Essays on Crude Oil Tanker Markets

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The PhD School in Economics and Management is an active national and international research environment at CBS for research degree students who deal with economics and management at business, industry and country level in a theoretical and empirical manner.

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Frederik,
Frederiksberg, December 2018

Introduction and Summaries

This thesis is submitted in partial fulfilment of the requirements for a PhD degree in Finance. Admittedly, the thesis is more closely related to the field of maritime economics and focuses on crude oil tanker markets. This thesis studies freight rates, which have sparked the interest of maritime economists at least since the seminal work by Tinbergen (1931) and Koopmans (1939). This thesis has special emphasis on how freight rates evolve, how they are linked to oil prices through the floating storage arbitrage relationship, and how they reflect the relative bargaining power of shipowners and charterers. The thesis consists of three chapters, which can be read independently.

Summaries in English

The Eye in the Sky - Freight Rate Effects of Tanker Supply

with Professor Nikos K. Nomikos

This paper studies how the evolution of crude oil tanker freight rates depends on the employment status and geographical positions of Very Large Crude Oil Carriers. We construct a novel measure of short-term capacity combining geospatial tracking data from vessels' Automatic Identification Systems (AIS) with information on vessel fixtures.

First, we characterize the geographical fixing pattern, i.e., where vessels are located when they are *'fixed'*. Next, we make heuristic rules, which label each vessel as either available or unavailable based on the vessel's position, self-reported loading condition, self-reported destination, and employment status. The capacity measure is then a proxy for the percentage of vessels in the fleet which are available to take an order. The capacity measure is negatively related to the weekly change in freight rates. Our findings suggest that AIS measures can explain a part of the freight rate evolution. We find that there is a considerable economic magnitude of our measure. We see that a standard deviation decrease in our capacity measure (decrease of 14 available vessels) leads to an increase in the freight rate level of $0.56/mt. This corresponds to an increase in the gross freight revenue equal to $151,200 for a typical cargo size of 270,000mt.

Crude Oil Contango Arbitrage and the Floating Storage Decision

with Professor Roar Adland

In the second chapter, we evaluate the economics of the floating storage trade and the floating storage decision of charterers. The floating storage trade is a simple cash and carry trade in the crude oil futures market. In addition to oil futures, the trade includes the leasing of an off-shore storage facility, in our case a Very Large Crude Carrier (VLCC). A necessary condition for the floating storage trade to be profitable is that the oil futures curve is upward-sloping, i.e., the futures curve is in contango. We find violations of the no-arbitrage condition using both time-series of time-charter rates and time-charter rates from fixtures.

We investigate storage profits across storage horizons. We find that in the aftermath of the Financial Crisis profits for short storage horizons exceeded profits for longer horizons. During the Oil Glut, we see the opposite picture, namely, that the profit associated with long-term storage (above one year) exceeds short-term storage profits. We attribute the difference to the distinction between oil supply and demand shocks. The Financial Crisis served as a negative oil demand shock and pushed down both the short end of the oil futures curve and spot freight rates. In contrast, the Oil Glut served as a positive demand shock to oil which pushed down the short end of the oil futures curve but stimulated spot freight rates through increased demand for transportation services.

We evaluate the ex-post usage of chartered ships using geospatial (AIS) ship-tracking data. We find that charterers are reluctant to use vessels for floating storage even in cases when they would have had positive profits. We compare the storage profits with the alternative strategy of using the vessel for transportation but hedging the market exposure using Forward Freight Agreements. We set forth the alternative trading strategy as a possible explanation for why vessels on time-charter are sailing when they would have had positive storage profits during the Oil Glut. The alternative trading strategy consists of three steps. First, the charterer time-charters a vessel and pays the time-charter rate. Second, the charterer employs the vessel in the voyage charter market earning voyage charter freight rates. Third, the charterer hedges the voyage charter freight rate exposure from the second step by entering into the paper-based freight derivatives Forward Freight Agreements. In absence of basis risk, the profit of the trading strategy is the FFA time-charter spread.

We derive the excess storage profits above the FFA time-charter spread and find that it is a significant predictor of charterers storage decisions. A possible explanation for this finding is that the charterer simply chooses the most profitable trading strategy. However, the FFA hedged time-chartering strategy is subject to basis-risk and we also find that vessels with an age above 15 years are more likely to be used for floating storage. Panellists are specifically instructed to exclude vessels with an age above 15 years when they make their Baltic panel spot rate assessment i.e. their assessment of the FFA settlement rate.

Bargaining Power in Crude Oil Tanker Markets

In the third chapter, I study the relative bargaining power of geographical traders and shipowners in the crude oil tanker market. Recent studies by Brancaccio et al. (2017), Brancaccio et al. (2018), Parker (2014) and Tvedt (2011) look at the equilibrium search and matching between geographical commodity traders and shipowners in bulk shipping markets. An important aspect of the search and matching models is the subsequent bargaining process and the relative bargaining power of the involved parties.

I set forth a simple model of the matching between shipowners and geographical traders. In the model, shipowners make dynamic ballasting choices to maximize their continuation value. The model differs from the model by Brancaccio et al. (2017) in two important aspects. First, shipowners are able to re-evaluate which loading region to ballast towards along their ballast leg. Second, the matching function is estimated parametrically using an EM algorithm to account for unreported fixtures. Furthermore, I utilize information on refining margins earned by geographical traders to find the relative bargaining power. I find that geographical traders are generally in possession of more bargaining power than shipowners. On average I find that shipowners' bargaining power coefficients, i.e., the proportion of the total value that the shipowner is able to extract is 24%.

Danske resuméer

The Eye in the Sky - Freight Rate Effects of Tanker Supply

Medforfatter professor Nikos K. Nomikos

I det første kapitel ser vi på, hvordan fragtrate udviklingen for olietankskibe af klassen Very Large Crude Oil Carriers (VLCCs) afhænger af skibenes geografiske placering samt deres arbejdsstatus. Vi fremsætter et mål for kapacitet, der er baseret på en kobling af information om skibenes positioner fra skibenes Automatic Identification Systems, samt information på skibenes bilaterale handler.

Vi starter med at beskrive det geografiske handelsmønster i VLCC markedet. På baggrund af det observerede handelsmønster fremsætter vi en heuristisk regel, som angiver, hvorvidt et givent skib er tilgængeligt på markedet. Den heuristiske regel baserer sig på 1) information om skibenes position, 2) et selvrapporteret mål for, hvor dybt skibet ligger i vandet, 3) en selvrapporteret angivelse af skibets destination, samt 4) information om hvorvidt skibet allerede har indgået en handel. Vores kapacitetsmål giver en indikation af, hvor mange skibe, som er i stand til at indgå en aftale om transport af en last, opgjort i procent af det samlede antal skibe. Vores resultater angiver, at en nedgang i vores kapacitetsmål på en standardafvigelse (ved gennemsnitsværdier svarer dette til, at der er 14 færre skibe ledige på markedet) medfører en forøgelse i fragtraten på $0,56/mt. Dette svarer til en forøgelse på $151.200 for en typisk last på 270.000mt.

Crude Oil Contango Arbitrage and the Floating Storage Decision

Medforfatter professor Roar Adland

I det andet kapitel ser vi på en arbitrage handelsstrategi, hvor man køber olien 'spot' og sælger olien på et fremtidigt tidspunkt via en futureskontrakt. I den mellemliggende periode lagrer man olien i en lejet Very Large Crude Oil Carrier. En nødvendig betingelse for, at handelsstrategien er profitabel er, at oliefutureskurven har en positiv hældning. Når vi ser på time charter raterne fra broker indeks og time charter fixtures ser vi, at der har været mulighed for at opnå en positiv arbitrageprofit.

Vi ser også på, hvordan profitten forbundet med at lagre olie ser ud på tværs af tidshorisonter.

Efter finanskrisen ser vi, at profitten ved at lagre olie var højere for kortere horisonter end for længere horisonter. Finanskrisen fungerede som et negativt efterspørgselsstød, der pressede både den korte ende af oliefutureskurven og fragtratekurven ned. Modsat fungerede Oil Glut perioden som et positivt udbudsstød, der pressede den korte ende af oliefutureskurven ned, men stimulerede den korte ende af fragtratekurven gennem den øgede efterspørgsel efter transport.

Vi benytter AIS information til at se på ex-post anvendelse af de lejede olietankskibe. Vi ser, at lejerne af skibene undlader at bruge skibene til at lagre olie på trods af, at det ville have medført en positiv profit. Vi sammenligner profitten forbundet med at lagre olie med en alternativ handelsstrategi. Den alternative handelsstrategi består af tre skridt. Først lejes en VLCC på time-charter og aktøren betaler time-charter rater. Dernæst anvendes VLCC i voyage charter markedet, hvor aktøren tjener voyage charter rater. Til sidst hedges eksponeringen mod udsving i voyage charter raterne med Forward Fragt Aftaler (FFAs). Vi udregner, hvor meget profitten ved at lagre olie overstiger FFA time-charter rate spændet og ser, at dette er en signifikant prædiktor for lejernes beslutning om at benytte de lejede skibe til at lagre olie.

Bargaining Power in Crude Oil Tanker Markets

I det sidste kapitel, ser jeg på den relative forhandlingskraft mellem råvarehandlende agenter og skibsejere. Studierne af Brancaccio et al. (2017), Brancaccio et al. (2018), Parker (2014) og Tvedt (2011) ser på ligevægtsjobsøgningsmodeller for agenter, der handler geografisk med råvarer og skibsejere. Et vigtigt aspekt i jobsøgningsmodellerne er forhandlingen af fragtraten mellem de involverede parter.

Jeg opstiller en simpel matching model mellem skibsejere og de råvarehandlende agenter. I modellen vælger skibsejerne dynamisk, hvilken region de vil sejle i ballast til, således at valget maksimerer ejerens fortsættelsesværdi. Modellen adskiller sig fra modellen i Brancaccio et al. (2017) på to afgørende punkter. For det første tillader modellen, at skibsejerne kan genoverveje deres valg af region under ballast sejladsen. For det andet estimeres matching funktionen, der beskriver matchingen mellem arbejdsgiver og arbejdstager, parametrisk ved brug af en EM-algoritme for at imødegå problemet med ikke rapporterede handler. Endvidere bruges profitten fra rafinering af råolien til at bestemme den relative forhandlingskraft mellem skibsejere og de råvarehandlende agenter. Resultaterne angiver, at de råvarehandlende agenter generelt besidder en højere forhandlingskraft end skibsejerne. Skibsejerne får i gennemsnit 24% af handlens værdi.

Contents

Chapter 1

The Eye in the Sky - Freight Rate Effects of Tanker Supply

Frederik Regli and Nikos K. Nomikos

A revised version of this chapter has been published in Transportation Research Part E: Logistics and Transportation Review

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Abstract

We show how the evolution of crude oil tanker freight rates depends on the employment status and geographical position of the fleet of very large crude oil carriers (VLCCs). We provide a novel measure of short-term capacity in the voyage charter market which is a proxy for the percentage of vessels available for orders. We find that our capacity measure explains parts of the freight rate evolution at weekly horizons, where traditional supply measures are uninformative. The fact that freight rates directly influence shipowners' profitability and charterers' expenditures makes our measure particularly relevant for these groups of market participants.

Keywords— AIS, Crude Oil, Forward Freight Agreements, Freight Rates, Tanker Markets, VLCC.

1.1 Introduction

Tanker freight markets are central to the distribution of crude oil which is the largest component of global energy consumption[1]. The tanker shipping industry is a cyclical and highly volatile industry

[1] According to of World Energy (2017) oil covered 33.27% of the global energy consumption in 2016. Oil is followed by coal and natural gas covering 28.11% and 24.13%, respectively, of the global energy consumption in 2016

characterised erratic fluctuations in freight rates - a stylized fact which is often attributed to short-term fluctuations in the balance between supply and demand. Recently, geospatial information on vessel movements has become available from the radio signals sent by vessels' Automatic Identification Systems (AIS). AIS information enables freight market participants to track the movement of vessels within any commercial segment providing them with a detailed view of the supply side in freight markets. We study the voyage charter market for very large crude oil carriers (VLCC). We combine AIS information with information on vessel fixtures and propose a novel measure of available short-term capacity. Our capacity measure is negatively related to change in freight rates over a weekly horizon, where traditional supply measures are uninformative. Furthermore, we show that our capacity measure adds to the freight rate price discovery above and beyond what is already explained by the FFA price. The fact that freight rates directly influence shipowners' profitability and charterers' expenditures make our measure particularly relevant for these market participants.

In tanker markets, the international trade of crude oil determines the demand for tanker services. The merchant fleet supplies charterers with tanker services, and the balance between demand and supply sets the level of competition. Stopford (2009) advocates a distinction between long-run supply and short-run supply of shipping services where our measure focuses on the latter.

In the long-run, the merchant fleet evolves with the levels of investment and scrapping. The pioneering works of Tinbergen (1931), Tinbergen (1934), Koopmans (1939), and Zannetos (1966) describe the cyclical interdependence between ship investment and freight rates. In the cycle, high freight rate levels stimulate shipbuilding which in turn puts a downward pressure on freight rates as it increases the size of the fleet. The early work laid the foundation for the structural equation models of the four shipping markets: the freight market, secondhand market, newbuilding market, and scrap market, (Hawdon, 1978; Norman and Wergeland, 1981; Charemza and Gronicki, 1981; Strandenes, 1984; Beenstock and Vergottis, 1989; Tvedt, 2003; Adland and Strandenes, 2007; Karakitsos and Varnavides, 2016). Recent studies by Papapostolou et al. (2014), Kalouptsidi (2014) and Greenwood and Hanson (2015) look at investment sentiment and outcomes in dry bulk market. Kalouptsidi (2014) shows the effect of time-to-build on investment in newbuildings and scrapping of existing vessels. Greenwood and Hanson (2015) develop a behavioural model in which shipowners over-invest. The over-investment is partly caused by over-extrapolation of demand shocks and partly by the negligence of competitors' investments in newbuildings.

In the short-run, the size of the merchant fleet is fixed or predetermined by the order book for new vessels. In a perfectly competitive market, freight rates are set such that they just compensate the operational costs of the marginal vessel. Demand is inelastic with respect to the freight rate, and the supply curve consists of two regimes, (Stopford, 2009). For low demand levels the supply curve is very elastic as spare tonnage with similar operational costs is easily available. However, as demand increases vessels with higher operational costs, typically older vessels, enter the supply schedule. This continues to the point where no spare capacity is available. When the fleet is fully utilized, supply can only increase if vessels speed up operations. By increasing speed vessels can increase the number of ton-miles supplied over a year. However, increasing speed also increases the operational costs as bunker consumption is convex in speed. We study the case of weekly fluctuations in supply. We argue that in the short-run some vessels are unavailable for charterers. A vessel may already have found new employment, it may lack the geographical proximity to a specific loading area or its course and reported destination may suggest that it is heading for another loading region.

To the best of our knowledge, we are the first to study how AIS derived capacity measures can be used to explain the evolution of freight rates. The previous literature based on AIS information include Aßmann et al. (2015) and Adland and Jia (2016) who empirically investigate vessels' speed decisions in a Ronen (1982) model framework. In addition to being an important supply metric, vessel speeds are a key determinant of vessels' bunker consumption and thereby vessels' emission of greenhouse gases. Aßmann et al. (2015) study the speed relation for VLCC tankers, and Adland and Jia (2016) study the speed relation for Capesize carriers. Both studies find that owners do not set speed in accordance with the Ronen (1982) model. Adland and Jia (2016) suggest that the deviation from the economic theory is caused by weather conditions and contractual frictions such as charter party speed clauses[2]. Adland, Jia and Strandenes (2017) find that AIS-based volume estimates for tankers align well with custom-based export numbers. Jia et al. (2017) estimate potential fuel savings by calculation of the optimal virtual arrival point for vessels, which limits waiting time of vessels at port. Closely related to our paper, Prochazka (2018, Chapter 1) looks

[2]A charter party speed clause specify the speed at which a vessel must operate during a voyage charter. See Devanney (2011).

at contracting decisions in the VLCC tanker market. In the paper, they find a contemporaneous relationship between the freight rate level and the distance from the fixture location to the loading port. This suggests that oil buyers secure tonnage earlier during strong tanker markets, i.e., when the freight rate is high. The methodology and aim in our paper are fundamentally different from their approach as we consider different types of AIS measures. Furthermore, we aim to explain the evolution in freight rates rather than the contemporaneous relationship between AIS measure and freight rates.

Brancaccio et al. (2017) use AIS information to study search frictions and the interplay between endogenous trading costs and trade flows in dry bulk markets. They find that the matching between exporters and ships is subject to search frictions. In contrast, we do not model the matching between exporters and ships or the dynamic ballasting choice of shipowners. Instead, we show that the observed number of seemingly unmatched ships explains parts of the freight rate evolution. In a follow-up paper, Brancaccio et al. (2018) study the impact of oil prices on world trade. They show that the elasticity of world trade is asymmetric and flattens out as fuel costs decline. Their explanation for the flattening out is that shipowners' bargaining power increases as relocation of the vessel becomes cheaper. Parker (2014) sets up a matching model between VLCC tankers and cargo traders. In the sample period used in Parker (2014), the AIS data lacked coverage especially in regions with a high number of ships transmitting AIS signals. Parker (2014) uses AIS data as a validation tool for the speed outcomes of the matching model.

In addition to traditional supply measures, FFA prices have been shown to contain important information regarding the price discovery of spot freight rates[3]. The FFA literature has looked FFAs ability to forecast future spot freight rates (Kavussanos and Nomikos, 1999, 2003; Batchelor et al., 2007), their hedging efficiency and the volatility transmission between the FFA market and the physical freight market (Kavussanos, Visvikis and Batchelor, 2004; Kavussanos et al., 2010,0; Alizadeh, Huang and van Dellen, 2015; Alexandridis et al., 2017). We find that our AIS measure contains additional information about the freight rate evolution above and beyond what is already incorporated by the FFA price. Supply measures influence on the freight rate volatility is studied in Xu et al. (2011). They analyze how the freight rate volatility depends on the

[3]Whenever, we use the term spot rates we mean voyage charter freight rates.

size of the commercial fleet. However, studying the volatility transmission between our AIS supply measure and freight rates is beyond the scope of our paper and therefore left to future research.

In summary, the existing AIS based papers have studied ship-operators dynamic speed choice, the presence of search frictions in the matching process between ship-operators and charterers, or the contracting decision by charterers. The approach and findings of our paper deviates from the existing papers. We create an empirical proxy of the level of supply in tanker markets. Our classification of vessels as available or unavailable is based on the historical fixing pattern in the VLCC spot market. Based on the fixing pattern, we set up our measure of spare capacity. We show that our is able to explain the evolution in freight rates at short horizons where traditional supply measures are uninformative. Furthermore, we show that our spare capacity measure is able to explain the evolution in spot rates above and beyond what can be explained by FFA prices. The economic magnitude of our results shows that at the average freight rate level in our sample, a standard deviation decrease in our capacity measure (decrease of 14 available vessels) leads to an increase in the freight rate level of \$0.56/mt. This corresponds to an increase in the gross freight revenue equal to \$151,200 for a typical cargosize of 270,000mt. Interestingly, we also see that the lagged change in the average speed of vessels sailing in ballast significantly predicts the evolution in the spot freight rates. This implies that vessels sailing in ballast on average decrease(increase) speed prior to an decrease(increase) in freight rates.

The outline of the rest of the paper is as follows: Section 1.2 describes how we construct our capacity measure and describes the AIS data; section 1.3 contains summary statistics, time-series plots and unit root tests; section 1.4 shows the estimation results; and section 1.5 concludes.

1.2 Construction of the capacity measure

The traditional structural econometric models of freight rates [4] are estimated using realized demand and the available fleet capacity. In these models, supply is measured by the size of the commercial fleet. The traditional models relies on realized ton-mile demand and does not consider spatial factors determining the availability of vessels such as distance to a loading area or the

[4]See Hawdon (1978), Norman and Wergeland (1981), Charemza and Gronicki (1981), Strandenes (1984), Beenstock and Vergottis (1989), Tvedt (2003), Adland and Strandenes (2007), and Karakitsos and Varnavides (2016)

employment status of the vessels. Our measure seeks to incorporate exactly these two features. We seek to identify the vessels that are available to provide tanker services irrespective of whether they end up supplying tanker services in equilibrium.

