$

However, the post-fixture ballast leg differs from the pre-fixture due to contractual constraints. Hence, the minimum post-fixture ballast sailing speed cannot be less than the minimum sailing speed needed to reach the load port in time for the last day of laycan (V_{laycan}). Thus, the post-fixture optimal speed will be as following:

$$V^*_{B\,post} = V_d(\frac{C_a}{(\epsilon-1)F_d\frac{D}{D_d}^{\frac{2}{3}}P_B})^{\frac{1}{\epsilon-1}}\ s.t\ V_{laycan} \leq V_L \leq V_{max} \tag{4.10}$$

The optimal speed in the post-fixture ballast leg state does not take sanctions of violating the contract into account. As this master thesis exclusively analyses fulfilled contracts, we will not dwell any further on this topic, however it is important to stress that for a more comprehensive model dealing with potential contractual disagreements, this should be included (Ronen, 1982).

4.2.1 Empirical hypothesis and model selection

As the objective of this thesis is to test the empirical relationship between market conditions and optimal speed, we need to adjust the model in order to make it plausible for multivariate empirical analysis. In order to do so, we introduce an error term for the deviation from the optimal relationship and the observed relationship (Assman et al. 2015; Jia et al. 2016).

$$V^*_B = V_d(\frac{C_a}{(\epsilon-1)F_d\frac{D}{D_d}^{\frac{2}{3}}P_B})^{\frac{1}{\epsilon-1}}e^u \tag{4.11}$$

Note that the only difference between the pre-fixture and post-fixture state, is the interval of possible speed. Hence, the same econometric model can be used to test the two contractual states. Furthermore, it is convenient to transform this into a log-linear relationship, in order to make use of linear estimation techniques, and to simplify the expression further (Assman et al. 2015). We define the following model:

$$ln(V_B) = \alpha + \beta_1 ln(C_a) + \beta_2 ln(P_B) + \beta_3 ln(\frac{D}{D_d}) + \beta_4 ln(F_d) + \beta ln(V_d) + \epsilon \qquad (4.12)$$

where α_0 is the intercept term and the β's are the coefficients which should represent the influence of the explanatory variables on the dependent variable. In a scenario where vessels where to optimize speed perfectly, the elasticity for freight rates and bunker fuel would be $\frac{1}{\epsilon-1}$ and $-\frac{1}{\epsilon-1}$ respectively for both states within the ballast leg. Given the assumption of $\epsilon = 3$ (Psaraftis Kontovas, 2013), the elasticity would be 0.5 and -0.5 (Assman et al. 2015).

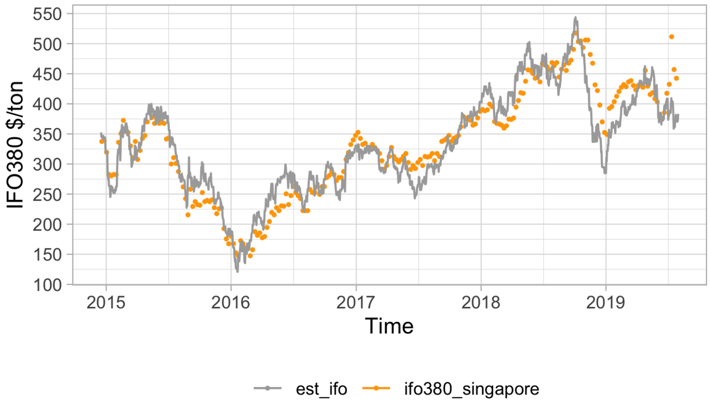
5 Methodology

5.1 Estimation of daily IFO380 using Brent oil prices

According to Stopford (2009) it exists an optimal speed for any level of freight rates and fuel costs. Even though vessels are not bunkering on a daily basis, one could argue that the value of the bunkers held on books (or aboard a vessel) is equal to the current spot price of that fuel. In practice, this could be portrayed as if the vessel operator each day enters into a cross hedge agreement in IFO380 for the corresponding volume, with a correlating (daily quoted) energy future as underlying instrument. How such a hedge could be undertaken is exemplified by Nguyen (2007), in which he calculates the performance of a portfolio consisting of Brent oil future and bunker fuel. Alizaheh & Nomikos (2009) show that hedging effectiveness between energy futures and bunkers is relatively low when compared to tailored bunker futures contracts. Nevertheless, it illustrates that vessel operators could be exposed to daily bunker price variations. We note that the hedging strategies for bunkers are plentiful, and that the we cannot know each vessel's true cost for fuel. However, in theory, the gains and losses from such hedges should not affect the vessel speed.

Having only the end-of-week price for IFO380, we need to estimate datapoints for all other days. Brent oil is suitable for such an estimation as it strongly correlates with bunker prices (UNCTAD, 2010). For weekends and holidays, we assume the Brent price to be equal to the preceding day. The estimation of daily IFO380 is done by running a linear regression with IFO380 end-of-week prices as dependent variable, and the Brent price as independent variable. Using the estimator for the coefficients, daily values for IFO380 are computed, illustrated in Figure 5.2.

Figure 5.1: Estimated (daily) fuel prices compared to (real) weekly prices



5.2 Interpolation of freight level indices

Before estimating how vessel speed respond to changes in the alternative cost C_a, we need to define it. In Ronen (1982), C_a is defined as a vessels daily alternative income, whereas Devanney (2010a) suggest to use the vessel owners expectations of earnings for the next voyage[6]. As the demand for freight services can be considered inelastic in the short run, the spot price fluctuates with the short-run supply of idle vessels (Norman & Wergeland, 1981). Thus, a vessel's C_a depends on its position. As illustrated in figure 3.3, the geographical position where fixtures occurs, varies to a large extent. This might be a result of the short-run balance between supply and demand (Prochazka et al., 2019). Hence, estimating C_a becomes a question of position.