To fix ideas, let us consider supply and demand in a perfect competitive tanker market. Under perfect competition, each individual shipowner will supply transportation services when she breaks even, i.e. is offered a freight rate which compensates the shipowner's voyage costs[5]. Voyage costs consist of fuel expenses, port charges, and possibly canal-dues. The main voyage cost is the fuel-expense which increases along with fuel prices and speed. The aggregate supply curve for all vessels will then, for any given level of ton-miles, reflect the fact that the freight rate only just compensate the marginal shipowner her voyage costs. Our approach differs from the traditional supply and demand models as we proxy the potential future supply rather than using past realizations of supply.

Figure 1.1 shows the short-run equilibrium freight rate and ton-miles quantity. The figure shows the effect of a demand shock for low and high levels of demand when spare capacity is low and high, respectively. We consider the effect of a positive demand shock which can be caused by either an increase in cargo quantities, an increase in the average voyage haul or both. The shape of the supply curve depends on bunker prices, bunker consumption which in turn depends on the level of vessels speeds, and the number of vessels available as spare capacity. In Figure 1.1, we assume that the only difference between the two supply curves is the number of vessels which are available to charterers.

We start by considering a positive demand shock when the level of demand is low. This is the case in Figure 1.1 where a positive demand shock shifts the demand curve from D_1 to D_2. The positive demand shock has negligible freight rate effects as both supply curves are almost perfectly elastic. By contrast, a positive demand shock in the high demand case shifts demand from D_3 to D_4. This causes a substantial increase in freight rates in the low-capacity case. In the short

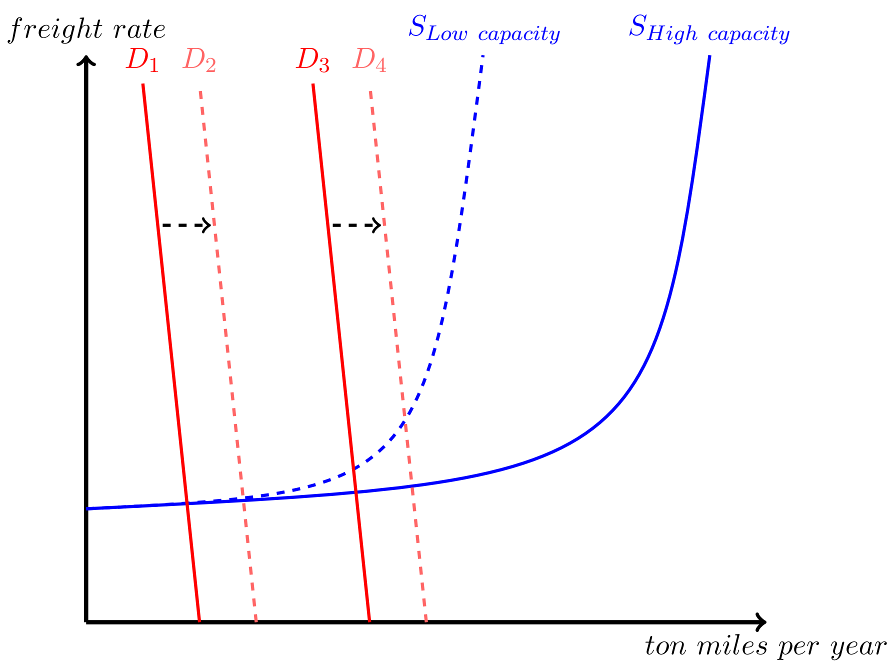
[5]In practice, shipowners needs to generate income to cover their capital expenditures. This implies that vessels have positive earnings measured by their time-charter equivalent. Koekebakker et al. (2006) show that earnings are stationary such that earnings mean-revert towards a certain level above the voyage costs. Adland and Strandenes (2007) show how freight rate levels occasionally deviate significantly from the cost of the marginal vessel. This is uncontroversial as ship-owners will also need to cover crew wages and capital expenditures in the long-run.

run, spare capacity in a given loading region will depend on the geographical proximity of vessels, whether they are sailing laden or in ballast, and their trading status. We set forth a proxy for the number of available vessels using AIS and fixture information. The number of open vessels are influenced by past trades as vessels can only transport one cargo at a time. Furthermore, a vessel needs to satisfy geographical proximity restrictions to be open for an order at a given loading region. We proxy the number of vessels open for a fixture by:

$$Available\ Vessels_t = K_t(1-\lambda_t^{unavaible}) = \sum_{i=1}^{K_t}(1-\mathbb{1}\{Fix_{i,t}=1\})\cdot \mathbb{1}\{Proximity_{i,t}=1\}, \quad (1.1)$$

where K_t is the active[6] stock of fleet, $\lambda_t^{unavaible}$ is the fraction of vessels in the fleet which are unavailable, $\mathbb{1}\{Fix_{i,t}=1\}$ is an indicator function which equals one when vessel i is employed, and $\mathbb{1}\{Proximity_{i,t}=1\}$ equals one when vessel i satisfies a proximity restriction. We normalize our measure of open vessels with the size of the fleet. Before we get to the econometric model and the results, we will describe our data and explicitly show how we set up our capacity measure.

Figure 1.1: **Supply and demand:**
This figure shows the static supply and demand equilibrium for short-run tanker services under conditions of perfect competition. The supply curve equals the operational costs of the marginal vessel for a given level of ton-miles per year.



[6]Active vessels are vessels which have been delivered for service and have not yet been scrapped. We exclude the fleet of the National Iranian Oil Company (NIOC) which faced embargo restrictions in our sample period. NIOC does not publicly report their fixtures.

1.2.1 Data and sample

In this section, we describe the data. The data consists of vessel specific information, voyage charter information, and time charter information from Clarkson's Shipping Intelligence Network (2016), Automatic Identification System information has kindly been provided by MarineTraffic. We use voyage charter fixtures data, and time charter fixtures data from Bloomberg L.P. (2016). Forward Freight Agreement data is from the Baltic Exchange.

Spot freight rates are provided by the Baltic Exchange. Each day the Baltic Exchange publishes a range of freight rate indices for a variety of routes and ship segments. We look at the TD3 tanker route, which is a VLCC route for a 265,000 mt cargo of crude oil from Ras-Tanura in the Arabian Gulf to Chiba in Japan[7]. The voyage roundtrip has a distance of 6,654nm for both the laden leg and the ballast leg. The roundtrip voyage takes approximately 50 days assuming a laden speed of 13.5 knots, a ballast speed of 12 knots, a sea margin of 5% and 4 port days. The TD3 index is an index based on daily assessments regarding the prevailing spot rate provided by a panel of ship brokers. We use rates published each Friday to construct a weekly time series of the spot rates. Spot freight rates are denominated in Worldscale (WS) and have been converted to $/mt using the corresponding flat rates published by the Worldscale Association. We also include the Forward Freight Agreement price for the TD3 route. FFAs are a derivative contracts trading over the counter (OTC). The FFAs are cleared via a clearing house. The 1-month FFA contracts are settled in cash against the average of following months realized spot rates. See Alizadeh and Nomikos (2009) for a detailed description of FFAs and their usage.

Our measure relies on terrestrial and satellite-based AIS information. The International Maritime Organization's revision of the Safety for the navigation of life at sea (SOLAS) made it mandatory for vessels engaged on international voyages and weighing more than 300 gross tonnage to install an AIS transponder. This also applied to all passenger ships. We observe AIS reports at varying frequencies. Most of the time, we observe a vessel at high frequencies, such that adjacent observations are two to three minutes apart, but in a few cases observations can be days or even weeks apart. We clean the data for outliers, i.e., observations where the vessel position briefly

[7]The TD3 route is the benchmark route within our sample period. The route has recently, since 22 January 2018, been replaced by the new TD3C route which loads in the Arabian Gulf and discharges in China.

jumps far away from the vessel's trajectory only to return to the trajectory at the next observation. We group intraday observations into daily observations for each vessel with an average speed and average draught. The draught of a vessel is the distance between the waterline and the bottom of the hull. Within our sample period from November 2014 to August 2016, we have AIS information on 676 VLCCs out of the 688 vessels present in the Clarkson's database. The AIS reports contain a time stamp as well as the vessel's latitude, longitude, course, speed in knots, self-reported draught, and self-reported destination. The self-reported fields are manually typed by a crew member. Occasionally, the self-reported fields are not up to date and at time they are even deliberately misleading. For instance we observe that crew members in certain areas report that they have armed guards on board in their destination slot. In the period where the crew signal that they have armed guards on board, they often also change their draughts to reflect that they are sailing in ballast. Loaded vessels are closer to the water surface where the vessel is easier to board by pirates. This obviously introduces some noise into our measure. However, we do not believe that the noise strengthens our results.

Table 1.1: **AIS data summary statistics**
This table shows summary statistics for 360,350 daily vessel observations on the loading condition and vessel speeds.

	Median	Average	Std	Laden(%)	Ballast(%)	Unknown(%)
Speed	11.41	8.87	5.51			
Ballast speed	10.86	8.70	5.69			
Laden speed	11.72	9.01	5.35			
Loading condition				53.59	44.20	2.21

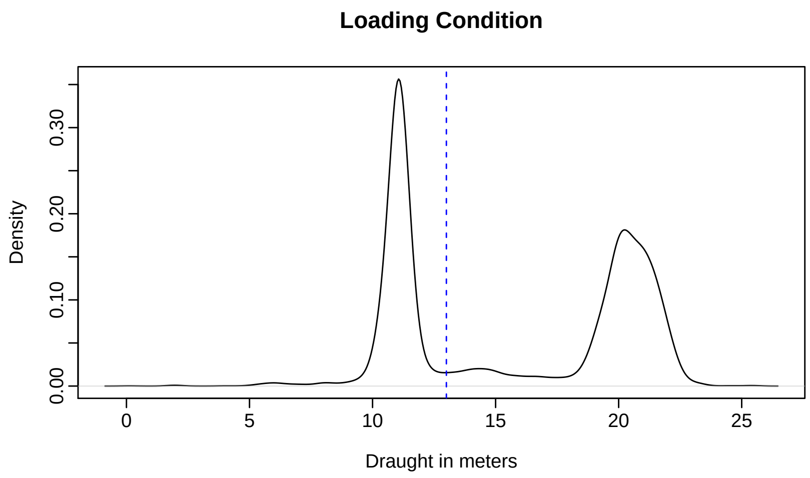
We have translated the manually typed destinations into geographical regions. Some destinations are straightforward to translate into regions as seen in the example in Table 1.2. Others are translated using port codes, e.g., AE FAT is translated into the Arabian Gulf as AE is the country port code for the United Arab Emirates. Sometimes, we are unable to translate the destination message into a geographical region. This is the case for messages such as ARMED GUARDS O/B, AVOID TYPHOON, DIVING OPERATION, FOR ORDERS, SEA TRIAL, etc.

Table 1.2: **Translation of destinations into regions example**
This table shows an example on how manually typed messages for vessels heading to Rotterdam are translated into a geographical region.

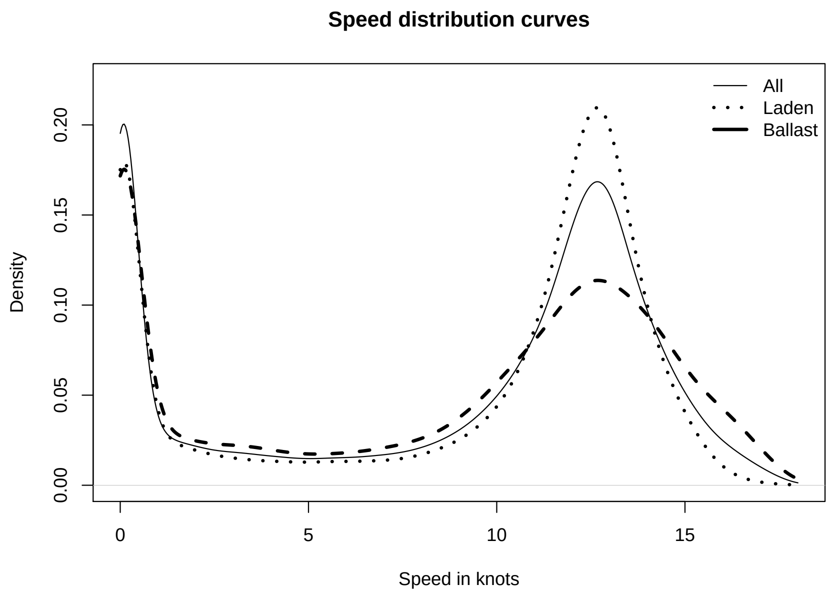
Destination	Translated region
ROTTERDAM, NL	UK AND CONTINENT
ROTTERDAM,NETHERLAND	UK AND CONTINENT
ROTTERDAM.NETHERLAND	UK AND CONTINENT
ROTTERDAM.NETHERLANM	UK AND CONTINENT
ROTTERDAME	UK AND CONTINENT
ROTTERDAMM	UK AND CONTINENT
ROTTERDAM-MET	UK AND CONTINENT
ROTTERDAM-OPL	UK AND CONTINENT
ROTTERDAN	UK AND CONTINENT
ROTTERDAR	UK AND CONTINENT

The sample period is from November 2014 to August 2016. We note that within our sample there is almost no coverage in the period between 23-27 May 2015. We determine the loading condition of the vessels from their reported draughts. Figure 1.2 shows the distribution of draughts and vessel speeds for daily observations. The figures show two-humped distributions. For draughts we use a cut-off point of 13 metres to distinguish between laden and vessels in ballast. For vessel speeds, we also see a bimodal distribution with a mode around zero knots and a mode around 12.70 knots.

Figure 1.2: **Loading condition and speed distribution**
This figure shows the distribution of reported draughts and speed density curves for daily data. The speed density curves are plotted for all vessels, laden vessels, and vessels in ballast. In panel (a), the vertical dashed line at 13 metres indicates the cut-off above which we consider vessels as laden. Panel (b) shows that the speed curves also are bimodal. There is a mode around zero knots and a mode for sailing vessels at approximately 12.70 knots.



(a) Loading condition



(b) Speed distribution curves

In our analysis, we use the average speed of the fleet. We calculate each vessels average speed over the week and then calculate the average fleet speed as the average across all vessels.

We use information on fixtures from Clarkson and Bloomberg. Clarkson's shipping intelligence network contains 4582 VLCC voyage charters from 1 January, 2014 to 31 August, 2016 and provides information on the day of the fixture, the start and the end of the laycan period[8], the loading region, the discharge region, the agreed voyage charter rate, the charterer, the shipowner, and the cargo quantity. The Bloomberg dataset comprises voyage charter and time charter information. We use data from both sources to increase our coverage of observed trades. The use of multiple sources also introduces duplicates of trades. Often, the day a voyage charter is reported differs across different sources. The Bloomberg dataset only contains information on the beginning of the laycan period and not the end. We will use the fixtures to determine whether a vessel is available or whether she has already entered into a new charter party. For this purpose, we use the ship's IMO number, the date that the fixture is reported, and the end of the laycan period for Clarksons fixtures, and the beginning of the laycan period for Bloomberg fixtures. A set of voyage charter duplicates will mark a vessel as fixed in overlapping periods. Within the sample, 212 voyage fixtures cannot be matched to a vessel. For 178 of the voyage charter fixtures, both the vessel and the owner group is unknown whereas the owner group is known for the remaining 34 voyage charters.

1.2.2 Trading Locations

In order to define our measure of availability, we analyze the geographical distribution of the reported fixtures. As we focus on freight rates for the route between the Arabian Gulf and the Far East we are interested in vessels we can label unavailable for voyage charters with a loading port in the Arabian Gulf. When labeling vessels as available we combine both AIS information and information from fixtures. We incorporate AIS information on the vessels' positions, their self-reported draughts and their self-reported destination. We combine the AIS information with the fixtures information to proxy which vessels that have already found new employment. We use information on the day the fixture is reported and the laycan period. When a vessel enters a fixture, it will be considered unavailable from the day the fixture is observed until five days past its laycan. On the sixth day after the laycan period, the vessel will still be considered unavailable if it is not sufficiently close to its discharge region. Our measure is set up to mimic the geographical trading locations of VLCCs which are loading in the Arabian Gulf. In this section, we show that

[8] The laycan period is the time window within which the shipowner must tender notice of readiness to the charterer. The notice of readiness ensures the charterer that the ship has arrived at the loading port and is ready to load the cargo.

vessels which are "fixed" (entering into new voyage charter contracts) to load a cargo of crude oil from the Arabian Gulf are typically sailing in ballast back from the Far East and the South East Asian region. However, laden vessels which approach their discharge destinations also enter new fixtures.

We start by looking at the trading locations for vessels sailing in ballast. Figure 1.3 shows 1064 positions for vessels reported as *"fixed"* with a loading port within the Arabian Gulf. The locations are graphed on the day where the fixtures are reported. We have translated the self-reported destinations into destination regions. The trading pattern shows that vessels are entering new fixtures throughout the entire ballast leg. In 614 of the cases, vessels report the Arabian Gulf as their destination when their fixture is reported. However, east of the Strait of Malacca vessels also report either the Southern Pacific Oceania Region (SPORE)[9] or the Far East as their destination. Vessels heading for the SPORE region continue their ballast leg towards the Arabian Gulf. Three hundred and sixteen have the SPORE region as their reported destination when the fixture is reported. The Far East comes in third with 74 reports. The Far East vessel reports consist of two types. The first type consists of vessels still in port. The second group comprises vessels which have started sailing their ballast leg but have not yet updated their self-reported destination. As mentioned earlier, some of the self-reported entries are not always up to date at all points in time. The vessels with unknown destination reports typically report that they have armed guards on-board, or that they are open for orders[10].

We turn to the trading locations for laden vessels which *"fix"* with a loading port within the Arabian Gulf. Figure 1.4 shows the location for laden vessels at the time when their fixture is reported. The figure shows how laden vessels enter into new voyage charters as they approach their destination region. We see vessels heading for West India and East India entering new trades along the East African coast. Additionally, vessels approaching Sikka, Vadinar, and Jamnagar in the Gulf of Kutch enter new trades. Vessels closing in on Visakhapatnam and Paradeep in the Gulf of Bengal enter new fixtures as well. We see similar patterns for vessels heading for the SPORE

[9]SPORE consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam.

[10]Figure 1.8 in appendix 1.6 shows the fixing pattern for vessels in ballast which will load in West Africa. We distinguish between vessels heading for the Arabian Gulf and West Africa by adding a condition. We categorize vessels with a southwest bound course, positioned south of the latitude of 3.9 degrees as vessel heading towards West Africa even if they report a destination within the Arabian Gulf.

Figure 1.3: **Locations where vessels in ballast enter fixtures with a loading port in the Arabian Gulf**

This figure shows the trading locations for 1064 voyage charters for vessels in ballast with a loading port within the **Arabian Gulf**. The distribution of the reported destinations is 614 within the Arabian Gulf, and 316 within the SPORE region. The SPORE region consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. Seventy-four are heading towards the Far East which covers China, Japan, South Korea, and Taiwan. Thirty-two has an unknown destination, 14 are heading for the East Coast of India, 6 for West Africa, 3 for West Coast of India, and 5 have other destinations. The vessels with an unknown destination signal that they are open for orders or that they carry armed security guards.

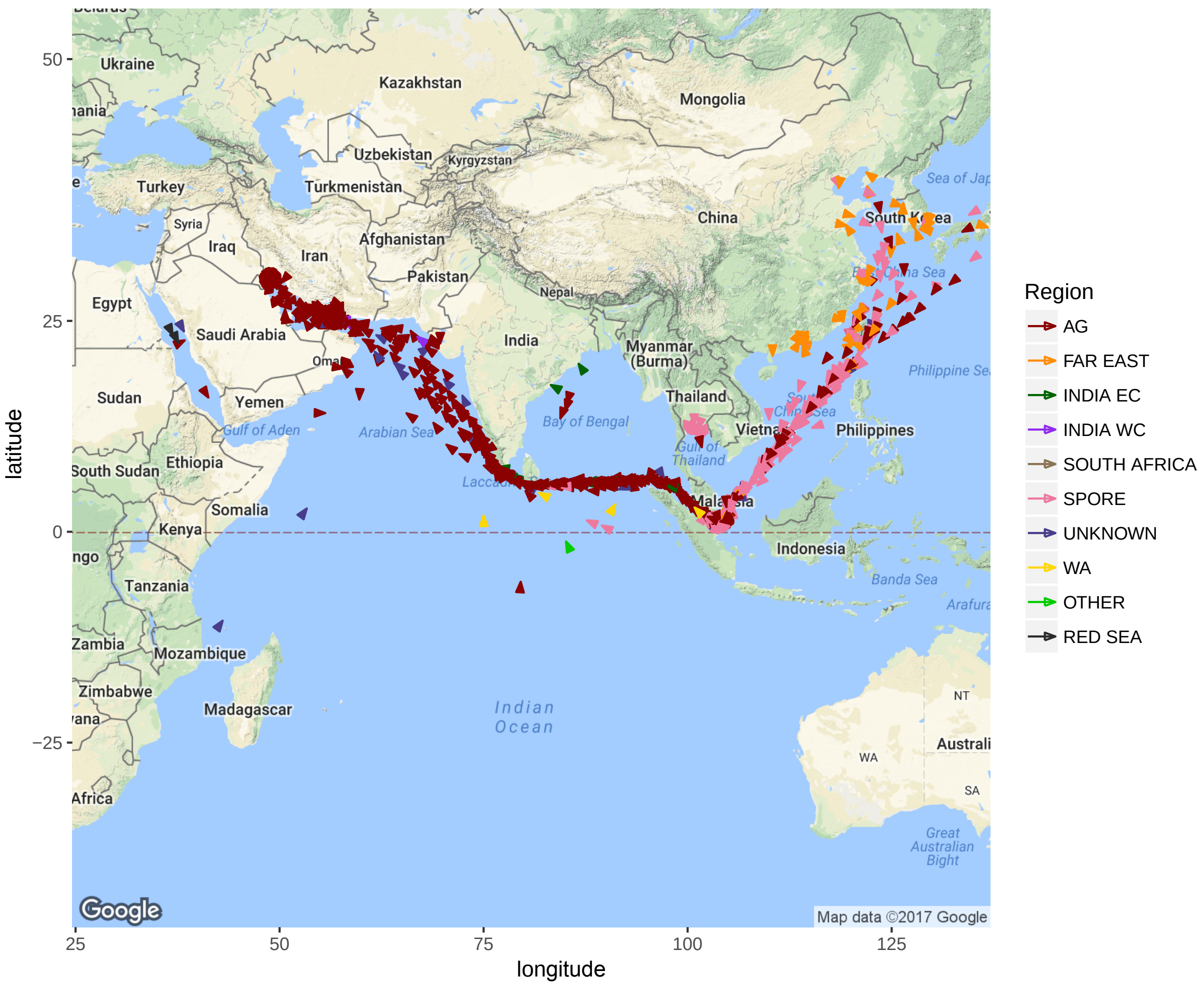
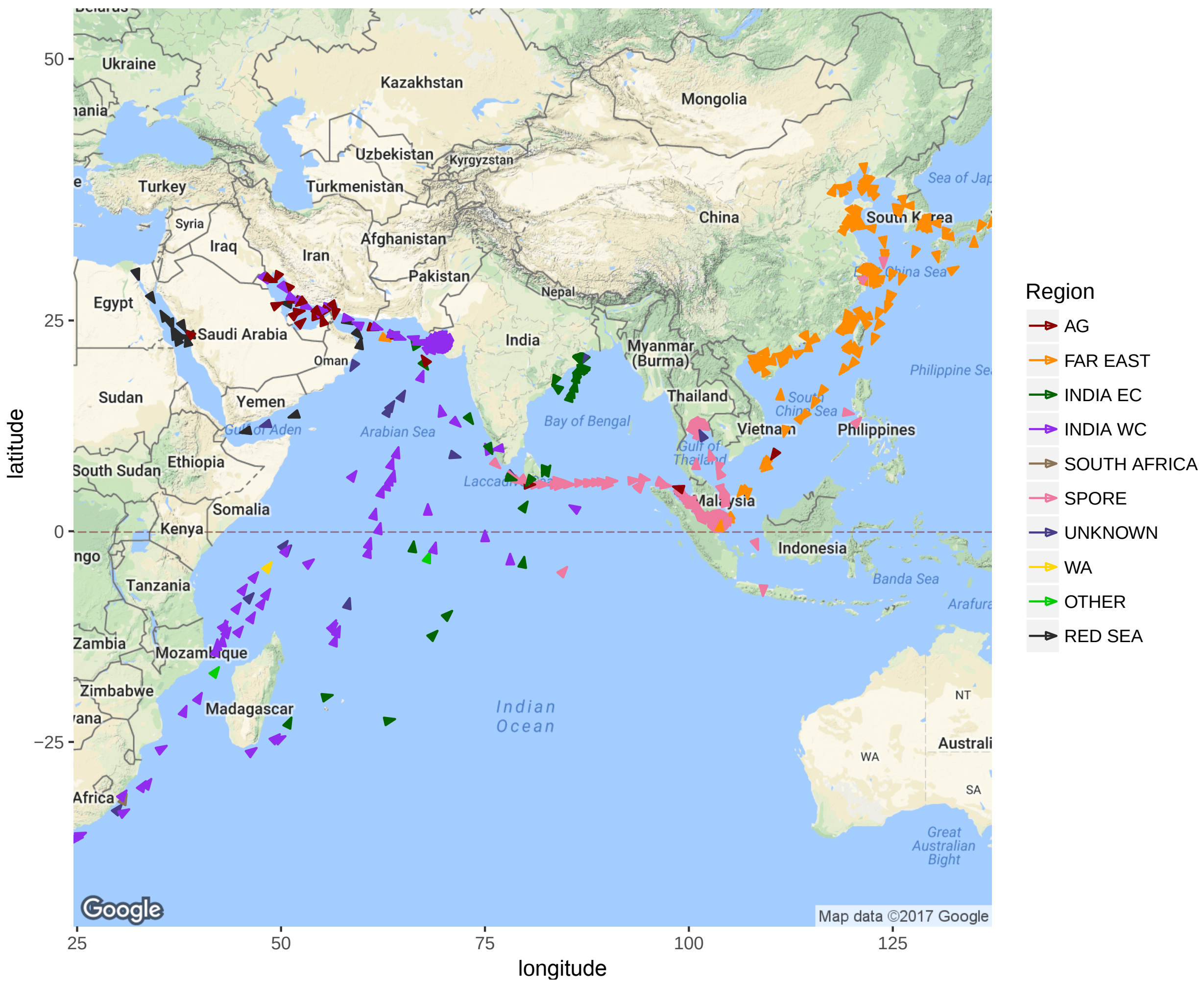


Figure 1.4: **Locations where laden vessels enter fixtures with a loading port in the Arabian Gulf**
This figure shows the trading locations for 495 voyage charters conducted by laden vessels. The voyage charters all have a loading port in the **Arabian Gulf**. One hundred and fifty-three are heading for the Far East which covers China, Japan, South Korea, and Taiwan. One hundred and fourth-three are heading for the SPORE region, which consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. Ninety-seven are heading for West India, 38 for East India, 24 sits in the Arabian Gulf, 17 has an unknown destination, and 23 have another destination. The vessels with unknown destination mainly signal that they have armed guards on-board.



region and the Far East. They also fix as they get close to their discharge port. Vessels going towards the SPORE region start trading just west of the tip of India whereas vessels heading for the Far East trade from just east of Singapore. A few laden vessels sitting in the Arabian Gulf are also being chartered. In the smaller region segments, there are vessels heading for Egypt within the Red Sea, and the Gulf of Aden[11].

In summary, vessels in ballast enter into new voyage charters along the entire ballast leg from the Far East and South East Asia to the Arabian Gulf. We also see that laden vessels enter new voyage charters as they get close to the port of discharge. We will now set up the availability measure based on the geographical trading patterns we have described in this section.

1.2.3 Construction of the Capacity Measure

In this section, we define our availability measure. The measure reflects the number of vessels open for a voyage charter with a loading port within the Arabian Gulf divided by the number of active vessels. The measure reflects the trading patterns as well as the employment status of the fleet. The geographical component is based on AIS information and is chosen to match the trading patterns described in section 1.2. The ratio is the percentage of vessels *available* for spot trading divided by the of all *active* vessels in the VLCC fleet:

$$Ratio_t = \frac{Available\ Vessels_t}{Active\ Vessels_t}. \tag{1.2}$$

We expect the level of competition to increase when the ratio increases, as the number of VLCCs available for spot trading increases with the ratio. The ratio is one when all active vessels are also available for spot trading; this reflects a scenario of fierce competition among shipowners for cargoes going out of the Arabian Gulf. The opposite extreme is when the ratio approaches zero. In this case, all vessels have either already found new employment or are not satisfying the geographical restrictions. This resembles a situation where cargo owners in the Arabian Gulf face difficulties in securing ships for their cargoes and are forced to pay premium rates in the spot market.

[11] In Figure 1.4 it looks as if a vessel is laden in the Suez channel, which is not possible for a VLCC. This is not the case, however, as the tip of the arrows indicates the exact location of a vessel. VLCCs do use the Suez channel. When they do, they offload part of their cargo which then gets transported by a pipeline and later reloaded onto the vessel.

Active vessels

At any given point in time, we consider a VLCC *active* if she has been delivered for service and is trading in the market. We discard the vessels of the National Iranian Oil Company (NIOC). Before 16 January 2016, Iran faced embargo restrictions from the European Union and the United States of America. From the AIS data, we can see that NIOC vessels carry out voyages to the Far East both before and after 16 January, 2016. They do not show up in our sample of publicly reported fixtures, however, and for this reason, we discard the NIOC vessels from our analysis.

Available vessels

We characterize a vessel as *available* if she satisfies certain geographical restrictions and has not already entered into a new voyage contract. Starting with the geographical restriction, a vessel is available if she is either sailing in ballast towards the Arabian Gulf, or carrying cargo and about to reach her destination. To be explicit about our restrictions, a vessel is available if:

1. She is in **ballast** and within a sailing distance of 6264 n.m. of the Arabian Gulf[12], which is equivalent to 18 days of sailing at 14.5 knots. Furthermore, she has to have a self-reported destination within the Arabian Gulf or the SPORE region[13]. We exclude vessels heading towards West Africa by removing vessels in ballast positioned south of the latitude of 3.9 on a southwest-bound course, i.e. courses between 90° and 270°. In addition, we also consider vessels in ballast with a self-reported destination in the Far East within 2000 n.m. of Chiba. We do this to account for the vessels in ballast that fix from a port in the Far East, and the vessels which have started their ballast leg but not yet updated their destination status.

2. She is **laden**, has a self-reported destination within West Coast India or East Coast India, and is within 4000 n.m. of Sikka[14][15].

3. She is **laden**, has a self-reported destination within the Far East[16], and is within 2000 n.m. of Chiba, Japan[17].

[12] Figure 1.9 in appendix 1.7 illustrates the boundary.

[13] Some vessels use the self-reported destination field to indicate that they are available. An example is a self-reported destination being "FOR ORDERS" or simply "ORDERS". These are considered available in addition to vessels with destinations within the Arabian Gulf.

[14] Figure 1.10 in appendix 1.7 illustrates the boundary.

[15] Vessels sailing along the East Coast of Africa typically change their destination to signal that they have armed guards on-board. To mitigate this feature, we also consider laden vessels less than 4000 n.m. from Sikka as available.

[16] The Far East covers China, Japan, South Korea, and Taiwan

[17] Figure 1.11 in appendix 1.7 illustrates the boundary.

4. She is **laden**, has a self-reported destination within the SPORE region and is within 1740 n.m. of Singapore[18].

Lay-up and floating storage

A vessel will also be unavailable to charterers if she is in lay-up or used for floating storage. Vessels in lay-up will typically switch off their transponder and are therefore not included in our sample of available vessels; at the same time, a vessel in hot lay-up near Singapore will potentially be misclassified as available when she satisfies the geographical restrictions. Similarly, vessels on time charter, which are reported to be used as floating storage facilities are classified as unavailable.

Trading status

In addition to the geographical restrictions, we also limit availability based on the trading status of the individual vessels. Vessels can be unavailable for charterers if they have already entered into a voyage charter or a time charter. A voyage charter contract yields a lump sum payment for a voyage from port A to port B, and the shipowner is responsible for paying port fees, fuel costs, and crew wages. In the case of a time charter, the charterer leases the vessel for a specific period, which can range from a couple of months to several years. The charterer pays the shipowner a daily hire and is responsible for paying port fees, and fuel costs, in contrast to the voyage charter.

It is obviously harder to determine whether a vessel on a time charter is competing for voyage charter fixtures. As an example, consider a vessel which is time-chartered by an oil company. The vessel can then be internally employed and will not be competing in the voyage charter market. However, if the oil company is unable to employ the vessel internally they have the option to let the vessel compete for fixtures in the voyage charter market. We have chosen to consider vessels which are time-chartered by oil companies as unavailable. However, we do consider vessels which are time-chartered by shipping companies or operators as available.

We will now turn to the availability restrictions for vessels in the voyage charter market. Naturally, once a vessel enters into voyage charter, it is expected that she will stop being available in the spot market. This is not always the case. There are cases of a vessel being reported as

[18]Figure 1.12 in appendix 1.7 illustrates the boundary.

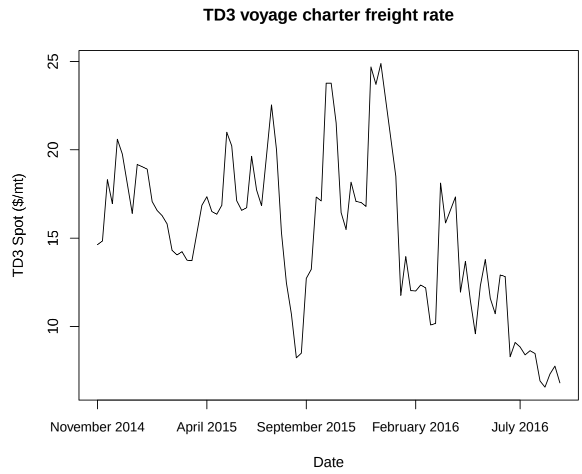
fixed, only for this to fall through after a few days (in which case the charter is said to have "failed on subjects"). We therefore observe vessels entering into multiple voyage charters within time windows that do not allow for both fixtures. We do not have data on which fixtures that fail on subjects. We disregard this issue and consider a vessel ineligible for additional trading once she has secured employment. We use the reported day of the fixtures and information on the laycan period to capture the feature that vessels become unavailable once they have traded. The laycan period is the time window within which the shipowner must tender notice of readiness to the charterer. The notice of readiness announces that the ship has arrived at the loading port and is ready to load the cargo. We consider a vessel as restricted from trade from the day the fixture is reported and until 5 days after the last known laycan day. The five days are added as vessels do not always update their self-reported draught immediately after loading. Most vessels continue to carry out their fixture five days past the last laycan day. They should therefore not be considered available. This is picked up by the geographical restrictions. Five days past the last known laycan day, the vessels have changed their draught report and will then be considered laden. Whether the vessel is then considered available depends on its sailing distance to its destination region.

1.3 Summary Statistics

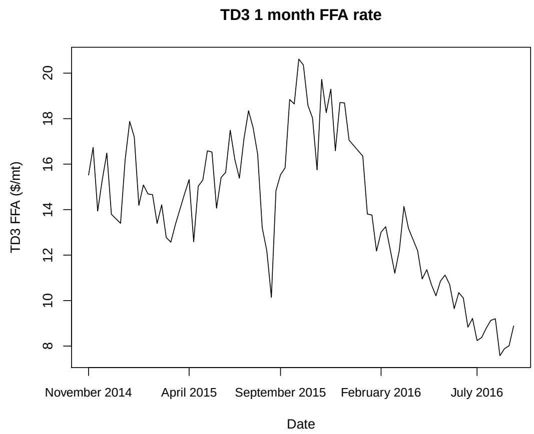
We will now provide summary statistics and unit root tests for the time-series. Figure 1.5 and Figure 1.6 show time series plots of the TD3 spot, the FFA rate, the Ratio, the average speed of the fleet in knots, the average speed of laden vessels in knots, the average speed of vessels in ballast measured in knots, bunker prices in $ per metric ton, fleet size measure in the number of vessels, and Clarkson's time-series of vessels due to arrive in the Arabian Gulf within the next four weeks.

Table 1.3 lists the range, median, average, and standard deviation for both the levels and log differences of the series. The voyage charter freight rate has an average over the sample period of \$14.9/mt and ranges between \$6.5/mt and \$24.9/mt. The ratio has an average of 33.8% and ranges between 28.3% and 39.5%. The average speed for the entire fleet is 12.3 knots on average and ranges between 11.6 knots and 12.7 knots. For the differenced series, averages do not differ significantly from zero. Jarque and Bera (1980) tests reject the null hypothesis that the skewness and kurtosis of the spot rates, FFA rates, and the ratio match the skewness and kurtosis of a normal distribution. Table 1.4 shows Dickey and Fuller (1981), Phillips (1988), and Kwiatkowski et al. (1992) unit root tests. The results show that spot freight rates, FFA rates and bunker prices are non-stationary while their log differences are stationary. On the other hand, the capacity ratio, the average total speed, the average ballast speed and the average laden speed are stationary.

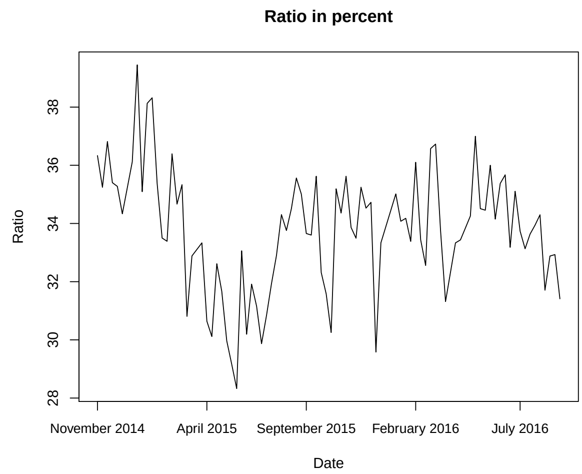
Figure 1.5: **Time series plots 1**
This figure shows the TD3 Spot and TD3 FFA series in \$ per mt. The Ratio is the ratio of available vessels to active vessels. Speed is the average speed of the fleet in knots for vessels sailing above 6 knots. The sample period runs from 14 November, 2014 to 26 August, 2016, and the sampling frequency is weekly.