By utilizing the vessel's current position, we continuously calculate the distance to its next load port. Additionally, by applying the average speed of each vessel, we are able to calculate the individual vessel's estimated time of arrival. Assuming that FFAs are adequate for price discovery, a modelled forward curve represents market participants expectations of future spot rates. Thus, we use each vessels estimated time of arrival to determine expected \$/tonne revenue.

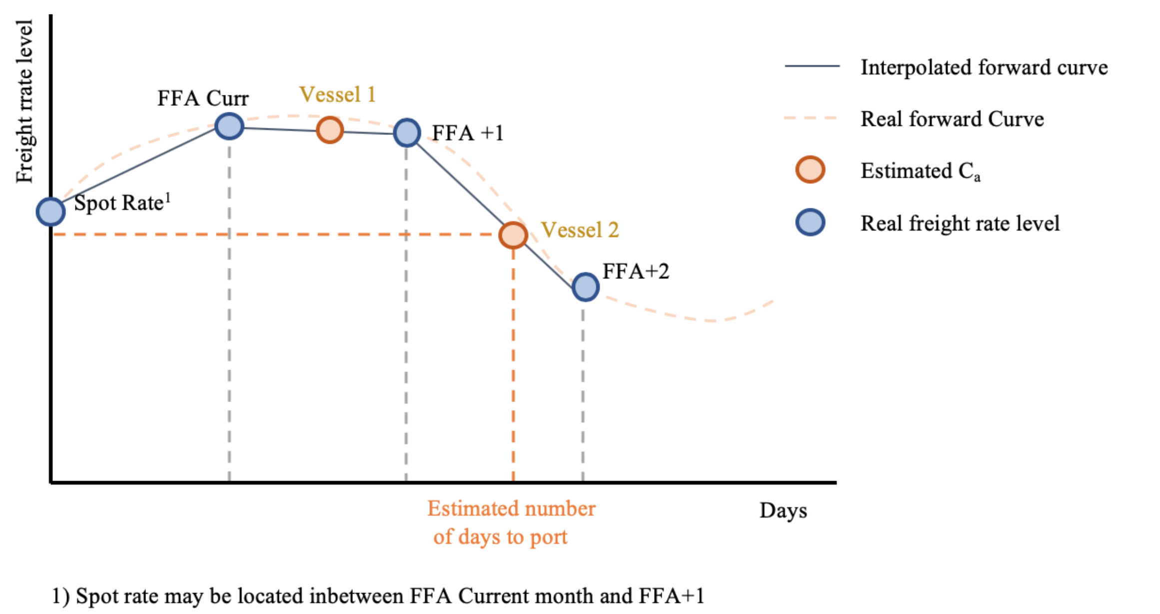
Linear interpolation is a method which simplifies forward curve modeling. It is a common procedure to estimate unknown datapoints in-between known observations, and it is also a frequently used method for approximation of a daily forward curve over short time-intervals (Roncoroni et al., 2015). There are more precise methods for modelling the

[6]This is independent of the vessels loading condition

forward freight curve. For example, Koekebakker and Adland (2004) model the forward curve dynamics using a smoothing function on implied forward prices. However, given the short time-interval, and the purpose of reflecting expectations as contrast to calculate term structure volatility, we find linear interpolation to be an adequate method.

To enable linear interpolation between the freight rate indices, we assume that the middle point in each month is a suitable proxy for the monthly average rate (i.e. the FFA-price the underlying month). In figure 5.1, we illustrate how the linear interpolation method is executed, with two vessels having different freight rate expectations based on their position. The following instruments are included to estimate expectations for freight rates: Current spot rate (SPOT_C3/C7), the current month FFA (CURMON_C3/C4), the next month FFA (FFA+1MON_C3/C4) and the two months ahead FFA (FFA+2MON_C3/C4). This leaves a two-dimensional estimate for freight rate expectations, allowing for vessels to have different revenue expectations at the same time, which can be substituted for C_a. For the remainder of the thesis this estimate for freight rate expectations is denoted as $E(FR)_{it}$, where $E(FR)$ is expected freight rates for vessel i at time t.

Figure 5.2: Interpolation of freight rates



5.3 Vessel specific variables

Even though Capesize vessels to a large extent are similar in terms of design and size, differences occur. Hull design, allowing for higher energy efficiency through reduced water displacement, is an example of such. The importance of these characteristics have varied over time as their economic implication (usually through fuel prices) have fluctuated (BMT, 2015). Hence, year of build might also be relevant for a vessel reported speeds. We have included the following operational variables: Year of build (*Year_ built*), hull slenderness (*HU_ SL*), dead weight ton (DWT), draught ratio (D/D_d) and design speed (V_d).

Draught ratio (D/D_d): We already use the draught ratio to define the loading condition of a vessel, however we can also use it as indication of the vessel's displacement in water. Thus, this variable can be a proxy for vessel design. We expect its coefficient to be negative, i.e. speed decreases with vessels water displacement.

Hull Slenderness (*HU_ SL*): Hull slenderness is an approximation to the shape of a vessel, with higher values indicating a fuller "box shape", which is less efficient as it would increase water displacement (Lindstad & Eskeland, 2015). *HU_ SL* = DWT / (L * B * T), where DWT is the deadweight capacity of the ship, L is the overall length, B is the beam and T is the design draught D_d of a vessel. *HU_ SL* is meant to substitute the vessel specific fuel consumption variable (F_c), in the speed optimization model (equation 4.12). We therefore expect it to have a negative coefficient with regard to speed.

Design speed (V_d): Vessels are optimized for certain speeds and loading conditions. If a vessel where to sail at design speed, irrespective of market conditions, we would expect the design speed to positively correlated to the actual speed (Adland Jia, 2018).

Deadweight tonnes (DWT): As a larger vessel will have larger income potential, the optimal speed is expected to increase with the size of the vessel (Adland & Jia, 2018).

Year_ built: If we assume that newer vessels achieve higher speeds at lower cost due to a more ecological design, we expect the coefficient to be positive. On the other hand, if we believe that newer vessels are designed to steam at lower speeds due to the increased attention towards fuel cost savings, it could also be negative.

Including and substituting vessel specific variables in the model depicted in equation (4.12) we get the following expanded model:

$$
\begin{gathered}
ln(V_B) = \alpha + \beta_1 ln(C_a) + \beta_2 ln(P_B) + \beta_3 ln(\frac{D}{D_d}) + \beta_4 ln(HU\_SL) + \\
\beta ln(V_d) + \beta ln(DWT) + \beta ln(Year\_built) + \epsilon
\end{gathered}
\tag{5.1}
$$

6 Discussion

6.1 Behavioral change upon entering a contract

As the initial analysis, we would like to investigate if there are any behavioral changes upon entering a contract. As presented under the theory section (equation 4.10), contractual constraints may cause the optimal speed to differ between the pre-fixture and post-fixture state. Consequently, we expect to see a change in speed depending on the contractual state. In order to test this empirically, we use a multivariate regression model with nominal speed (depicted in knots) as dependent variable. As explanatory variable, we use a dummy variable indicating if a vessel has been contracted, i.e. post-fixture. In addition, we control for time fixed effects such as seasonal patterns, with dummy variables for each quarter of the year. The results are presented in table 6.1.

Table 6.1: Contractual status and speed

	Dependent variable:	
	Speed	
	(1)	(2)
Fixdummy	0.54***	0.54***
	(0.04)	(0.04)
QuarterQ2		-0.33***
		(0.05)
QuarterQ3		-0.20***
		(0.05)
QuarterQ4		0.19***
		(0.05)
Constant	10.97***	11.07***
	(0.03)	(0.04)
Observations	8,257	8,257
R^2	0.02	0.04
Adjusted R^2	0.02	0.04
Residual Std. Error	1.70 (df = 8255)	1.68 (df = 8252)
F Statistic	205.70*** (df = 1; 8255)	79.47*** (df = 4; 8252)
Note: Q1 is base in model 2		*p<0.1; **p<0.05; ***p<0.01

The dummy variable indicative of contractual state appears to be significant on a 99% level with a positive sign, implying that vessels sail faster when having entered into a contract. The coefficient indicates an average vessel speed increase of 0.54 knots or approximately 4.9% (relative to the constant term[7]), and does not change when time fixed effects are accounted for. We note that Q2 and Q3 represents on average lower speeds relative to Q1 and Q4.

6.2 Contractual barriers and its effect on speed optimization

To better understand what affects the speed decision prior and post fixture, we subset our sample by contractual state, allowing us to analyze them individually. One of the main contributions of this thesis is to analyze vessel behavior free from contractual constraints. In the following we therefore have an enhanced focus on the pre-fixture state, and the difference in results between the contractual states.

Referring to log-linear model (4.12) in the theory section, we expect operators to dynamically adjust their speed according to prevailing market conditions, more specifically; the alternative cost of slow steaming C_a and fuel prices P_B. For freight rates we include our estimate $E(FR)$ as substitute for C_a. For the purpose of testing how appropriate this estimate is, we include a model with *C3_spot* price as substitute. F_B is daily estimated fuel prices. Furthermore, we run the expanded model (5.1) to control for vessel specific effects.

The coefficient for $E(FR)$ and *C3_spot* are expected to have a positive sign, whereas the coefficient for P_B is expected to have a negative sign. The models are ran on a log-log basis to measure the relative change in the dependent variable.

6.2.1 Pre-fixture speed optimization

Regressions for pre-fixture observations are presented in Table 6.2. Model (1) follows the original speed optimization model presented in (equation 4.12), although only including market variables. $E(FR)$ substitutes the alternative cost C_a, and F_B denotes fuel price.

[7]The constant term represent the average speed for vessels pre-fixture

Table 6.2: Speed and market conditions pre-fixture - controlling for operational variables

	Dependent variable:			
	ln(Speed)			
	(1)	(2)	(3)	(4)
$\ln(P_B)$	0.025*	-0.029*	0.007	-0.053***
	(0.013)	(0.017)	(0.013)	(0.018)
ln(E(FR))	0.009		0.023**	
	(0.009)		(0.009)	
ln(C3_spot)		0.062***		0.082***
		(0.014)		(0.015)
D/D_d			0.058***	0.061***
			(0.019)	(0.019)
HU_SL			2.171***	2.294***
			(0.292)	(0.291)
V_d			-0.022***	-0.021***
			(0.004)	(0.004)
DWT			0.00000	0.00000
			(0.00000)	(0.00000)
Year_built			-0.002***	-0.002**
			(0.001)	(0.001)
Constant	2.219***	2.393***	5.264***	4.632***
	(0.063)	(0.072)	(1.555)	(1.555)
Observations	3,816	3,816	3,597	3,597
R^2	0.003	0.008	0.036	0.043
Adjusted R^2	0.003	0.008	0.034	0.041
Note:				*p<0.1; **p<0.05; ***p<0.01

Contrary to what we expected, we find that vessel speed does not respond significantly to changes in expectations of freight rates. Fuel price has a significant effect at a 90% level, however with a positive sign, which is both unexpected and paradoxical. In Model (2) we apply current spot freight rate for the route C3 (Tubaraou-Beilun and Baoshan), and find that this has a strongly significant effect on speed, although still with a small magnitude. Fuel prices are now also strongly significant and negatively correlated with speed. When controlling for vessel specific variables in Model (3), fuel price become insignificant, while the estimated freight rate is strongly significant, also with a small coefficient. In model (4), we control model (2) for vessel specific effects, and find that the magnitude of the coefficients are increasing.