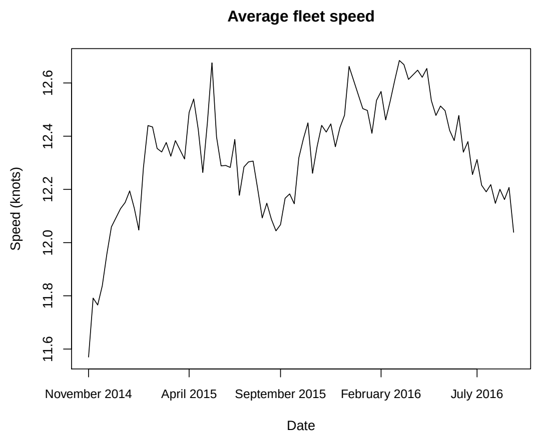
(a) TD3 Voyage Charter Rate



(b) TD3 FFA Rate

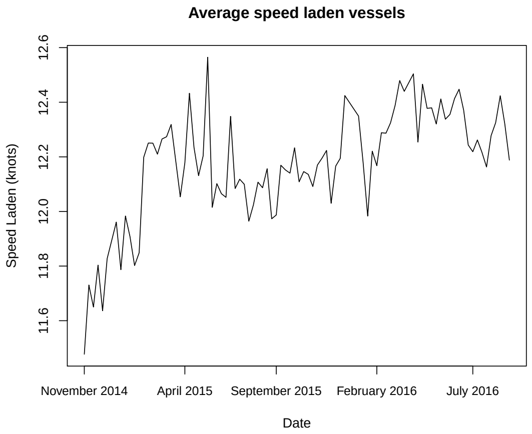


(c) Availability Ratio

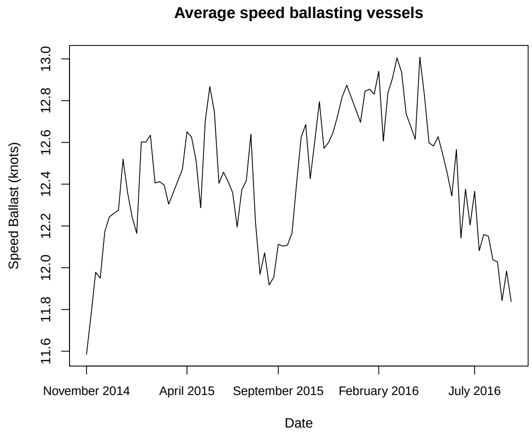


(d) Fleet Speed

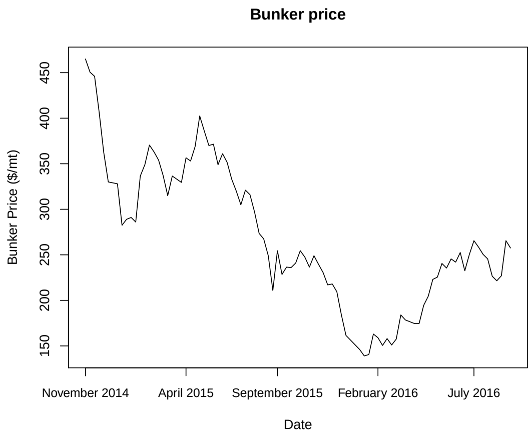
Figure 1.6: **Time series plots 2**
This figure shows the average speed in knots for both the laden vessels and the vessels in ballast, and the 380 cst Fujairah bunker price in $ per mt.



(a) Speed Laden Vessels

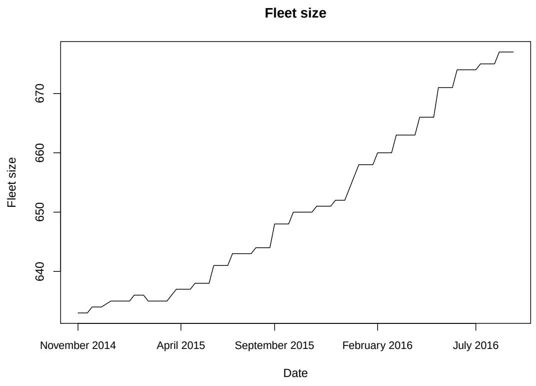


(b) Ballast Speed

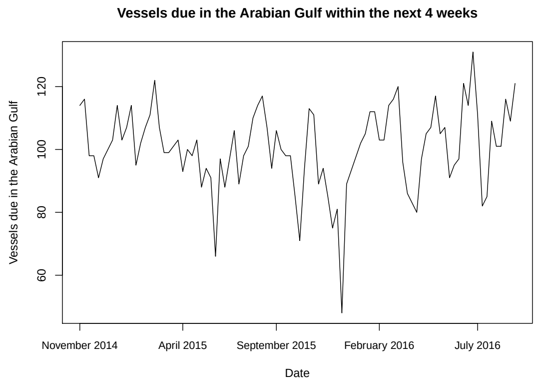


(c) Bunker price

Figure 1.7: **Time series plots 3**
This figure shows the fleet size and Clarkson's measure of vessels due in the Arabian Gulf within the next four weeks.



(a) VLCC fleet size



(b) Vessels due in the Arabian Gulf

Table 1.3: **Summary Statistics**
This table shows summary statistics. The sample period runs from 14 November 2014 to 26 August 26, 2016 and time-series have a weekly frequency. Both the TD3 Spot and TD3 FFA series are in $ per mt. The Ratio is the ratio between available vessels and active vessels. Speed is the weekly average of the fleet's speed in knots for vessels sailing above 6 knots. Similarly, the ballast speed and laden speed are the average speeds for the vessels sailing in ballast and laden respectively. Fuel is the 380 cst Fujairah bunker price in $ per mt. Fleet size is the number of VLCCs in the fleet and vessels due are the expected number of vessels which will reach the Arabian Gulf within the next four weeks. The sample period is from the 14 November, 2014 to the 26 August, 2016, and the sampling frequency is weekly.

Panel A: Levels

	Average	Std	Median	Min	Max
TD3 Spot	14.9	4.5	15.6	6.5	24.9
TD3 FFA	14.1	3.5	14.7	7.5	20.6
Ratio	33.8	2.1	33.8	28.3	39.5
Speed	12.3	0.2	12.3	11.6	12.7
Speed Ballast	12.2	0.2	12.2	11.5	12.6
Speed Laden	12.4	0.3	12.4	11.6	13
Bunker Fuel Price	268.3	78	251.5	139	465
Fleet Size	651.1	14.4	650	633	677
Vessels Due	100.2	13.5	101	48	131

Panel B: ln Differences

	Average	Std	Median	Min	Max	Skewness	Kurtosis	J-B Statistic	J-B p-value
TD3 Spot	0.003	0.05	0.002	-0.1	0.3	1.9	10.3	473.2	0
TD3 FFA	0.002	0.04	0.001	-0.2	0.2	0.5	6.8	184.0	0
Ratio	-0.002	0.1	-0.002	-0.2	0.2	0.1	0.2	0.6	0.7
Speed	0	0.01	0.001	-0.02	0.02	-0.04	-0.04	0.03	1.0
Speed Ballast	0	0.01	0	-0.03	0.04	-0.1	-0.2	0.2	0.9
Speed Laden	0.001	0.01	0.001	-0.04	0.03	-0.3	1.7	13.6	0.001
Bunker Fuel Price	-0.01	0.1	-0.02	-0.2	0.2	0.4	0.3	3.5	0.2
Fleet Size	0.001	0.002	0	-0.002	0.01	2.7	7.5	344.6	0
Vessels Due	0.001	0.2	0.02	-0.5	0.6	0.4	2.7	33.5	0

Table 1.4: **Unit root tests**
This table shows test statistics for unit root tests. ADF is the Augmented Dickey and Fuller (1981) test. The lag order is chosen by minimizing the SBIC criteria, Schwarz (1978). The ADF regression includes an intercept. PP is the Phillips (1988) test. The critical values for the ADF and PP test are -3.51 at a 1% level, and -2.89 for a 5% level. KPSS is the Kwiatkowski et al. (1992) unit root test. The null hypothesis in the Kwiatkowski et al. (1992) test states that the time series is stationary. The critical values are 0.463 at a 5% level, and 0.739 at a 1% level. We use log differences for the unit root tests of the differenced time series. Asterisks denote significant tests such that ** indicates significance at a 1% confidence level, and * indicates significance at a 5% level.

	ADF L	ADF D	PP L	PP D	KPSS L	KPSS D
TD3 Spot	-2.494	-7.925**	-2.580	-10.127**	0.914**	0.097
TD3 FFA	-1.435	-7.473**	-1.238	-9.213**	1.093**	0.164
Ratio	-3.618**	-9.381**	-5.460**	-15.168**	0.224	0.053
Speed	-2.834	-8.402**	-3.537**	-11.024**	0.688*	0.597*
Speed Laden	-3.368*	-9.184**	-4.339*	-14.153**	1.400**	0.216
Speed Ballast	-2.392	-8.240**	-2.960*	-12.440**	0.350	0.431
Bunker Fuel Price	-2.490	-5.969**	-2.603	-9.285**	1.655**	0.270
Fleet Size	0.850	-8.956**	1.158	-11.360**	2.411**	0.408
Vessels Due	-4.380**	-9.641**	-5.506**	-14.166**	0.192	0.048

1.4 Results

1.4.1 Comparison with traditional supply measures

In this section, we compare our AIS capacity measure with the traditional supply measures. The traditional measures are fleet size and the speed of the vessels in the merchant fleet, Beenstock and Vergottis (1989). The empirical analysis of shipping market supply measures are mainly conducted with annual and monthly frequencies. Before AIS data was available, the speed of vessels were unobservable to the econometricians which therefore relied on proxies to capture the dynamics of the speed of the fleet. In a Ronen (1982) model framework, the natural logarithm of the optimal speed is linearly related to the natural logarithm of the ratio between freight rates and bunker prices, (Aßmann et al., 2015; Adland and Jia, 2016). In addition to fleet size and the freight rate bunker ratio, we also look at the number of VLCCs due in the Arabian Gulf within the next 4 weeks reported by Clarkson's shipping intelligence network.

Table 1.5 shows predictive regressions for the weekly evolution in freight rates for the traditional supply measures and the AIS-based supply measures. We find that the traditional measures of supply are unable to explain the weekly-evolution in freight rates. We find a significant effect from our ratio of available vessels to active vessels and from the fleet speed of vessels sailing in ballast. In column (10) we test the joint significance of the ratio and the ballasting speed. The F-test for the joint removal is rejected even though the p-value for both variables, (the p-value for the ratio is 6.61% and similarly the p-value for the ballasting speed is 5.98%.), are insignificant at a five percent level. In Table 1.6, we show estimation results for predictive regressions of the fleet speed for vessels sailing either laden or in ballast. First, we see that the ratio between freight rates and bunker prices is unable to explain the evolution in vessel speeds. Second, we see that the level of the ratio between freight rates and bunker prices is able to explain some of the variation in the speed level of the vessels sailing in ballast. In the predictive regression of the speed level of vessels sailing laden the p-value of the coefficient for the level of the freight rate bunker price ratio is 5.32% and therefore close to being significant. The result that the speed level of vessels sailing in ballast is more responsive to the freight rate bunker price ratio is consistent with Aßmann et al. (2015) and Adland and Jia (2016). The missing responses in laden vessel speeds have been argued to be a result of charter party speed clauses, (Devanney, 2011; Adland and Jia, 2016).

Table 1.5: **Predictive regressions on supply measures**

This table shows predictive regressions of the weekly evolution in freight rates on the supply measures: the number of available vessels over the number of active vessels, fleet size, the freight rate bunker price ratio, the fleet speed of vessels sailing in ballast, the fleet speed of vessels sailing laden, the number of VLCCs due to arrive in the Arabian Gulf within the next four weeks. Standard errors are in parentheses.

	Dependent variable: ln *differences in the TD3 freight rate*									
	$\Delta TD3_t$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\Delta \ln Ratio_{t-1}$	-0.567^{*}									-0.522
	(0.284)									(0.281)
$\Delta \ln Fleetsize_{t-1}$		6.892								
		(9.243)								
$\ln Fleetsize_{t-1}$			-0.001							
			(0.003)							
$\Delta \ln(TD3/Bunker)_{t-1}$				-0.029						
				(0.102)						
$\ln(TD3/Bunker)_{t-1}$					0.001					
					(0.006)					
$\Delta \ln \underset{Ballast}{Speed_{t-1}}$						2.484^{*}				2.296
						(1.216)				(1.205)
$\Delta \ln \underset{Laden}{Speed_{t-1}}$							-1.678			
							(1.492)			
$\Delta \ln(Vessels\ Due)_{t-1}$								-0.152		
								(0.111)		
$\ln(Vessels\ Due)_{t-1}$									-0.002	
									(0.004)	
Observations	93	93	93	93	93	93	93	93	93	93
R^2	0.042	0.006	0.002	0.001	0.0005	0.043	0.014	0.020	0.002	0.078
Adjusted R^2	0.031	-0.005	-0.008	-0.010	-0.010	0.033	0.003	0.009	-0.00	0.058
F Statistic	3.994^{*}	0.556	0.226	0.084	0.044	4.170^{*}	1.265	1.890	0.224	3.870^{*}
Note:	$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$									

Table 1.6: **Predictive regressions of fleet speed**
This table shows predictive regressions of the weekly speeds on the lagged ratio between freight rates and bunker prices. Standard errors are in parentheses.

	Dependent variable: ln *speed differences*			
	$\Delta \ln Speed_t$ *Ballast*	$\Delta \ln Speed_t$ *Ballast*	$\Delta \ln Speed_t$ *Laden*	$\Delta \ln Speed_t$ *Laden*
	(1)	(2)	(3)	(4)
$\Delta \ln(TD3/Bunker)_{t-1}$	0.014		0.009	
	(0.009)		(0.007)	
$\ln(TD3/Bunker)_{t-1}$		−0.0001		−0.0002
		(0.001)		(0.0004)
Observations	93	93	93	93
R^2	0.027	0.0002	0.018	0.003
Adjusted R^2	0.016	−0.011	0.008	−0.008
F Statistic (df = 1; 92)	2.534	0.015	1.712	0.287
Note:	*p<0.05; **p<0.01; ***p<0.001			

	Dependent variable: ln *speed levels*			
	$\ln Speed_t$ *Ballast*	$\ln Speed_t$ *Ballast*	$\ln Speed_t$ *Laden*	$\ln Speed_t$ *Laden*
	(5)	(6)	(7)	(8)
Intercept	2.521***	2.654***	2.500***	2.524***
	(0.003)	(0.014)	(0.002)	(0.012)
$\Delta \ln(TD3/Bunker)_{t-1}$	−0.004		−0.013	
	(0.016)		(0.010)	
$\ln(TD3/Bunker)_{t-1}$		0.046***		0.008
		(0.005)		(0.004)
Observations	93	93	93	93
R^2	0.001	0.514	0.019	0.040
Adjusted R^2	−0.010	0.508	0.008	0.030
F Statistic (df = 1; 91)	0.062	96.166***	1.719	3.836
Note:	*p<0.05; **p<0.01; ***p<0.001			

1.4.2 The FFA spot rate vector error correction model

In this section, we nest our measure into the VECM framework to see whether the freight rate price discovery of our measure is already captured by the FFA price. This also allows us to study the lead-lag relationship between our availability measure and the spot freight rate. Granger (1981), Engle and Granger (1987), Johansen (1988), and Johansen (1995) introduced the VECM framework. We start by considering the Vector Auto Regressive (VAR) model representation. We set up the VECM from the Vector Autoregressive VAR model with p lags. We assume that all individual variables are either $I(1)$ (integrated of order one), or $I(0)$ (integrated of order zero) such that stationarity can be achieved in all of the k variables by taking first differences. The VAR(p) model is defined by:

$$y_t = \sum_{i=1}^{p} \boldsymbol{A}_i y_{t-i} + u_t. \tag{1.3}$$

where y_t is a $k \times 1$ vector containing the levels of the time series, $\boldsymbol{A}_i$ are $k \times k$ matrices of coefficients for $i \in \{1, \cdots, p\}$, and $\boldsymbol{u}_t$ is an error term of dimension $k \times 1$. $\boldsymbol{u}_t$ is a white noise process and has a contemporaneous covariance matrix $\boldsymbol{\Sigma}$ of dimension $k \times k$. By subtracting y_{t-1} on both sides, we take the first difference, and since all variables are either $I(1)$ or $I(0)$, this will achieve stationarity. We then arrive at the vector error correction form:

$$\Delta y_t = \alpha\beta' y_{t-1} + \sum_{i=1}^{p-1} \boldsymbol{\Gamma}_i \Delta y_{t-i} + u_t. \tag{1.4}$$

where Δ denotes the first difference operator such that $\Delta y_t = y_t - y_{t-1}$. $\alpha\beta' y_{t-1}$ is the error correction term which is related to the VAR(p) model in equation (1.3) by $\alpha\beta' = -(\boldsymbol{I}_k - \boldsymbol{A}_1 - \cdots - \boldsymbol{A}_p)$[19]. Furthermore, $\boldsymbol{\Gamma}_i = -(\boldsymbol{A}_{i+1} + \cdots + \boldsymbol{A}_p)$ for $i = \{1, ..., p-1\}$. Both α and β are $k \times r$ matrices where r is the number of cointegration relationships. $\beta' y_{t-1}$ gives a stationary linear combination of variables in levels. The FFA spot basis has been used in many studies of vector error correction models of spot freight rates and FFA prices. It is therefore natural to nest our new availability measure into a model of this class. See Kavussanos and Nomikos (1999), Kavussanos and Nomikos (2003), Kavussanos, Visvikis and Menachof (2004), Batchelor et al. (2007), and Alexandridis et al. (2017) for VEC freight rate models.

We will now show the estimated results of the vector error correction model containing the spot freight rate, the FFA price, and the ratio. This is the simplest extension of the Kavussanos and Nomikos (1999), Kavussanos and Nomikos (2003), Kavussanos, Visvikis and Menachof (2004), and Batchelor et al. (2007) type VECM specification, which contains our capacity measure, in addition to the spot freight rate and the FFA price.

$$y_t = [\ln TD3_t \;\; \ln FFA_t \;\; \ln Ratio_t]$$

We estimate a VECM with one lag as Table 1.7 suggests that one lag minimizes the SBIC criteria,

[19] $\boldsymbol{I}_k$ is the identity matrix of dimension k.

(Schwarz, 1978). The we test for the number of cointegration relationships. In our specification, we restrict $\ln Ratio_t$ to zero in the cointegration vector as unit root tests from Table 1.4 suggest that the ratio is stationary in levels. We then test whether the cointegration rank for $\ln TD3_t$ and $\ln FFA_t$ is zero or one. Both the Johansen (1991) eigenvalue test in Table 1.8 and the trace test in Table 1.9 suggest that the cointegration rank is one. Furthermore, the over-identification restriction test in Table 1.10 shows that the cointegration relationship can be restricted to be the basis of the voyage charter freight rate and the one-month FFA price. We then estimate the coefficients α and $\mathbf{\Gamma}_1$ from equation (1.4), which are shown in Table 1.11. The evolution of the voyage charter rate is negatively related to the basis of the voyage charter rate and the FFA price. This means that the voyage charter rate tends to increase(decrease) when the FFA price is above(below) the voyage charter rate. The voyage charter rate tends to decrease(increase) after an increase(decrease) in the ratio.

In order to clarify the economic magnitude, we consider a one standard deviation decrease in our capacity measure. In Table 1.3, we see that the sample average of our capacity measure is 33.8%, corresponding to 211 vessels satisfying the availability restrictions and 624 active vessels on average during our sample period. A one standard deviation decrease in our capacity measure, i.e. 2.2[20] percentage points between period $t-1$ and period t, implies an increase in freight rates of approximately[21] 3.75%. At the average freight rate level, this corresponds to an increase in the freight rate of \$0.56/mt, which leads to an increase in gross freight revenue equal to \$151,200 for a typical cargo-size of 270,000mt. The evolution in the FFA prices cannot be explained by the past values of the ratio, voyage charter rates, FFA prices, nor the difference between the voyage charter rate and the FFA price. The Ratio exhibits negative autocorrelation and also has a negative relation to the past evolution in the voyage charter rate. This causes a feedback effect such that the ratio which reflects the number of available vessels decreases after an increase in freight rates. We interpret this as vessels being more willing to enter fixtures when freight rates increase. Simultaneously, when fewer vessels are available, freight rates tend to increase.

Our sample period is November 2014 and August 2016. Our sample overlaps with the global

[20] At the average values, this corresponds to a decrease in available vessels from 211 to 197.

[21] All other things being equal, a one standard deviation decrease in our capacity measure will, at the sample average values for the ratio and the freight rate, increase freight rates by 3.75%$= -0.558 \cdot \ln\left(\frac{\bar{Ratio}-sd(Ratio)}{\bar{Ratio}}\right)$

Oil Glut during which oil prices dropped significantly. Expenses for bunker fuel is as mentioned the main component of voyage costs. A natural concern is that oil price movements are driving the evolution in freight rates. We control for oil prices in two ways. First, we add bunker prices to the predictive regression. Second, we look at predictive regressions for the time charter equivalent freight rate earnings. In table 1.12, we see that when we control for bunker prices the ratio becomes significant at a five percent level rather than only at the ten percent level. Furthermore, results in table 1.13 shows that results are statistically even stronger when we look at the time charter equivalent earnings rather than the freight rate.