The effects from market conditions seem to be unstable across the different models. In particular, it is surprising to observe speed respond positively to an increase in P_B in model (1). It is reasonable to assume that freight rates to some extent are correlating with fuel prices, as this cost eventually reaches charters. This could be even more relevant at lower freight rate levels, when operators struggle to break-even. Moreover, a Spearman correlation test reviles that *E(FR)* correlates less with fuel prices than *C3_ spot*, which can mean that P_B in model (1) and (3) becomes misleading as its paired with a weaker estimator for freight rates. Models including *C3_ spot* produce stronger results, although also unstable. We note that the sign on some of the vessel specific variables are unexpected, e.g. that speed decrease with higher design speed. Some of the vessel specific variables could also be a suspect of multicollinearity, for example could vessel age correlate with eco-design (HU_SL) or design speed V_d. However, computation of variable variance inflation factor (VIF) for all models give no indication of multicollinearity.

6.2.2 Post-fixture speed optimization

Estimating the exact same models in the post-fixture state we get slightly differing results, presented in table 6.3. In Model (1), *E(FR)* is significant at the 99% level, whereas P_B is strongly significant and has a negative sign. Using *C3_ spot* as indicator for freight rates in Model (2), we get larger coefficients for both variables, whilst still being strongly significant. When controlling Model (1) and (2) for vessel specific characteristics, coefficients increase marginally for both variables. Also in post-fixture the vessel specific variables have different signs than expected. However, the same tests for multicollinearity show no indication of such. We note that correlation between P_B and $E(FR)$ is weaker than between P_B and *C3_ spot*.

Table 6.3: Speed and market conditions post-fixture - controlling for operational variables

	Dependent variable:			
	ln(Speed)			
	(1)	(2)	(3)	(4)
ln(E(FR))	-0.025**	-0.077***	-0.031***	-0.081***
	(0.011)	(0.015)	(0.012)	(0.015)
$\ln(P_B)$	0.025***		0.029***	
	(0.007)		(0.007)	
ln(C3_spot)		0.072***		0.074***
		(0.011)		(0.011)
D/D_d			-0.119***	-0.105***
			(0.034)	(0.033)
HU_SL			1.541***	1.575***
			(0.252)	(0.251)
V_d			-0.018***	-0.018***
			(0.003)	(0.003)
DWT			0.00000***	0.00000***
			(0.00000)	(0.00000)
Year_built			-0.005***	-0.005***
			(0.001)	(0.001)
Constant	2.518***	2.694***	12.009***	11.517***
	(0.055)	(0.064)	(1.421)	(1.418)
Observations	4,441	4,441	4,217	4,217
R^2	0.003	0.009	0.048	0.053
Adjusted R^2	0.003	0.009	0.046	0.052
Note:		*p<0.1; **p<0.05; ***p<0.01		

6.2.3 Interaction effects between macro variables and contractual state

In table 6.4 we present two additional regression models, representing the interaction effect between the contractual state, the freight market and fuel price variables. The only difference between the two models is our indicator for freight rates, being *E(FR)* in Model (1) and the *C3_spot* in Model (2).

The interaction effects from P_B and contractual state are equal (-0.05) and significant in both models. This implies a difference in the extent to which a vessel change speed based

Table 6.4: Interaction between speed and contractual status

	Dependent variable:	
	ln(Speed)	
	(1)	(2)
$\ln P_B$	0.02**	-0.03*
	(0.01)	(0.02)
lnE(FR)	0.01	
	(0.01)	
lnC3_spot		0.06***
		(0.01)
fixdummy	0.30***	0.30***
	(0.08)	(0.10)
$\ln P_B : fixdummy$	-0.05***	-0.05**
	(0.02)	(0.02)
lnE(FR):fixdummy	0.02	
	(0.01)	
lnC3_spot:fixdummy		0.01
		(0.02)
Constant	2.22***	2.39***
	(0.06)	(0.07)
Observations	8,257	8,257
R^2	0.03	0.03
Adjusted R^2	0.03	0.03
Note:	*p<0.1; **p<0.05; ***p<0.01	

on fuel price between the two contractual states. This interaction further has a negative sign, suggesting that vessels reduce speed as response to increased fuel prices more easily during post-fixture relative to pre-fixture. In other words, vessels are decelerating at a higher rate when fuel prices increase after having entered into a contract.

The interaction effect from freight rates and contractual state is insignificant, indicating that vessels react similarly to changes to freight rates pre- and post-fixture.

6.3 Discussion

As illustrated in table 6.1, we observe a change in vessel speed upon entering a contract. However, when comparing the regressions for the different fixture states to one another, contractual constraints does not seem to limit speed optimization. On the contrary, it seems like speed optimization more likely is occurring in the post-fixture state rather than pre-fixture. The interaction effect estimation in table 6.4 further confirms this, showing that the marginal response in speed with changes to fuel price is relatively stronger post-fixture. Generally, the results from the different regression models in pre-fixture are unstable with varying signs and significance levels, while they are more aligned and stable post-fixture. Interestingly we find that the current spot rate is a better predictor for vessel speed rather than the estimated vessel specific *E(FR)* independent of contractual state. This could mean that vessel operators are considering the current market to a larger extent than the forward market when deciding speed. Furthermore we find it questionable whether speed respond to fuel price changes in pre-fixture, as the results are unstable, independent of freight rate indicator. Conversely, in post-fixture the results are much more stable, indicating that speeds do respond to changes in the fuel price.

The fuel price and freight rate elasticises are derived to be -0.5 and 0.5 respectively (Assman et al. 2015)[8]. Comparably, the largest results found in the pre-fixture state are -0.053 for fuel price and 0.082 for freight rates (*C3_ spot*). In post-fixture state the largest results are -0.081 and 0.074. For both contractual states the elasticises are reduced drastically when considering the estimated *E(FR)*, as opposed to the C3 spot rate. While our results deviates substantially from what is expected in speed optimization theory, it somewhat aligns with more recent empirical studies. Analyzing VLCCs[9] going out of the Arabian Gulf, Assman et al. (2015) estimates the fuel price and freight rate elasticity to be -0.184 and 0.166 respectively.

In brief, our results suggest that vessels do behave differently depending on their contractual state. However, the contract does not seem to discourage operators from adjusting speed to market conditions. On the contrary, it seems like speed optimization occurs to a larger extent post-fixture. Lastly, operators expectations of freight rate as opposed to prevailing freight rates does not seem to be a better estimator of speed.