Table 1.7: **Lag selection**
This table shows the SBIC criteria (Schwarz, 1978). The VECM is estimated with one lag as it minimizes the SBIC.

Lags	1	2	3	4	5
SBIC	-14.048	-13.895	-13.778	-13.616	-13.362

Table 1.8: **Cointegration eigenvalue test**
This table shows the Johansen (1991) cointegration eigenvalue test for $y_t = [\ln TD3_t \;\; \ln FFA_t \;\; \ln Ratio_t]$. The $Ratio_t$ coefficient is restricted to zero in the cointegration term as the unit root test in Table 1.4 indicates that it is stationary. $ECT_t = \ln TD3_t - 1.24 \ln FFA_t + 0.58$

Eigenvalue test	Test Statistic	10pct	5pct	1pct
H_0 : r $\leq$ 1	3.62	7.52	9.24	12.97
H_0 : r = 0	17.69	13.75	15.67	20.20

Table 1.9: **Cointegration trace test**
This table shows the Johansen (1991) cointegration trace test for $y_t = [\ln TD3_t \;\; \ln FFA_t \;\; \ln Ratio_t]$. The $Ratio_t$ coefficient is restricted to zero in the cointegration term as the unit root test in Table 1.4 indicates it is stationary. $ECT_t = \ln TD3_t - 1.24 \ln FFA_t + 0.58$

Trace test	Test Statistic	10pct	5pct	1pct
H_0 : r $\leq$ 1	3.62	7.52	9.24	12.97
H_0 : r = 0	21.31	17.85	19.96	24.60

Table 1.10: **Over-identification restriction test**
This table shows the linear restriction test. It tests whether the cointegration vector can be reduced to the spot-FFA basis.

$ECT_t = \ln TD3_t + \beta_1 \ln FFA_t + \beta_2$	Test statistic	p-value
$H_0 : \beta_1 = -1, \;\; \beta_2 = 0$	3.7386	0.4425

Table 1.11: **VECM estimation**
This table shows the coefficients of the vector error correction model from equation (1.4) where $p = 2$ and the error correction term is $ECT_t = \beta' y_t = [\ln TD3_t - \ln FFA_t]$.
Variance inflation factors $\text{VIF}_i = \dfrac{1}{1 - R_i^2}$ are
$\text{VIF}(ECT_{t-1}) = 1.21$
$\text{VIF}(\Delta \ln Ratio_{t-1}) = 1.01$
$\text{VIF}(\Delta \ln TD3_{t-1}) = 1.61$
$\text{VIF}(\Delta \ln FFA_{t-1}) = 1.60$

	Dependent variable:		
		y	
	$\Delta \ln TD3_t$	$\Delta \ln FFA_t$	$\Delta \ln Ratio_t$
	(1)	(2)	(3)
$\Delta \ln Ratio_{t-1}$	-0.558^{*}	0.028	-0.439^{***}
	(0.271)	(0.192)	(0.089)
$\Delta \ln TD3_{t-1}$	0.029	0.069	-0.114^{**}
	(0.122)	(0.086)	(0.040)
$\Delta \ln FFA_{t-1}$	0.061	-0.231	-0.032
	(0.187)	(0.133)	(0.062)
$\ln TD3_{t-1} - \ln FFA_{t-1}$	-0.343^{***}	-0.086	0.050
	(0.096)	(0.068)	(0.031)
Observations	92	92	92
R^2	0.191	0.040	0.314
Adjusted R^2	0.155	-0.003	0.283
F Statistic (df = 4; 88)	5.205^{***}	0.925	10.074^{***}
Note:	*p<0.05; **p<0.01; ***p<0.001		

Table 1.12: **Predictive regressions**

This table shows predictive regressions where the error correction term is $ECT_t = \beta' y_t = [\ln TD3_t - \ln FFA_t]$. Standard errors are in parentheses. $\text{VIF}_i = \dfrac{1}{1 - R_i^2}$ in column (6) are

$\text{VIF}(ECT_{t-1}) = 1.24$
$\text{VIF}(\Delta \ln Ratio_{t-1}) = 1.03$
$\text{VIF}(\Delta \ln TD3_{t-1}) = 1.84$
$\text{VIF}(\Delta \ln FFA_{t-1}) = 1.67$
$\text{VIF}(\Delta \ln Bunker_{t-1}) = 1.14$
$\text{VIF}\left(\underset{Ballast}{\Delta \ln Speed_{t-1}}\right) = 1.07$
$\text{VIF}\left(\underset{Laden}{\Delta \ln Speed_{t-1}}\right) = 1.04$

	Dependent variable:					
	$\Delta \ln TD3_t$					
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln Ratio_{t-1}$		-0.544^{*}		-0.493	-0.523	-0.539^{*}
		(0.263)		(0.257)	(0.268)	(0.267)
$\underset{Ballast}{\Delta \ln Speed_{t-1}}$			2.784^{*}	2.603^{*}	2.452^{*}	2.472^{*}
			(1.119)	(1.107)	(1.157)	(1.155)
$\underset{Laden}{\Delta \ln Speed_{t-1}}$					-1.118	-1.163
					(1.395)	(1.393)
$\Delta \ln TD3_{t-1}$					0.008	0.058
					(0.121)	(0.128)
$\Delta \ln FFA_{t-1}$					0.035	-0.006
					(0.184)	(0.187)
$\Delta \ln Bunker_{t-1}$						-0.287
						(0.246)
$\ln TD3_{t-1} - \ln FFA_{t-1}$	-0.350^{***}	-0.346^{***}	-0.363^{***}	-0.359^{***}	-0.348^{***}	-0.358^{***}
	(0.087)	(0.086)	(0.085)	(0.084)	(0.094)	(0.094)
Observations	93	93	93	93	92	92
R^2	0.149	0.187	0.203	0.234	0.241	0.253
Adjusted R^2	0.140	0.169	0.186	0.209	0.188	0.191
F Statistic	16.100^{***}	10.483^{***}	11.602^{***}	9.182^{***}	4.545^{***}	4.107^{***}
Note:	*p<0.05; **p<0.01; ***p<0.001					

Table 1.13: **Predictive regressions for the time charter equivalent earnings**
This table shows predictive regressions for the evolution in time charter equivalent earnings. The error correction term is $ECT_t = \beta' y_t = [\ln TD3TCE_t - \ln FFATCE_t]$. Standard errors are in parentheses.

	Dependent variable:					
	$\Delta \ln TD3TCE_t$					
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln Ratio_{t-1}$		-0.743^{*}		-0.673^{*}	-0.731^{*}	-0.763^{*}
		(0.338)		(0.329)	(0.339)	(0.335)
$\Delta \ln \underset{Ballast}{Speed_{t-1}}$			3.838^{**}	3.596^{*}	3.224^{*}	3.254^{*}
			(1.434)	(1.415)	(1.466)	(1.450)
$\Delta \ln \underset{Laden}{Speed_{t-1}}$					-1.380	-1.472
					(1.766)	(1.747)
$\Delta \ln TD3TCE_{t-1}$					-0.004	0.089
					(0.150)	(0.157)
$\Delta \ln FFATCE_{t-1}$					0.239	0.170
					(0.220)	(0.221)
$\Delta \ln Bunker_{t-1}$						-0.534
						(0.309)
$\ln TD3TCE_{t-1} - \ln FFATCE_{t-1}$	-0.500^{***}	-0.502^{***}	-0.517^{***}	-0.517^{***}	-0.507^{***}	-0.526^{***}
	(0.105)	(0.103)	(0.102)	(0.100)	(0.107)	(0.106)
Observations	93	93	93	93	92	92
R^2	0.198	0.239	0.257	0.290	0.306	0.330
Adjusted R^2	0.190	0.222	0.241	0.266	0.258	0.275
F Statistic	22.783^{***}	14.290^{***}	15.736^{***}	12.253^{***}	6.332^{***}	5.980^{***}
Note:	*p<0.05; **p<0.01; ***p<0.001					

1.4.3 Evidence from fixtures

In this section, we will look at the evidence from the individual voyage charter fixtures. We will estimate a freight rate panel-regression for the individual fixtures as in Alizadeh and Talley (2011) and Adland et al. (2016). In this way we control, for vessel- and fixture-specific characteristics. We estimate regression coefficients in a fixtures regression where we regress the natural logarithm of the freight rate on the natural logarithm of the ratio. We also control for the utilization rate of the vessel given as the cargo size in mt divided by the vessel's dead weight tons, a dummy equal to one if the vessel is more than 15 years old, the DWT(in 100,000) of the vessel, the ln distance from the vessel to the loading region, the natural logarithm of the bunker price at the time where the fixture is reported, the natural logarithm of of the FFA price at the time where the fixture is reported, and charterer and owner effects.

The expected signs of the regression coefficients are the following: We expect our capacity measure to be negatively related to the freight rate level as rates should be higher when there are fewer vessels available for orders. The utilization rate is expected to be negatively related to the freight rate, the reason being that the differences in voyage costs for a fully loaded and partially loaded vessel are not substantially different. A partially loaded vessel will still need to pay port charges and sail to the discharge port. Hence, a partially loaded cargo should result in a high freight rate in \$ per ton given the lower amount of tons. Freight rates are expected to be decreasing with age as charterers' vetting requirements favor younger vessels. We include a dummy for whether the vessel's age is above 15 years. The freight rate is expected to decrease in vessel size given the increasing returns to scale in size. Freight rates are expected to increase with the vessel's distance to the loading region. The intuition here is that when freight rates are high there are few vessels close to the loading region and the charterers need to book vessels far away to make sure that they find a vessel for their cargo. Bunker prices are expected to be positively related to the freight rate as bunker fuel constitutes the main voyage costs. When voyage costs are high, shipowners pass through costs to charterers by demanding a higher freight rate. Finally, the FFA price is expected to be positive and close to 1 given the well established long-run cointegration relationship between spot rates and FFA rates.

We do not include the TD3 index as an independent variable. We leave out the TD3 index given the recent critique by Adland, Cariou and Wolff (2017) who argue that including the index itself potentially captures part of the heterogeneity. We estimate the regression coefficients of the specification:

$$\ln FR_{i,t} = \beta_0 + \beta_1 \ln Ratio_t + \beta_2 Utilization_{i,t} + \beta_3 1_{\{Age_{i,t}>15\}} + \beta_4 DWT_{i,t} + \beta_5 \ln Dist\ to\ AG_{i,t} + \beta_6 \ln Bunker_t + \beta_7 \ln FFA_t + \epsilon_{i,t}. \quad (1.5)$$

The panel regression results in Table 1.14 show that our capacity measure is negatively correlated with the freight rate even after adjusting for vessel-specific effects in the form of vessel age, size and macro variables bunker prices, and FFA prices. The ratio is insignificant in column (7) when we estimate both owner and charterer effects[22]. Most of the coefficients align well with our

[22] Here the p-value of the t-test is 0.0566. The coefficient estimate is close to the estimate in specification (6) which only includes owner effects.

expectations. We see that the utilization rate point estimates are generally negative but insignificant. Vessels, which are older than 15 years, have a negative point estimate, but it is generally insignificant. The size measured by the vessel's DWT also has a negative but again insignificant point estimates in the different specifications. Distance to the loading has a positive but generally insignificant point estimate. Bunker prices as expected, are positively related to the freight rates. This is what we expect as higher bunker prices increase voyage costs, which in turn need to be compensated for through a higher freight rate paid by charterers. Finally, we see that the effect of our capacity measure is still significant after we control for the FFA price.

Table 1.14: **Fixtures regression**
This table shows regressions where the dependent variable is the natural logarithm of freight rate.

	Dependent variable:									
	$\ln Freight\ Rate_t$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\ln Ratio_t$	-0.86^{***}	-0.87^{***}	-0.85^{***}	-0.62^{**}	-0.57^{*}	-0.49^{*}	-0.48	-0.42^{***}	-0.38^{**}	-0.37^{**}
	(0.23)	(0.23)	(0.23)	(0.22)	(0.23)	(0.24)	(0.25)	(0.11)	(0.12)	(0.12)
$Utilization_{i,t}$		-1.64	-1.60	-1.91	-1.81	-1.45	0.63	-2.19^{**}	-2.46^{**}	-1.29
		(1.51)	(1.51)	(1.44)	(1.44)	(1.59)	(2.11)	(0.70)	(0.76)	(1.01)
$1_{\{Age_{i,t}>15\}}$		-0.13^{**}	-0.13^{**}	-0.08^{*}	-0.07	-0.08	-0.05	-0.03	-0.03	-0.03
		(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.06)	(0.02)	(0.03)	(0.03)
$DWT_{i,t}$		-0.55	-0.54	-0.58	-0.57	-0.43	0.16	-0.60^{**}	-0.74^{**}	-0.41
		(0.46)	(0.46)	(0.44)	(0.44)	(0.50)	(0.63)	(0.21)	(0.24)	(0.30)
$\ln Distance\ to\ AG_{i,t}$			0.01		0.02	0.02	0.02	0.02^{**}	0.02^{**}	0.02^{**}
			(0.01)		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\ln BunkerPrice_t$				0.31^{***}	0.32^{***}	0.34^{***}	0.34^{***}	0.14^{***}	0.17^{***}	0.16^{***}
				(0.05)	(0.05)	(0.05)	(0.05)	(0.02)	(0.03)	(0.03)
$\ln FFA_t$								1.06^{***}	1.06^{***}	1.07^{***}
								(0.03)	(0.03)	(0.03)
Intercept	1.66^{***}	4.79	4.71	3.65	3.39	2.50	-1.44	2.26	2.83^{*}	0.71
	(0.25)	(2.70)	(2.71)	(2.59)	(2.59)	(2.91)	(3.76)	(1.26)	(1.40)	(1.80)
Owner	No	No	No	No	No	Yes	Yes	No	Yes	Yes
Charterer	No	No	No	No	No	No	Yes	No	No	Yes
Observations	475	475	475	475	475	475	475	475	475	475
R^2	0.03	0.05	0.05	0.14	0.14	0.27	0.33	0.80	0.83	0.85
Adjusted R^2	0.03	0.05	0.04	0.13	0.13	0.14	0.14	0.79	0.80	0.80
F Stat.	13.86^{***}	6.70^{***}	5.41^{***}	14.67^{***}	12.69^{***}	2.00^{***}	1.72^{***}	261.02^{***}	26.14^{***}	18.75^{***}
F Stat. df	(1; 473)	(4; 470)	(5; 469)	(5; 469)	(6; 468)	(75; 399)	(107; 367)	(7; 467)	(76; 398)	(108; 366)
Note:	$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$									

1.5 Conclusion

Recently, the vessel movements in the freight market has become observable via the radio signals sent by vessels' Automatic Identification System. AIS information enables freight market participants to track the movement of vessels within any commercial segment. This paper is the first to use an AIS derived capacity measure to explain the evolution in voyage charter freight rates.

Our measure incorporates the geographical trading patterns observed in the VLCC market. We find that AIS supply measures are able to explain the short-term freight rate evolution where traditional supply measures such as fleet size are uninformative. Our sample period falls within the recent Oil Glut where the oil price experienced a severe drop. We find that our results get statistically stronger when we control for bunker prices or model the evolution in the time charter equivalent earnings.

Our findings suggest that AIS measures can explain parts of the freight rate evolution, which is not already explained by traditional supply measures or FFA prices. We find that the evolution of freight rates depends on the fleet's geographical distribution as well as its employment status. We find that there is an considerable economic magnitude of our measure. We see that a standard deviation decrease in our capacity measure (decrease of 14 available vessels) leads to an increase in the freight rate level of \$0.56/mt. This corresponds to an increase in the gross freight revenue equal to \$151,200 for a typical cargo size of 270,000mt. Furthermore, we also find that the speed of vessels in ballast explains part of the freight rate evolution. When vessels in ballast start sailing faster(slower) this is a sign that freight rates will increase(decrease) in the following week. We encourage future research on the interplay between freight rates and AIS based measures in longer sample periods and other commercial shipping segments.

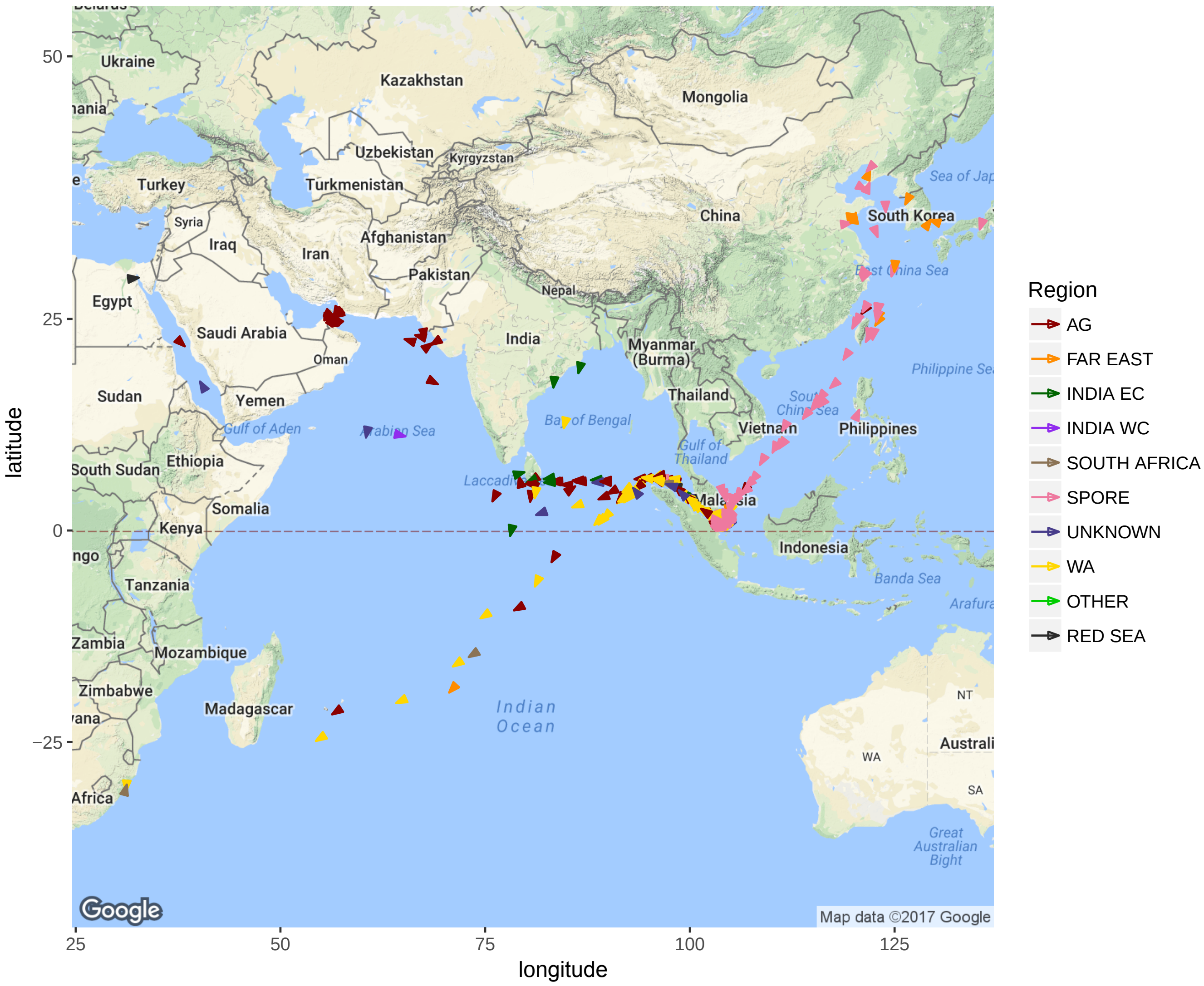
Acknowledgements

We are extremely grateful to MarineTraffic for the data sample provision. Regli acknowledges financial support from the Danish Maritime Fond. We are grateful to Roar Adland and participants at the IAME 2017 conference in Kyoto for helpful comments and suggestions.