[8]Follows from taking the partial derivative of speed with respect to freight rate (R) and fuel price $(F_c) inequation 4.11 in the theory section$

[9]Very Large Crude Carriers

6.4 Elements of uncertainty

6.4.1 Interpolated freight rates as estimator

The fact that our estimate for operators expectations of freight rates is a bad predictor can be due to severeal reasons. The first reason is that vessel operators could be considering today's freight rates more important than the forward rates, implying that forward rates is a bad predictor of future spot rates. Secondly, our approach to estimate individual market conditions for each vessel is inaccurate. This may further be due to that our estimation method allocates the freight market indices, C3 or C7, depending on where vessels are taking cargo (trans-Atlantic or front-haul). As C3 is a route with load port in Brazil, this market is geographically much closer for vessels having sailed from North-East Asia, and is effectively a market that should concern all sampled vessels when in the pre-fixture state. Furthermore, only a small proportion of vessels are actually performing the route depicted by C7, as most trans-Atlantic cargoes are loaded in Brazil. Thus it could have been wrong to include C7 as route as a whole. Lastly, lack of liquidity in our chosen FFAs could deteriorate the price discovery functions described under section 5.

6.4.2 Practical significance of coefficients

When assessing the magnitude of our coefficients, we note that the implied effect of changes in freight rates or fuel prices will provide a minuscule real life effect. To exemplify, lets assume the C3 spot rate increases with 50%. Ceteris paribus the average vessel would still only increase speed by 4,1% in the pre-fixture state (0.082). Hence, it is reasonable to question the practical existence of speed optimization, as it might as well just be a statistical phenomenon.

6.4.3 Reliability of the "cubic rule"

Classical speed optimization theory relies heavily on the "cubic relationship" between speed and fuel consumption[10]. A recently published empirical study conducted by Adland et al. (2020), questions the correctness of this assumption. They argue that the cubic relationship does not hold over intervals of speed that differs substantially from design

[10] Depicted in equation 4.4 in the theory section

speed. As a result speed optimization could be relatively less effective when already slow steaming. Thus, studies utilizing an exogenous elasticity for fuel consumption might overestimate the impact of speed adjustments to fuel consumption. As the vessels analyzed in this thesis reports on average a much lower speed relative to average design speed, this could be an explanatory factor to why elasticises are marginal.

7 Concluding Remarks

In this thesis, we have investigated the effect of contractual limitations on vessel speed optimization. By analyzing only the ballast leg of Capesize vessels operating in the spot market, we have isolated observations before and after contracting (fixture) of vessels. As an initial result we conclude that vessel operators set speed differently based on the contractual status, sailing on average slower pre-fixture relative to post-fixture.

When testing classical speed optimization theory given the contractual state of a vessel, we find that vessels that have been chartered (post-fixture) to a larger extent optimize speed compared to vessels who have not yet been contracted (pre-fixture). For pre-fixture we are inconclusive about whether operators are optimizing speed according to classical speed optimization theory. This is contrary to what was expected prior to the study, as contractual constraints were expected to hamper the possibility of speed optimization. We also find that our estimate of expected freight rates is a less reliable predictor of speed compared to prevailing spot market rates.

As vessels do not optimize speed during the pre-fixture stage it is reasonable to question whether vessels are optimizing speed at all. Several studies point towards the existence of contractual constraints, and at the same time theory is clear about the vessel operator being the beneficiary from speed optimization, not the charterer. As a result, we cannot conclude that speed optimization occurs, independent of contractual state. We therefore argue that although speed optimization theory may provide a good theoretical framework to understand the dynamics of freight markets, it does not serve as a framework which vessel operators adhere to.

This thesis joins the ranks of studies that question the existence of speed optimization in shipping, and thus the effectiveness of potential regulative measures imposed on the sector. If vessel operators to a smaller extent reduce speeds when facing increased fuel cost, the effect from a potential fuel levy would likely be overestimated. This has consequences for supranational policy makers which urgently needs to find ways to reduce emissions in the shipping industry.

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Appendix

Figure A0.1: Pre-fixture: Model (1)

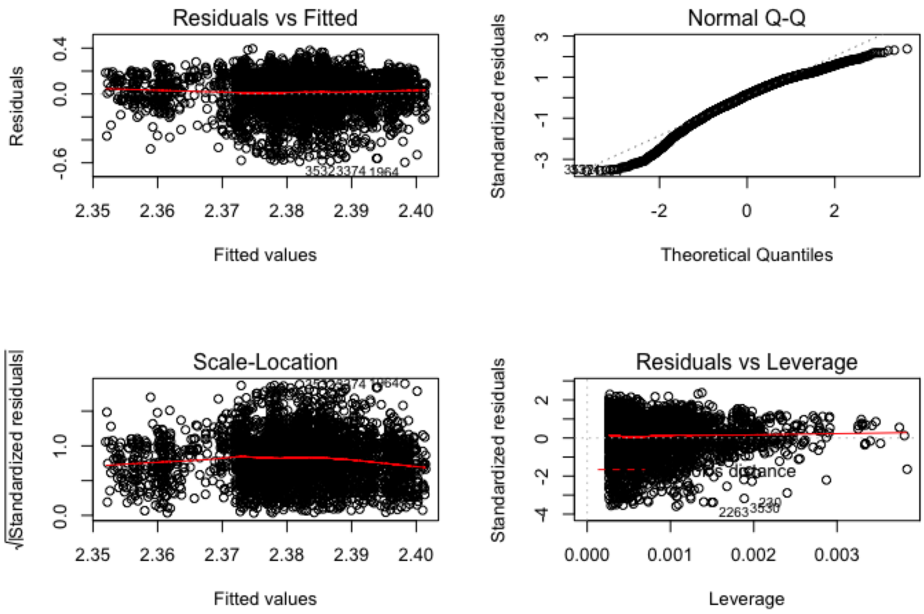


Figure A0.2: Pre-fixture: Model (2)