1.6 Appendix: Fixing location for vessels sailing in ballast with a loading port in West Africa

Figure 1.8 shows vessels in ballast entering into fixtures *loading in West Africa*. East of Singapore, vessels are either heading for the SPORE region, the Far East or West Africa. This is similar to the pattern for vessels loading in the Persian Gulf in Figure 1.3. West of Singapore some of the vessels are on the direct ballast leg for West Africa, whereas others are following the ballast leg towards the Arabian Gulf. This gives the impression that some ship operators maintain the option of entering trades that load in West Africa when sailing towards the Arabian Gulf. They seem to keep this option to redirect until they pass the tip of India. The small group of vessels in the Gulf of Kutch and near Ras Tanura have not been sailed in ballast back from the Far East, but have delivered Oil in the Gulf of Kutch. At first, it seems a bit strange that these vessels fix in West Africa when the ballast leg to the Arabian Gulf is much shorter. An inspection of the sailing patterns for these vessels shows that these vessels have just completed voyages to West India and are picking up bunker fuel at Fujairah before sailing in ballast back to West Africa. Within the Indian Ocean, there are three vessels having a self-reported destination in South Africa which in our figure falls within the category: Other.

Figure 1.8: **Locations where vessels in ballast enter fixtures with a loading port in West Africa**
This figure shows the trading locations for 255 voyage charters of vessels which are on their ballast leg. The voyage charter has a loading port in **West Africa**. 96 of the vessels report a destination within the SPORE region which consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. 64 are heading for West Africa, 50 are heading for the Arabian Gulf, 12 towards the Far East which covers China, Japan, South Korea, and Taiwan. 10 are unknown and 23 report other destinations.



1.7 Appendix: Boundary conditions

This section contains plots of the boundary conditions.

Figure 1.9: **Arabian Gulf proximity boundary for vessels in ballast**
This figure shows vessel positions with a sailing distance to Fujairah (the big black dot) between 6124 n.m. and 6264 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 1. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf. The colors of the triangles indicate whether the self-reported destination region is SPORE or the Arabian Gulf.

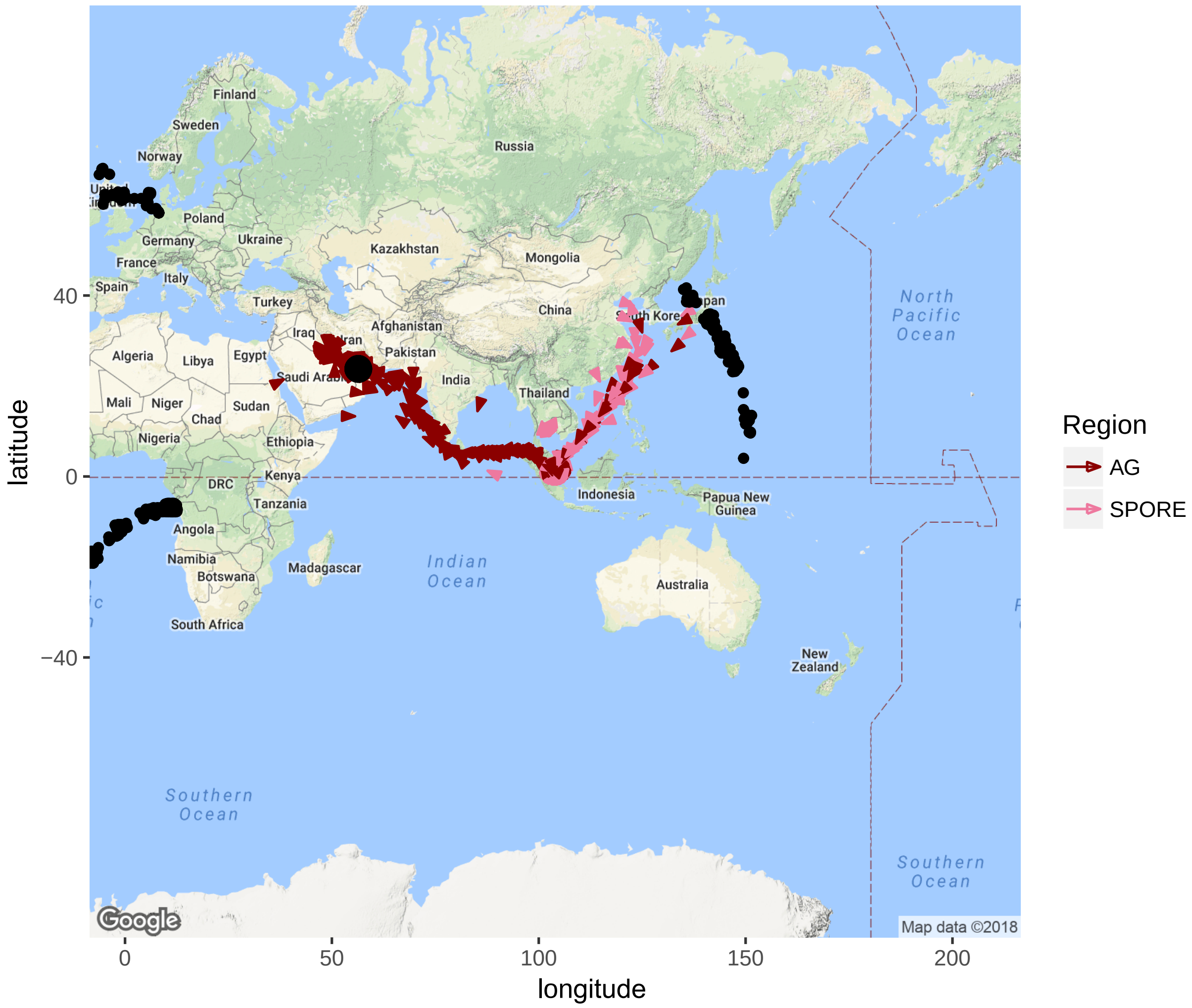


Figure 1.10: **India proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Sikka (the big black dot) between 3900 n.m. and 4000 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 2. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf. The colors of the triangles indicate whether the self-reported destination region is the east coast of India or the west coast of India.

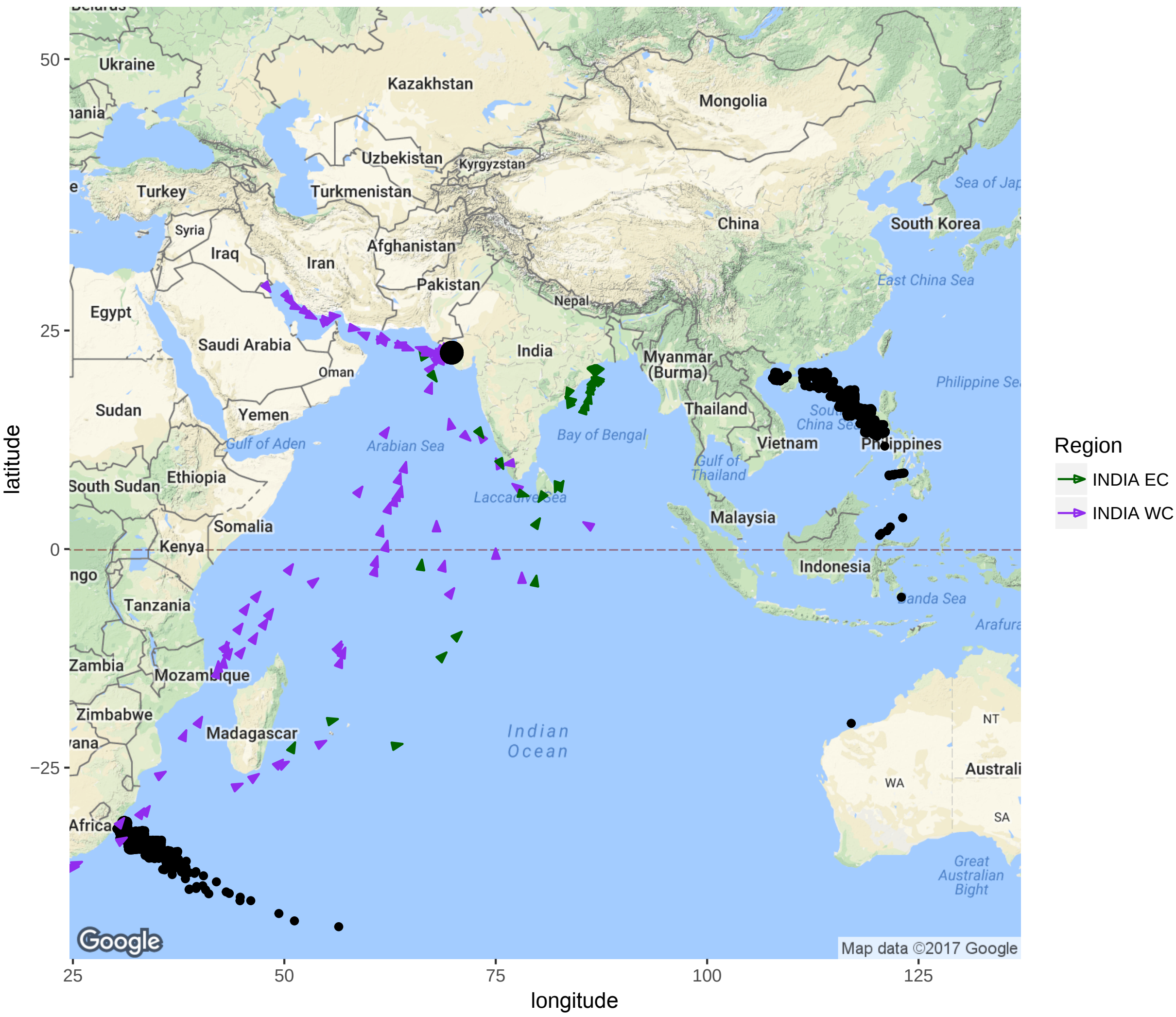


Figure 1.11: **Far East proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Chiba (the big black dot) between 1900 n.m. and 2000 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 3. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf.

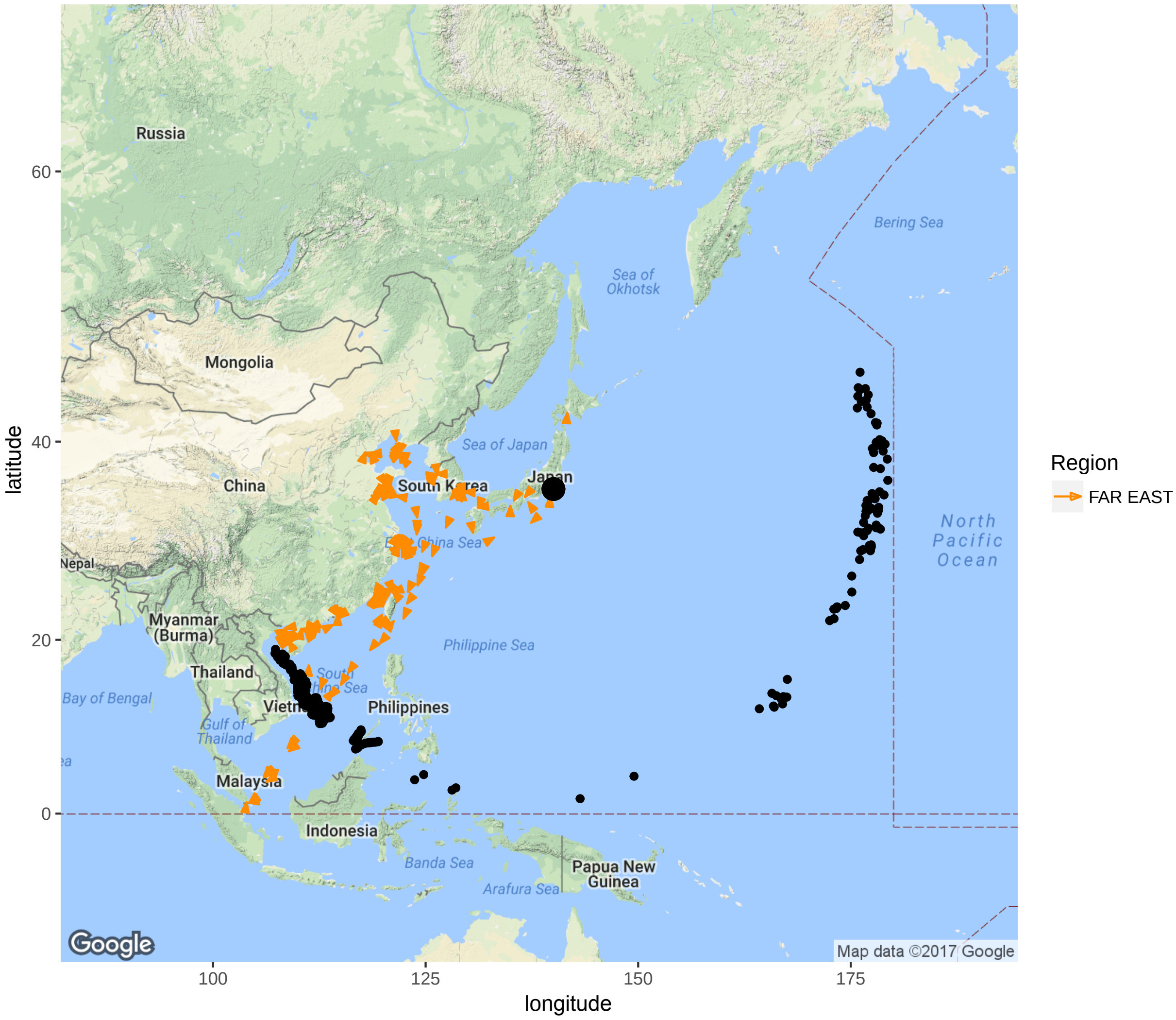
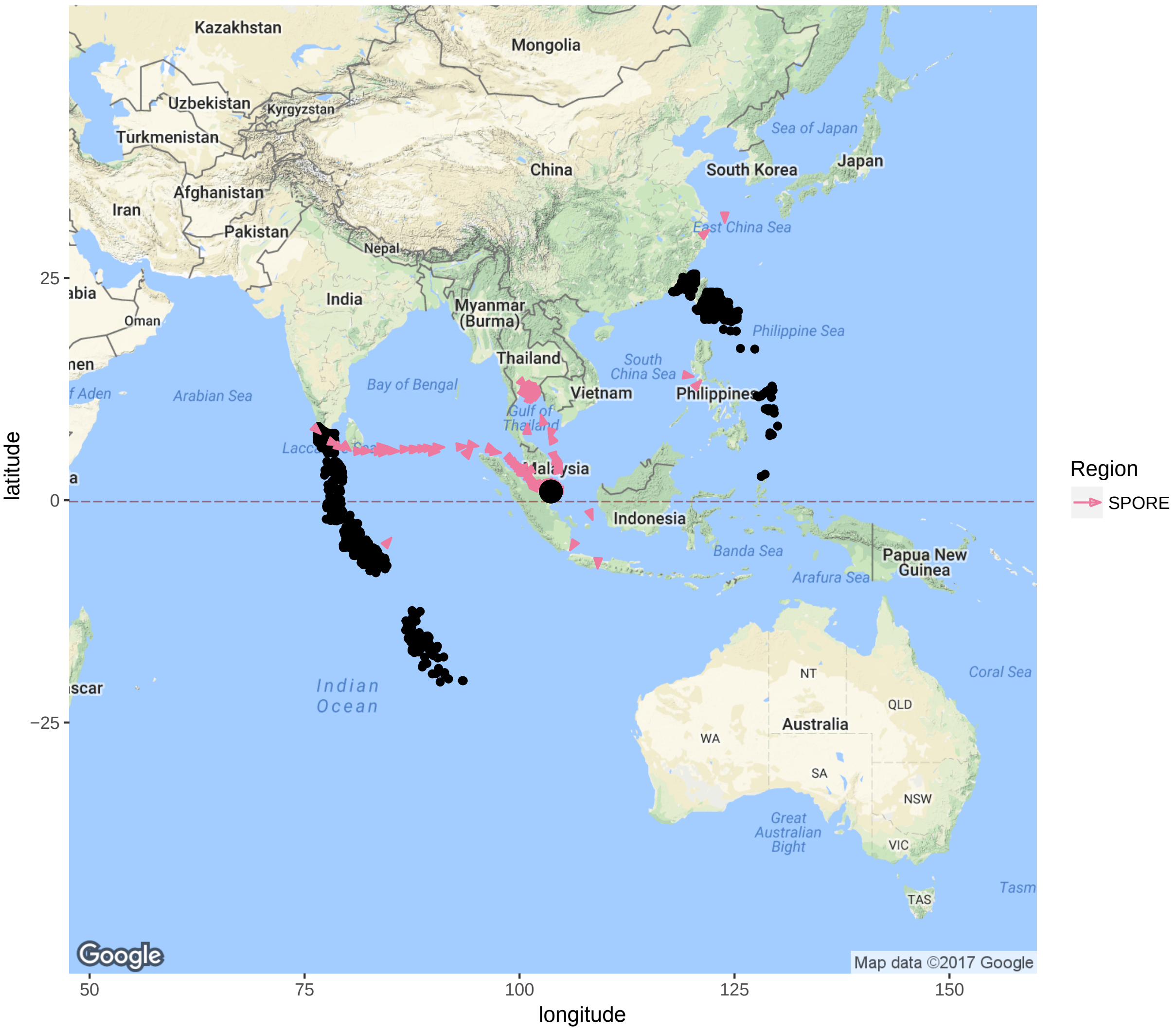


Figure 1.12: **Singapore proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Singapore (the big black dot) between 1600 n.m. and 1740 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of condition 4. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf.



Chapter 2

Crude Oil Contango Arbitrage and the Floating Storage Decision

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Abstract

We investigate charterers' ability and willingness to exploit floating storage arbitrage opportunities. Using time-series and fixtures data on time-charter rates, we find that arbitrage opportunities were present during the Financial Crisis and the recent Oil Glut. An investigation of storage profits across storage horizons suggests that positive oil supply shocks favour longer storage horizons than negative oil demand shocks. Evidence from spatial ship-tracking data suggests charterers are reluctant to exploit the arbitrage opportunity when the implied value of transportation from Forward Freight Agreements (FFAs) exceeds the storage profit. Our findings are of interest to maritime economists and oil market participants.

Keywords — Contango, Crude Oil, Floating Storage, Forward Freight Agreements, Freight Rates, Time charter rates.

2.1 Introduction

In this paper, we evaluate the economics of the floating storage trade and the floating storage decision of charterers. The floating storage trade is a simple cash and carry trade in the crude oil futures market. In addition to oil futures, the trade includes the leasing of an off-shore storage facility, in our case a Very Large Crude Carrier (VLCC). A necessary condition for the floating storage trade to be profitable is that the oil futures curve is upward-sloping i.e. the futures curve is in contango.

To illustrate how the floating storage trade works, we consider a numerical example. A trader buys 1 month Brent crude oil futures and sells 13 month Brent crude oil futures with principal of two million barrels (2mbbl). After one month, the trader takes delivery and thereby gains physical control of the crude oil for twelve months. When the trader takes delivery, she loads the oil into a VLCC which has been chartered for twelve months to conduct the crude oil storage. The trader's profit is the price difference between the futures prices minus the costs associated with hiring and operating the vessel, the transaction costs associated with trading the futures contracts, insurance costs for the crude oil stored, and the financing costs of the trade. An example of income and expense items is summarized in Table 2.1.

Table 2.1: **Numerical example**
This table shows a numerical example of the floating storage trade for a VLCC with a capacity of 2 million barrels (mbbl). The first column shows the items, the second column shows the expenses and the third column shows the income.

Item	Expenses	Income
Oil purchase	2mbbl · \$50.11/bbl = \$100.22m	
Trading costs	\$0.11m	
Insurance costs	\$0.06m	
Time-charter expenses	\$14.60m	
Fuel costs	\$1.73m	
Port charges	\$0.22m	
Financing costs	\$0.60m	
Oil sale		2mbbl · \$61.24/bbl = \$122.48m
Total	\$117.55m	\$122.48m
Profit		\$4.93m

The recent Oil Glut (2014-2016) and the Financial Crisis (2008-2009) both caused severe drops in oil prices. The Financial Crisis led to an contraction the global economy and led to a steep decline in demand for energy commodities including oil. This caused a significant decline in oil prices. The Brent crude oil price dropped from 144.49 US dollars per barrel (\$/bbl) on the 11th of July, 2008 to \$36.61/bbl on the 24th of December, 2008. The recent Oil Glut which was primarily caused by the North American shale oil revolution and OPEC's decision[1] to maintain production levels also put a downward pressure on oil prices. Within the Oil Glut period, oil prices fell from \$103.19/bbl on the 29th of August, 2014 to \$46.59/bbl on the 13th of January, 2015[2].

Despite their separate nature, the Oil Glut serving as a positive oil supply shock and the crisis as a negative oil demand shock, both occasions led oil supply to exceed demand and moved the oil futures curve into contango. The spread between the 13 month and 1 month Brent futures prices reached \$17.93/bbl on the 4th of December, 2008 and \$12.02/bbl on the 13th of January, 2015. In contango markets, commodity traders can earn an arbitrage profit if they are able to store oil at an expense lower than the contango spread. On both occasions commodity traders actively leased VLCCs to benefit from the contango market conditions:

"In order to capitalise on the contango structure we took on significant storage positions during the course of the year and for a period of time a number of Very Large Crude Carriers (VLCCs) for use as floating storage." Trafigura annual report 2015

The dual existence of arbitrageurs and arbitrage opportunities is associated with the inherent paradox that if arbitrageurs are able to instantly correct mispricing then there should be no arbitrage opportunities left in the data. However, if there are no arbitrage opportunities then arbitrageurs have no incentive to monitor markets. Furthermore, even in the case where arbitrage opportunities are observed empirically, they might be an artefact of frictions imposing limits to arbitrage on the arbitrageurs, (Shleifer and Vishny, 1997).

The purpose of our paper is to investigate if floating storage arbitrage opportunities arise and whether traders are both able and willing to exploit them. We evaluate the no-arbitrage relation stating that agents cannot make an arbitrage profit by simultaneously trading in oil futures and leasing a vessel on a time charter for storage purposes. The alternative usage of the vessel is important as storage demand creates demand for tanker vessels in addition to the natural demand for transportation. The floating storage trade has, however, received limited attention in the lit-

[1] The 166th Meeting of the OPEC, 27th of November, 2014.

[2] The Brent Oil price was \$27.88/bbl at its lowest on the 20 January, 2016. However, the level of contango was at its highest in January 2015.

erature. Existing empirical studies fail to account for the shape of term-structure of time-charter rates, rely solely on broker assessment of time-charter rates which are provided even when there are no actual underlying trades, and do not investigate whether the hired tanker vessels are actually used for floating storage.

Our research provides numerous contributions to the limited literature dealing with floating storage. Firstly, our empirical evaluation of arbitrage opportunities is comprehensive and properly accounts for both the time horizon of the oil futures trade and the shape of the term-structure of tanker timecharter rates. Secondly, we point out how the value of the alternative use of the vessel (i.e. for transportation rather than storage) should be accounted for and show how this can be evaluated based on FFA prices. Thirdly, we also investigate the profitability of actual timecharter transactions (fixtures) rather than basing the analysis only on standardized freight rate series. The analysis of fixtures is important as the weekly time-charter rate time-series is an assessment by brokers. This means that brokers provide a time-charter rate even when there are no actual underlying fixtures in the relevant week, Adland et al. (2019). Finally, we evaluate the impact of vessel specifications on the probability to be hired for storage by considering the ex-post usage of chartered ships using geospatial (AIS) ship-tracking data.

The rest of this paper is structured as follows. Section 2.2 reviews the related literature. Section 2.3 presents the cash-and-carry trading strategy and the no-arbitrage condition. Section 2.4 presents the microeconomic evidence from time charter fixtures. Section 2.5 presents the evidence on the actual usage of chartered ships using AIS ship-tracking data. Section 2.6 concludes.

2.2 Literature review

The literature has mainly focused on the relationship between regional oil prices, geographical arbitrage, and the relationship between refinery margins and the import of crude oil. Alizadeh and Nomikos (2004) study the transatlantic arbitrage relationship. They consider an arbitrageur who delivers Brent or Bonny crude oil under the West Texas Intermediate (WTI) futures contract. In addition to the spot price of crude oil, the cost of carry includes financing costs, storage costs, and transportation costs. A similar geographical cash and carry strategy is set forth in Ellefsen

(2010) where the arbitrageur buys Dated Brent and sells futures on light Louisiana sweet crude oil. The earlier paper of Mayr and Tamvakis (1999) looks at the cash and carry including the refinery market. They show that crack spreads Granger causes US crude oil imports.

Acharya et al. (2013) model risk-averse oil producers with access to a storage technology and capital constrained speculators. They study the relationship between managerial risk-aversion and hedging activity for oil producers. Empirically, they find that proxies for hedging demand forecast returns on oil futures. Kirilenko and Kruglova (2017) extend the Acharya et al. (2013) model by adding carry traders who have access to an offshore storage technology. Empirically, they use bills of lading[3] to identify shipments from a trader to itself and use that as a proxy for speculative storage. They show that their proxy of speculative floating storage is positively related to the slope of the Brent futures curve and negatively related to storage costs.

Bucca and Cummins (2011) set forth a statistical arbitrage trading strategy based on mean-reversion between floating storage costs and oil futures prices. They create a synthetic storage price from freight rates and oil futures prices. In their synthetic storage price, they use the time charter equivalent[4] (TCE) of the spot rate for the TD3 route between Saudi Arabia and Japan. Their usage of the TCE of voyage charter freight rates for storage horizons up to 12 months is an implicit assumption that the term-structure of time charter rates is flat. As shown in Koekebakker and Adland (2004), the true term-structure can have complex shapes and will typically not be flat.

Ghafouri and Davison (2017) value the rolling intrinsic storage value which can be added on top of the static floating storage trade by rolling forward contracts. They model the evolution in the land-locked WTI forward curve using the Schwartz and Smith (2000) two-factor model. A limitation of using WTI forward contracts to evaluate the arbitrage is that a lack of available pipeline capacity from Cushing to the US Gulf will impose limits to arbitrage. Ederington et al. (2017) study the physical limits to storage arbitrage for WTI oil futures in Cushing. They find

[3] A Bill of Lading is a document that establishes the written evidence of a contract for the carriage and delivery of goods sent by sea.

[4] When a charterer charters a vessel on voyage charter the freight rate covers voyage costs. However, when a charterer charters a vessel on time charter voyage costs are not included. To make voyage charter freight rates comparable with time charter rates, spot rates can be restated in terms of their time charter equivalent. The time charter equivalent is quoted in $/day and is the freight income minus voyage costs divided with the number of voyage days for the round trip.

that arbitrage opportunities persist when storage approaches onshore capacity limits. A limitation of their approach is that they do not observe storage costs.

The previous papers evaluate the floating storage arbitrage by using either the landlocked WTI futures contracts as in Ghafouri and Davison (2017), extrapolating the voyage charter TCEs to obtain time-charter rates as in Bucca and Cummins (2011), or focus on the inherent short-term storage associated with a voyage charter Alizadeh and Nomikos (2004), Mayr and Tamvakis (1999) and Ellefsen (2010). We evaluate the floating storage economics using Brent crude oil which can be loaded into VLCCs at the Sullom Voe terminal, thereby avoiding potential limits to arbitrage due to limited pipeline capacity for the landlocked WTI.

To our knowledge we are the first to study how oil futures prices, time-charter rates and FFA prices jointly relates to the floating storage decision i.e. the decision of whether to store oil or transport oil. The previous literature on freight rate derivatives has primarily looked at their role in price discovery and ability to forecast future physical freight rates (Kavussanos and Nomikos, 1999, 2003; Haigh, 2000; Kavussanos, Visvikis and Menachof, 2004; Batchelor et al., 2007; Goulas and Skiadopoulos, 2012), hedging efficiency (Kavussanos and Nomikos, 2000*b*,0; Alizadeh, Huang and van Dellen, 2015; Shi et al., 2017), and volatility spillover effects (Kavussanos and Visvikis, 2004; Kavussanos et al., 2010; Alizadeh, 2013; Li et al., 2014; Alexandridis et al., 2017).

The FFA literature suggests that freight derivatives incorporate market participants expectations of future realizations of spot rates. For short maturities FFAs have been shown to be unbiased estimators, while monthly FFAs with longer maturities have been shown to be biased. The bias is potentially partly caused by lower liquidity in the monthly FFAs with longer maturities (Alizadeh, Kappou, Tsouknidis and Visvikis, 2015). In our paper, we use the FFA curve to represent the implied earnings of operating a vessel in the voyage charter market as an alternative to floating storage. The implied earnings from the FFA curve can also be viewed as a component in a FFA hedged time charter trading strategy. The difference between FFA rates and time-charter rates represents the profit which can be earned on a trading strategy in the absence basis risk and default risk. Adland and Alizadeh (2018) investigate what drives the difference between time charter rates and FFA rates in the dry bulk market. They find that time charter rates predominantly exceed the equivalent rate from FFAs. They argue that part of the positive difference can be explained by a risk premium associated with default risk of the bilateral time-charter agreements. Another factor is the convenience yield associated with having commercial control of the time-chartered vessel which FFAs do not provide.

We calculate the excess storage profit over the FFA time charter basis which can be taken to indicate whether the value of storage trade exceeds the alternative trading strategy in the absence of basis risk. We find that this is a better predictor of whether a vessel on time charter will be used for floating storage than the plain storage profit. We also find that vessel age is an important determinant. Specifically, vessels older than 15 years, which panellists shall exclude in their Baltic panel assessment, are more likely to be utilized as floating storage.

2.3 The floating storage trade and the no-arbitrage condition

We start by considering an agent who wants to store one barrel of crude oil between time t and T with $t < T$. At time t, the agent finances and buys a barrel of crude oil in the spot market[5]. Simultaneously, the agent sells an oil futures contract on a barrel with a futures price of $F_{t,T}$. $F_{t,T}$ is the price of the futures contract observed at time t with maturity at time T. The agent leases a storage facility with storage costs of $SC_{t,T}$ paid at time t. The agent earns a profit on the storage trade at time T of

$$\pi = F_{t,T}(1 - TRC) - e^{r_{t,T}(T-t)} \left(S_t(1 + TRC) + INS\right) - e^{r_{t,T}(T-t)} SC_{t,T} \tag{2.1}$$

where $r_{t,T}$ is the funding rate at which the agent can borrow between time t and T such that $e^{r_{t,T}(T-t)}$ incorporates the financing costs associated with the purchase of the crude oil barrel. INS is the insurance cost in \$ per barrel, TRC represents trading costs from bid-ask spreads in percentage of the futures prices and $SC_{t,T}$ is the cost of storage between time t and T.

We will now turn to the case where the agent uses a tanker vessel as floating storage. The agent can hire a tanker by entering into a time-charter contract. The hire rate, also called the time-charter rate, is quoted on a USD/day basis. The time-charter rate will constitute the storage

[5]Technically, there is no spot market and we use the future with the shortest time to delivery as the spot price.

cost together with a port charge and an expense for fuel consumed by the auxiliary engine. We denote the time-charter rate between time t and T by $TC_{t,T}$, the port charge at the loading port[6] PC and the expense for marine gas oil $MGO_{t,T}$. At time T the agent will have earned a profit on the floating storage trade amounting to:

$$\pi = \Big(F_{t,T}(1 - TRC) - e^{r_{t,T}(T-t)}\left(S_t(1 + TRC) + INS\right)\Big)\, w - e^{r_{t,T}(T-t)}\left(TC_{t,T}(T-t) + MGO_{t,T} + PC\right), \tag{2.2}$$

where w is the storage capacity in barrels (bbl) of the leased tanker vessel. The no-arbitrage condition for the storage trade is then:

$$\Big(F_{t,T}(1 - TRC) - e^{r_{t,T}(T-t)}\left(S_t(1 + TRC) + INS\right)\Big)\, w - e^{r_{t,T}(T-t)}\left(TC_{t,T}(T-t) + MGO_{t,T} + PC\right) \leq 0. \tag{2.3}$$

If the time-charter rate and crude oil futures prices do not satisfy the above relation an agent will be able to create an arbitrage. The agent can then finance and purchase w barrels in the spot-market, hire a tanker vessel on a time-charter of duration $T - t$, and simultaneously sell oil futures on w barrels.

We will now present storage profits calculated on the basis of time-series information on time-charter rates. The trade is constructed by selling the 13 month Brent future and buying the 1 month Brent future. The main storage cost is the time-charter rates. We use the broker assessment made by Clarksons for the one-year time-charter rate by a 310,000 dwt tanker. We assume the amount of marine gas oil consumed by the auxiliary engine[7] to be 10mt/day and use marine gas oil prices for Rotterdam. We add a premium of 0.05% to the purchase price and discount the selling price by 0.05% to reflect bid-ask spreads[8]. Insurance costs[9] are \$0.03/bbl. Port costs

[6] We do not incorporate anchorage charges for the storage period. We are also assuming that the tanker does not sail far from the loading area. In reality, we expect that the arbitrageur will sell the cargo towards the end of the storage period to a new agent such as a refinery. If the refinery is not located at the loading port it will have to pay a freight rate for the voyage. The freight rate will then compensate the arbitrageur for the costs associated with the voyage such as fuel expenses and port-charges. Hence the freight rate paid by the refinery will keep the arbitrage profitable.

[7] Hamilton (2015) suggests a fuel consumption of 10mt/day which is similar to what is used in TCE calculations for VLCCs at anchor.

[8] The premium and discount of 0.05% reflect the median transaction cost we observe in the period from the 1st of January, 2008 to the 23rd August, 2017. See appendix 2.10

[9] See Alizadeh and Nomikos (2004). This a bit more conservative than the insurance cost of \$0.02/bbl presented in Hamilton (2015).

are set to \$223,815[10]. Table 2.2 shows summary statistics and time-series plots are in appendix 2.8.

Table 2.2: **Summary Statistics**
This table shows summary statistics. Time-charter rates and bunker prices are weekly time-series. The LIBOR rate is annualized. The sample period is from January 2006 to August 2017.

Statistic	N	Mean	St. Dev.	Min	Max
Brent 1 Month \$/bbl	3,005	81.02	26.31	27.88	146.08
One-year contango \$/bbl	3,004	1.49	5.50	−12.03	17.93
One-year time-charter rate VLCC \$/day	604	39,784.56	17,169.19	18,000	90,000
Bunker Fuel Price \$/mt	626	690.73	221.25	227.50	1,317.50
One-month LIBOR	3,032	1.35	1.86	0.15	5.82

Figure 2.1: **Twelve month storage profits**
This figure shows the profit for the VLCC floating storage trade. Profits are given by equation (2.2). The storage horizon is fixed at one year and the storage capacity at 2Mbbl. The trade consists of a short 13 month Brent futures position and a long 1 month Brent futures positions. The time-charter rate is Clarksons' 1 time-charter rate year for a modern 310,000 dwt tanker. We account for insurance costs of \$0.03/bbl. We use a fixed premium and discount of 0.05% for the futures prices. We use the LIBOR term-structure as funding rate.

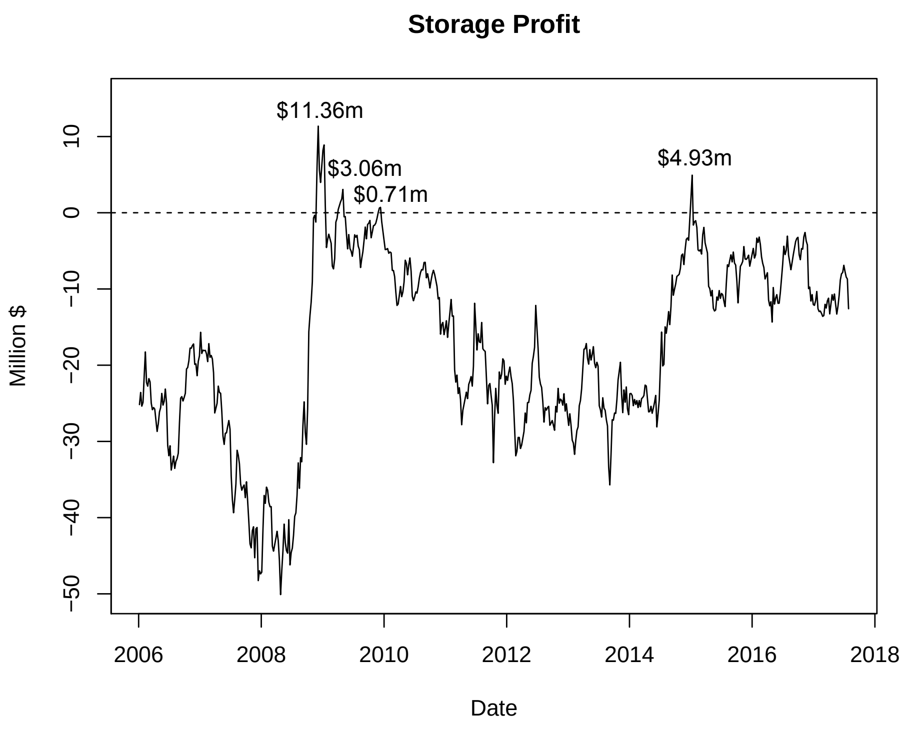


Figure 2.1 shows the profit for the one-year VLCC floating storage trade. In Figure 2.1, the agent is able to fund the storage trade at LIBOR. Commodity traders will in practice do secured

[10]Port charges are for Sullom Voe and are from Corry Brothers. Sullom Voe is one of the loading points for the Brent crude oil grade.

borrowing, pledging the commodity as collateral, (Tang and Zhu, 2016). As we cannot observe the secured borrowing rates for the commodity traders involved in the trade, we use LIBOR which is a measure of the unsecured inter-bank funding rate for a panel of large banks. We acknowledge that the use of LIBOR will underestimate the unsecured capital costs for most of the potential arbitrageurs, though we also expect arbitrageurs to borrow secured pledging the crude oil as collateral. Secured borrowing will result in lower borrowing rates relative to unsecured borrowing. Hence, our assumed borrowing rates suffer from one positive and one negative bias. We construct our yield curve using the LIBOR curve which we extend with swap rates for maturities above one year. There are four periods where the arbitrage condition is violated. The first period is from November 2008 to January 2009. This is the period with the largest violation peaking with a storage profit of \$11.36M. The second window where the arbitrage opens is at the end of April 2009 peaking in the beginning of May 2009 with a profit of \$3.06M. There is another violation in December 2009 with an arbitrage profit of \$0.71M. Finally the arbitrage is open in January 2015, where the trade profits peaked at a value of \$4.93M.

2.3.1 Sensitivity analysis

In this section, we look at how sensitive the no-arbitrage violations are with respect to the arbitrageur's funding rate and transaction costs.

Financing costs

We investigate the sensitivity of the arbitrage opportunities to the arbitrageur's funding rate by backing out the funding rate where the arbitrage profit is equal zero (the implied no-arbitrage funding rates). Agents who cannot fund themselves at a rate lower than the implied no-arbitrage funding rate are unable to exploit the arbitrage opportunity. Table 2.3 shows the implied no-arbitrage funding rates in the violation periods. The largest violation is on the 5th of December, 2008. Here the implied no-arbitrage funding rate premium is 10.55 percentage points above LIBOR. During the Oil Glut, the implied no-arbitrage funding rate premium peaks at 4.63% on the 9th of January, 2015. The fourth column shows a premium constructed from an index of yields on seasoned Baa corporate bonds, i.e. bonds with a maturity above 20 years. The premium is the yield on the bonds minus the average of the 20 year and 30 year swap rates. The premium serves as reference point under the assumption that the term-structure of the premium is flat across maturities. The Baa reference is an estimate of the unsecured funding rate premium and will be conservative relative to the unobserved secured borrowing rates. An agent who is able to fund herself at a funding rate equal to LIBOR plus the Baa premium would only have been able set up the arbitrage in four weeks of our sample.