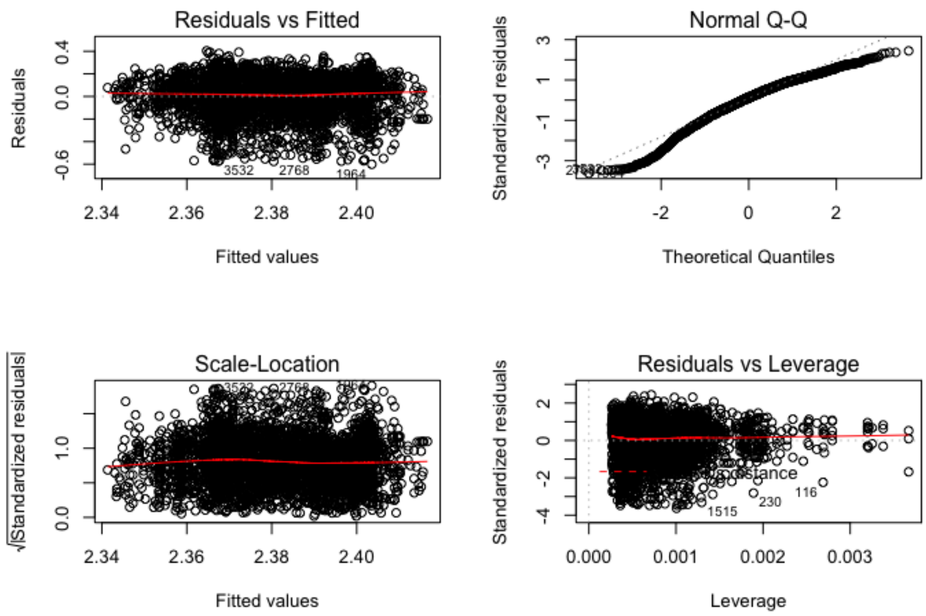


Figure A0.3: Pre-fixture: Model (3)

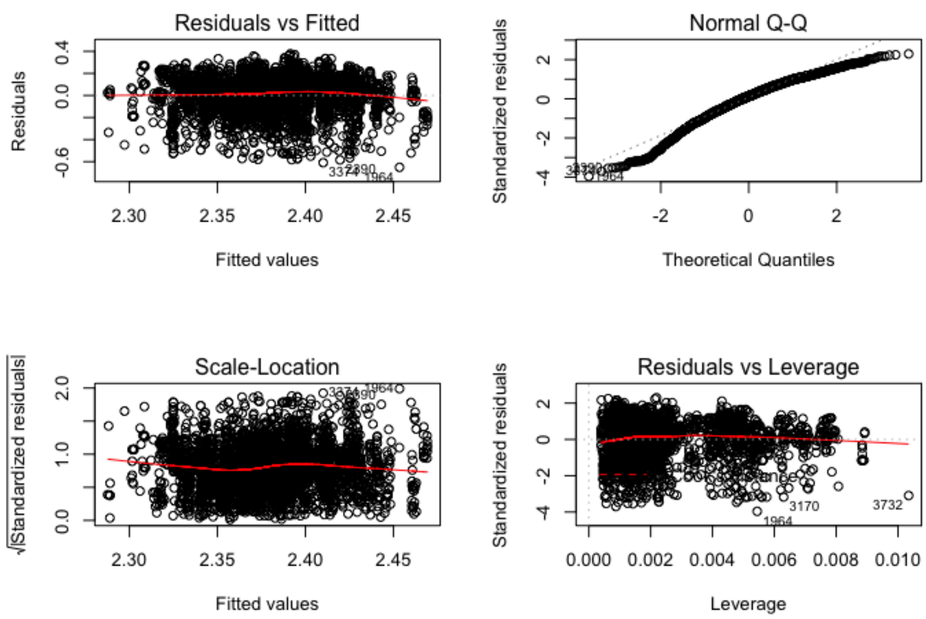


Figure A0.4: Pre-fixture: Model (4)

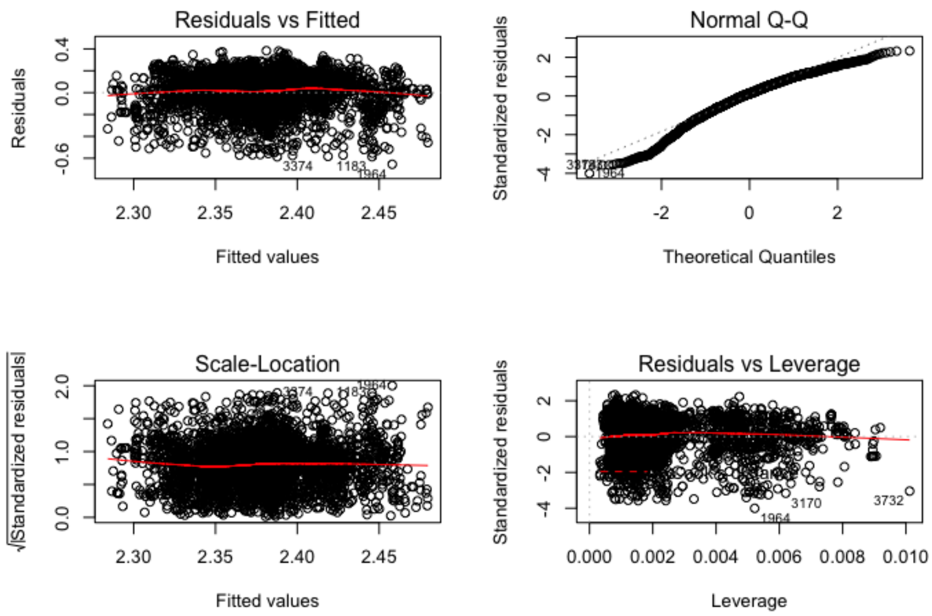


Figure A0.5: Post-fixture: Model (1)

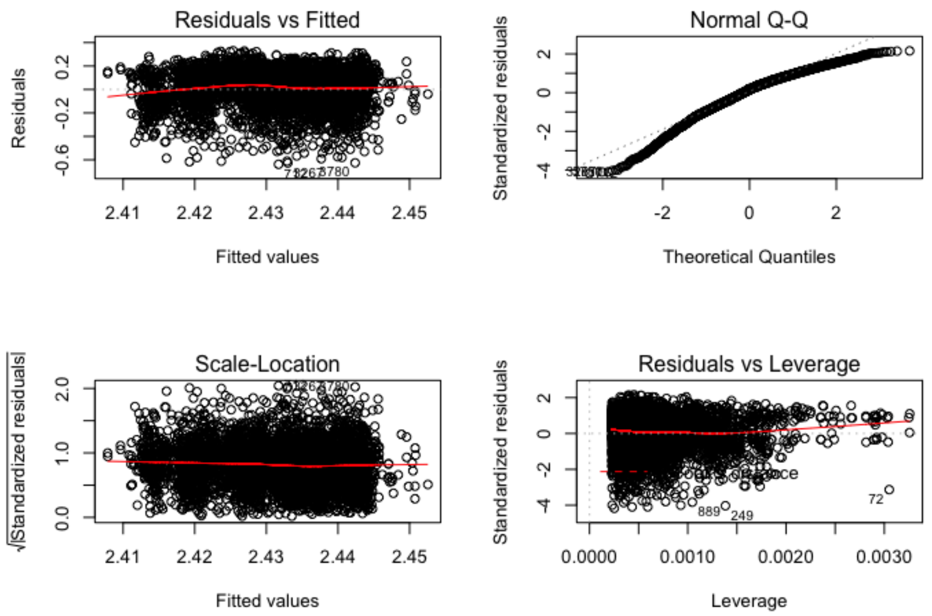


Figure A0.6: Post-fixture: Model (2)

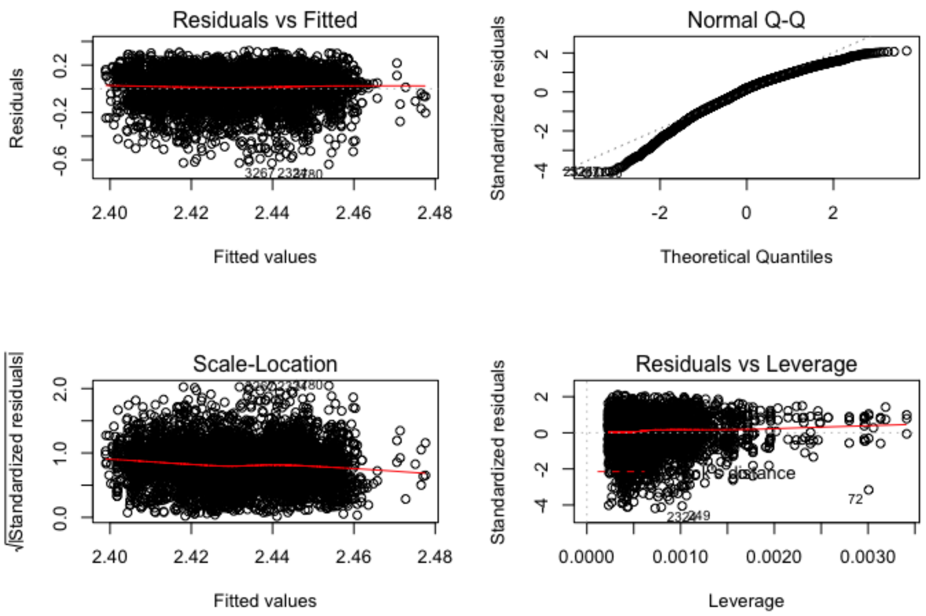


Figure A0.7: Post-fixture: Model (3)

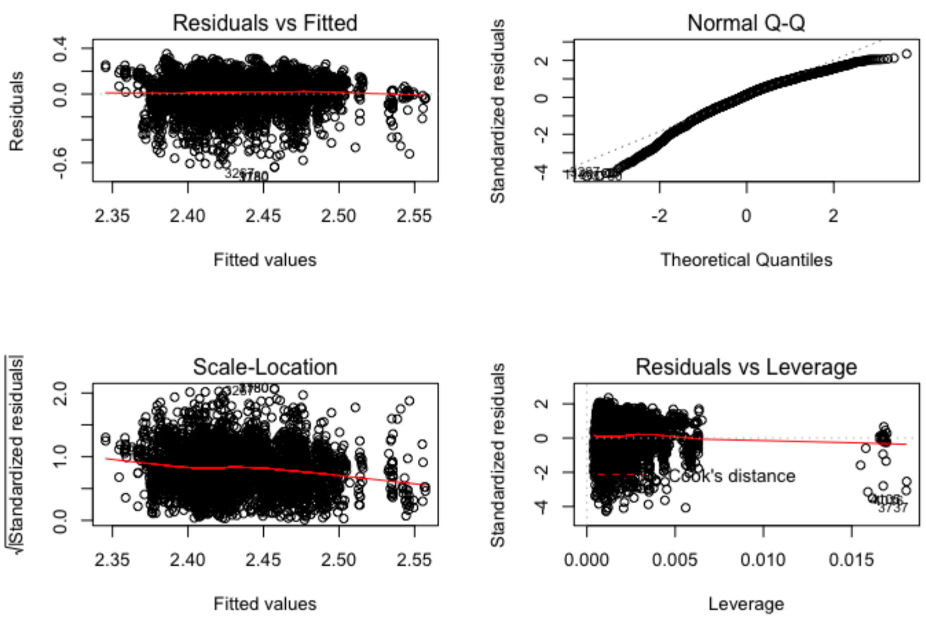


Figure A0.8: Post-fixture: Model (4)

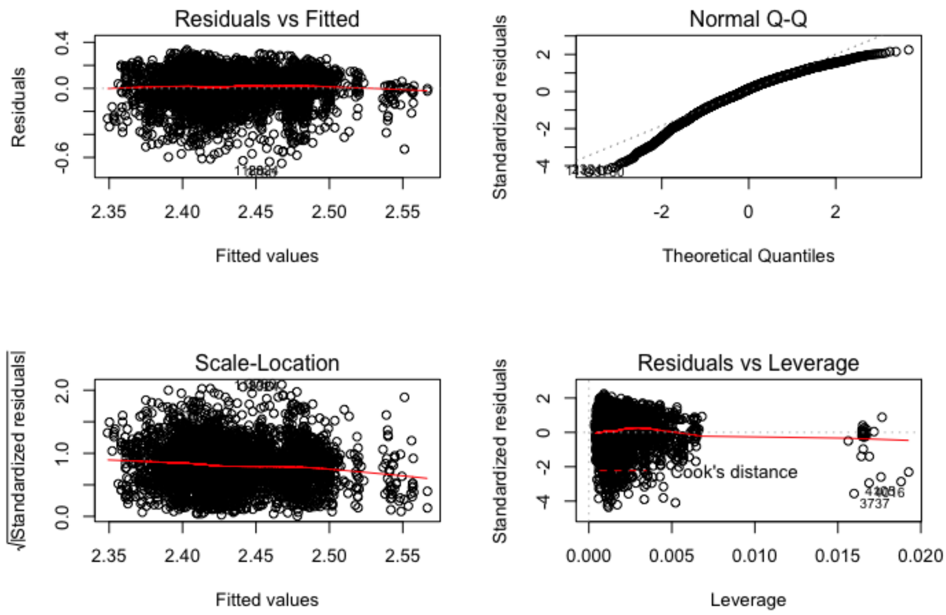


Figure A0.9: Parametric time-trend for the sample speed. Monthly averages. Note that both tails should be discarded as these represent single vessels

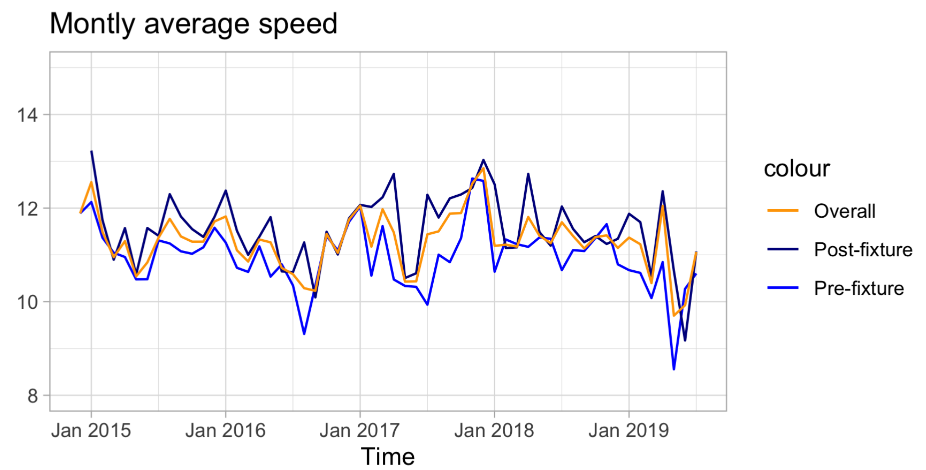


Figure A0.10: Distribution of load ports

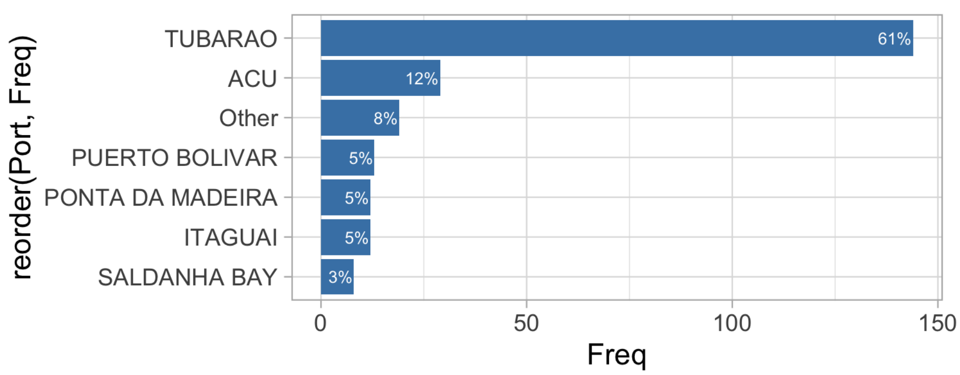
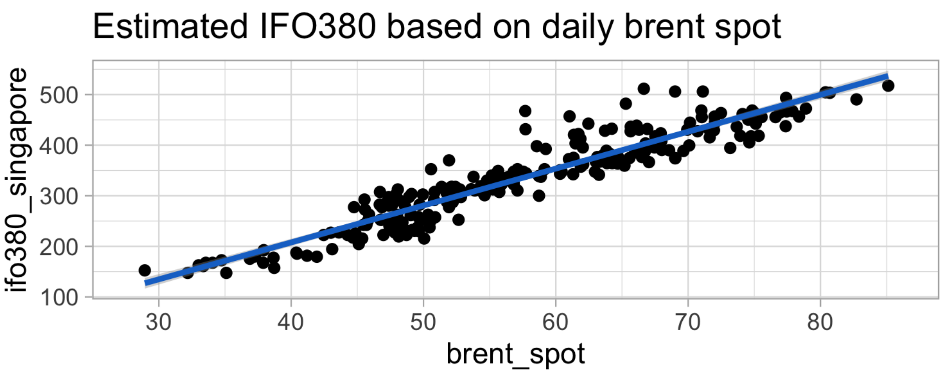


Figure A0.11: Fit of line - regression line for estimation of daily IFO380 prices



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