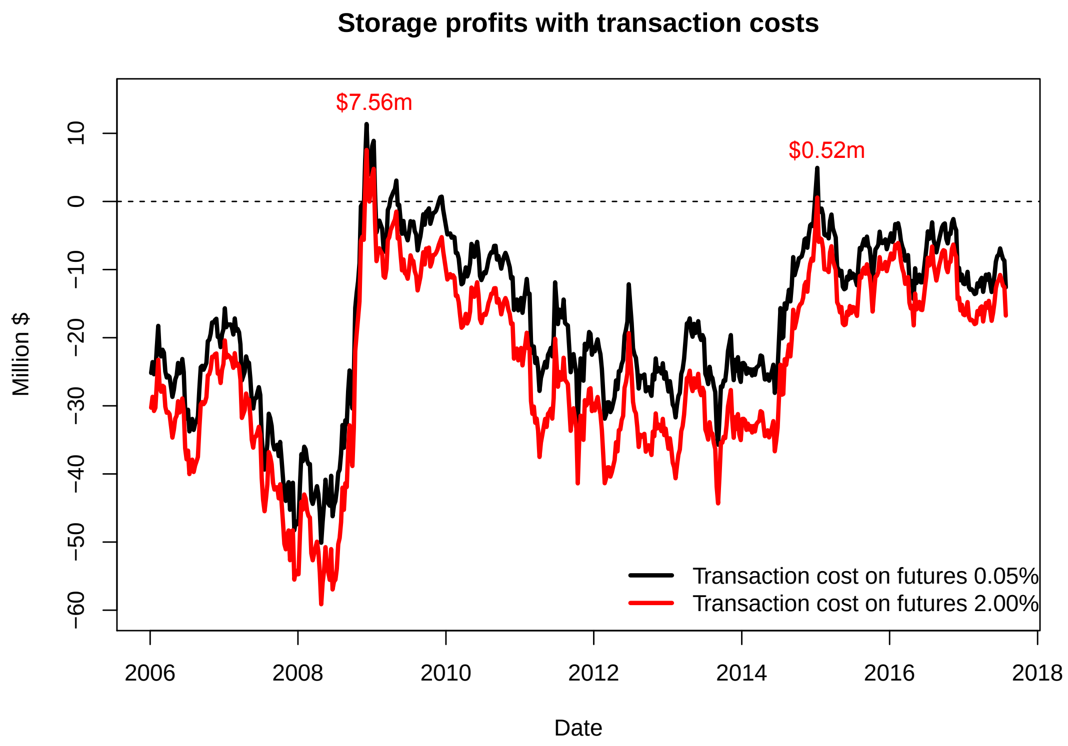
Table 2.3: **Implied no-arbitrage funding rate premiums**
This table shows implied no-arbitrage funding rates. The first column shows the dates in the weekly time-series where the no-arbitrage condition is violated. The second column shows the profit in million US dollars. The third column shows the implied no-arbitrage premium. The implied no-arbitrage premium is the spread in percentage points above LIBOR where the arbitrage profit is exactly zero. The fourth column shows a premium derived from Moody's seasoned Baa corporate bond yield from the Federal Reserve Bank of ST. Louis. The seasoned bonds have a maturity above 20 years. The premium is constructed as the Baa yield minus the average of the 20 year and 30 year swap rates. The premium serves as reference point under the assumption that the term-structure of the premium is flat across maturities.

Date	Profit ($m)	No-arbitrage premium (%)	Baa premium (%)	Violation
2008-11-28	6.01	4.49	5.98	
2008-12-05	11.37	10.55	5.88	yes
2008-12-12	5.60	4.70	5.92	
2008-12-19	3.98	3.52	5.58	
2009-01-02	8.18	6.77	5.24	yes
2009-01-09	8.90	7.66	5.28	yes
2009-01-16	1.00	0.84	5.17	
2009-04-03	0.41	0.33	5.20	
2009-04-17	1.44	1.15	4.95	
2009-04-24	1.80	1.48	4.78	
2009-05-01	3.06	2.45	4.54	
2009-11-27	0.01	0.01	2.22	
2009-12-04	0.62	0.36	2.18	
2009-12-11	0.71	0.44	2.12	
2015-01-02	1.97	1.51	2.03	
2015-01-09	4.93	4.11	2.10	yes

Transaction costs

In this section, we look at the sensitivity of the storage profits with respect to transaction costs. In Figure 2.2, we illustrate the difference between profits in our base case to a scenario with extreme transaction costs. In our base case, we use a transaction cost of 0.05%, close to the median (see, appendix 2.10). This means that a premium of 0.05% is added on futures purchased by the arbitrageur. Similarly futures contracts sold by the arbitrageur are discounted by 0.05%. In our extreme scenario, we use transaction costs of 2% which exceeds the observed 95 percentile by a large margin, see appendix 2.10. The storage trade remains profitable both in the aftermath of the Financial Crisis and during the Oil Glut. With transaction costs of 2% the profit peaks at $7.56m compared to $11.36m in the base case. Similarly, the storage profit during the Oil Glut peaks at $0.52m compared with a storage profit of $4.93m in the base case.

Figure 2.2: **Sensitivity of storage profits to transaction costs**
This figure shows the sensitivity of the storage profit with respect to transaction costs.



2.3.2 Storage profits across horizons

Before we evaluate the storage profits for the individual time-charter fixtures directly, we will apply the term-structure smoothing approach[11] of Koekebakker and Adland (2004) to evaluate storage profits across the term-structure of oil prices and time-charter rates. Here we face the issue of calibrating the short-end of the term-structure as there is no time-charter index with a horizon below one year. In order to estimate storage profits with horizons below one year, we incorporate time-charter equivalent earnings from voyage charter rates as a proxy for very short period time-charters. As an example, Figure 2.3 shows the smoothed time-charter and forward time-charter curves on January, 2nd 2015. The forward rates are bootstrapped from Clarksons' time-charter rates with horizons of one, three and five years respectively. We use the spot TCE rate as our two-month time-charter rate. The spot TCE is for a modern 2010-built VLCC tanker for the route from Ras Tanura to Chiba. We note that this might underestimate storage profits associated with hiring older and cheaper vessels. In panel (b) of Figure 2.3, we compare the

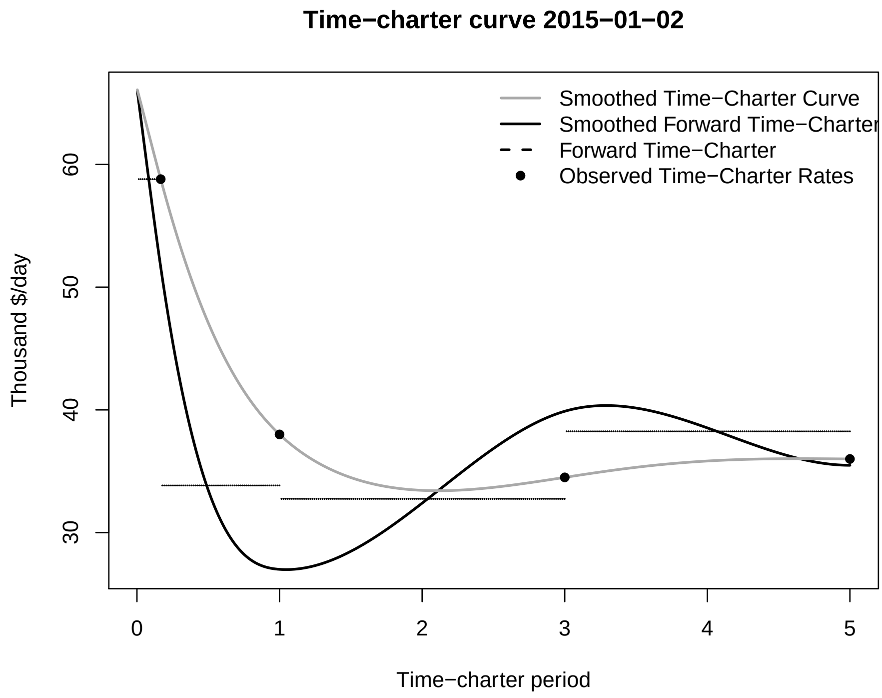
[11] See appendix 2.9 for brief outline of the approach.

Koekebakker and Adland (2004) with the Nelson and Siegel (1987) smoothing method. The two methods show only small differences in smoothed values. We have a slight preference for the Koekebakker and Adland (2004) smoothing method as it always matches the observed time-charter rates.

Interestingly, figure 2.4 shows that short-term storage profits for two and six months were higher than the one-year storage profit during the Financial Crisis. During the Oil Glut, we see the opposite picture such that storage profits of 18 months exceeds the profit associated with shorter storage horizons of two months, six months, or twelve months. The different shapes (spreads) over time can be attributed to the different nature of oil supply and demand shocks. The Financial Crisis served as a negative oil demand shock which depressed both the short-run demand for crude oil (large contango) and tanker services (flat and low term structure of TC rates). Conversely, the Oil Glut served as a positive oil supply shock. A positive oil supply shock (increased production) pushes down the short end of the oil futures curve (large contango) but also stimulates short-run tanker rates (downward sloping term structure of TC rates). Higher production generally leads to an increase in demand for tanker services, (Shi et al., 2013), though this will also depend on the degree of oversupply of tankers. This leads to the observation that long-term storage was more profitable than short-term storage during the Oil Glut. Figure 2.4 shows frequent small violations of two month storage arbitrage. This suggest that a voyage itself acts as a type of floating storage which connects oil and freight markets. To address the potential concern that our smoothed time-charter rates do not reflect actual rates traded, we will now evaluate storage profits directly from actual time-charter fixtures.

Figure 2.3: **Smooth time-charter rate curve**

This figure shows the smoothest continuous forward rate function on the 2nd of January 2015. The forward rate function is given by equation (10) in Koekebakker and Adland (2004). The grey line shows the smoothed time-charter rates in panel (a) and (b). Observed time-charter rates are from Clarksons' and cover horizons of one, three, and five years. We use the spot TCE to proxy the short end of the curve. The spot TCE is for a modern 2010 tanker and is the VLCC earnings for the route Ras Tanura to Chiba. The spot earnings are assumed to proxy a time-charter with a horizon of 60 days. Panel (b) compares the Koekebakker and Adland (2004) smoothing method with the method of Nelson and Siegel (1987).



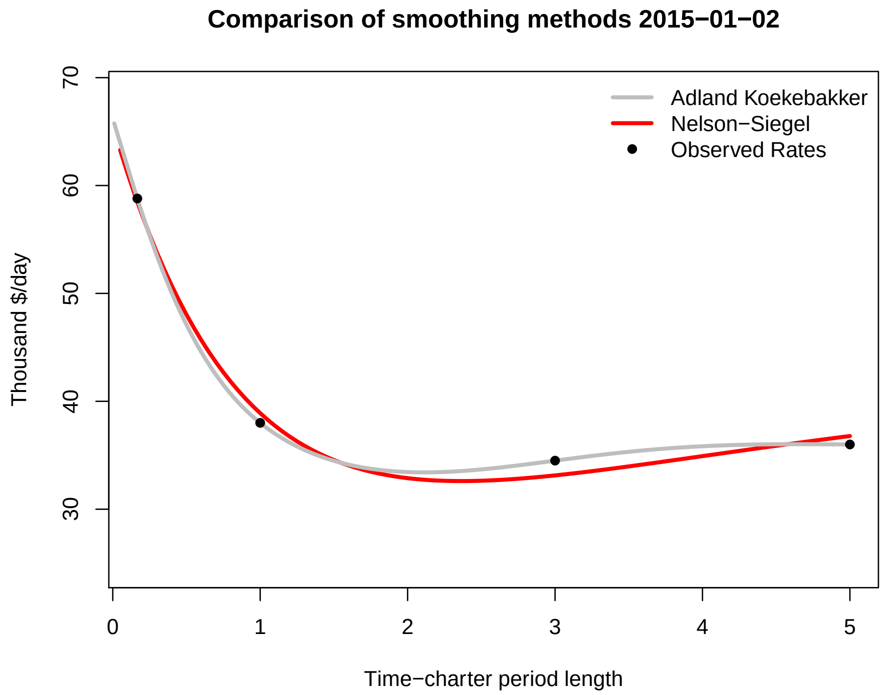
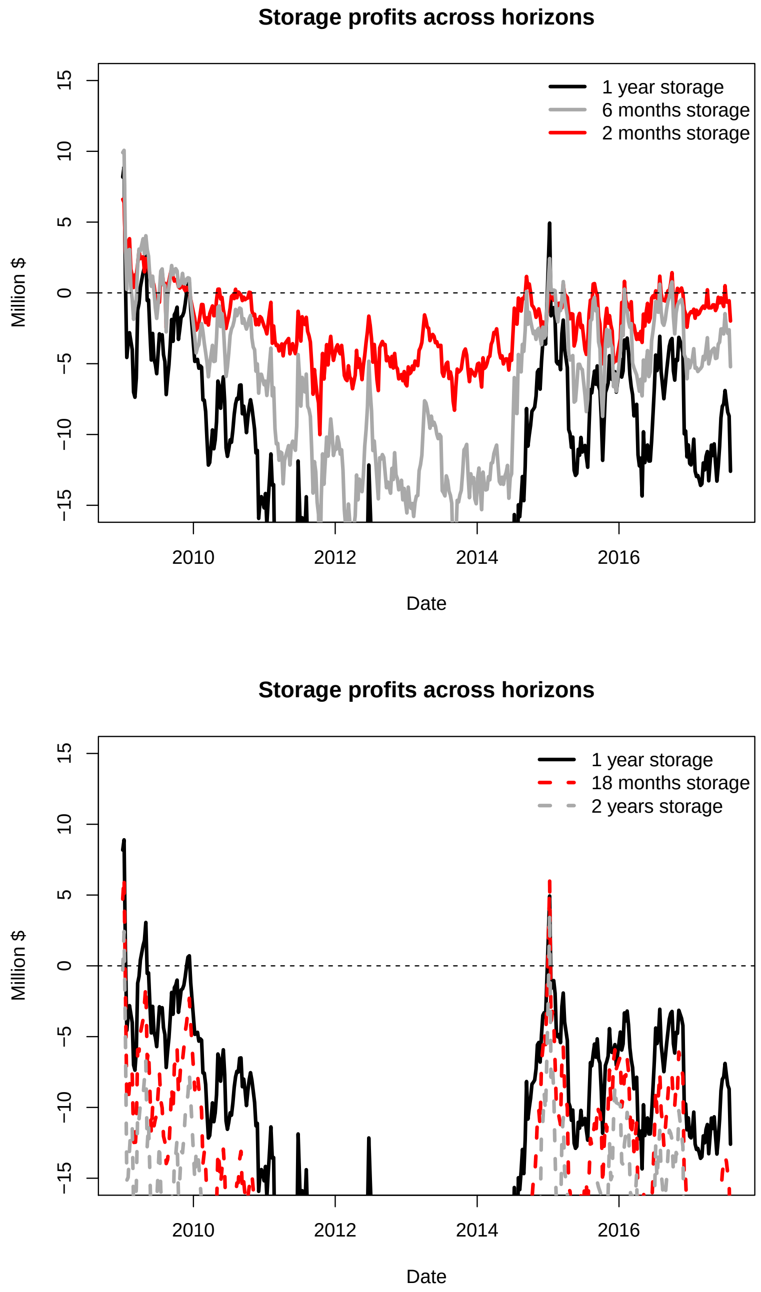


Figure 2.4: **Storage profit across lengths of the storage period**

This figure shows the storage profit for storage periods of 1 year, 6 months and 2 months in the first panel. The second panel shows storage profits for storage periods of 1 year, 18 months and 2 years.



2.4 Microeconomic evidence from fixtures

We will now turn to the microeconomic evidence from fixtures. Between 2008 and 2017, we observe 316 unique time-charter fixtures in the VLCC segment. We have collected the individual time-charter fixtures from Clarksons Shipping Intelligence (2011-2017) as well as IHS via Bloomberg

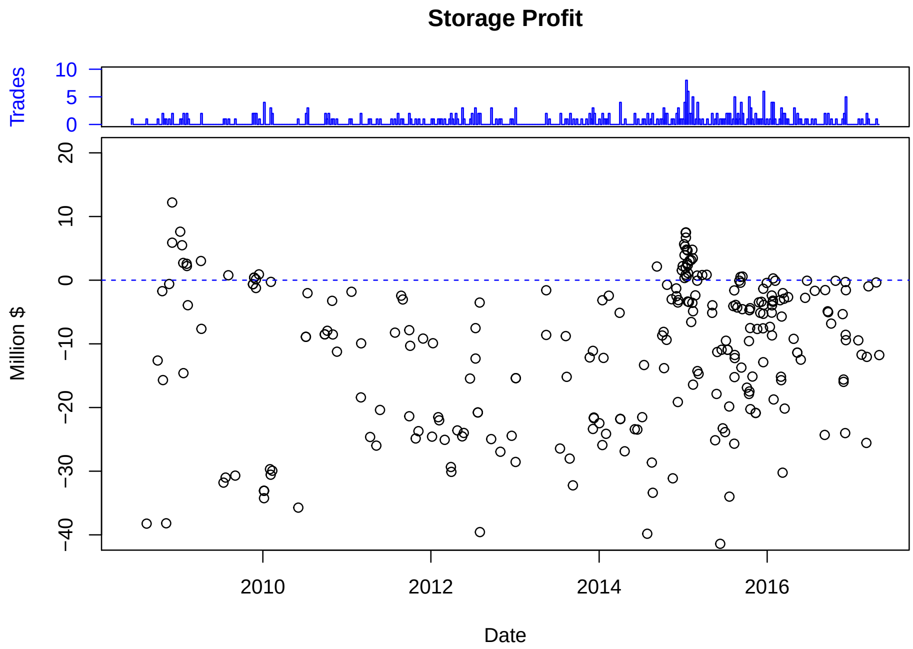
(2008-2017). Information on the TC rates are public for 291 out of the 316 fixtures. Table 2.4 shows summary statistics for the time-charter fixtures. We use the fixtures to see whether agents are able and willing to time-charter vessels during periods of arbitrage violations. An agent can enter a time-charter fixture either for transportation or storage purposes. For each individual time-charter fixture i with $i = 1, 2, ..., N$, we compute the floating storage profit as:

$$\pi_i = \Big(F_{t_i,T_i}(1 - TRC) - e^{r_{t_i,T_i}(T_i - t_i)}\left(S_{t_i}(1 + TRC) + INS\right)\Big) w_i \\ - e^{r_{t_i,T_i}(T_i - t_i)}\left(TC_{i,t_i,T_i}(T_i - t_i) + MGO_{t_i,T_i} + PC\right). \quad (2.4)$$

It is important to note that we do not observe whether the charterers also enter crude oil futures positions. Instead we use the futures prices which match the maturity of the time-charter agreement T_i and the 1 month Brent future. We note that a portion (72) of the time-charters have embedded extension options. This provides the time-charterer with the option to extend the period at a pre-specified rate. For time-charter fixtures which have extension options, storage profits are calculated for the base period only (i.e. excluding the extension period). This will underestimate the value of the trade as it ignores the option value associated with the charterers option to dynamically roll the storage into the extension period.

Figure 2.5: **Storage profits for the individual fixtures**

This figure shows the storage profits calculated as in equation 2.4 for the individual time-charter fixtures. The histogram panel above the storage profit panel shows the number of fixtures at a weekly frequency.



In figure 2.5, we show the storage profits for the fixtures. The figure shows that agents are able to time-charter vessels during periods with violations of the no-arbitrage condition. The histogram in the top panel shows the number of fixtures at a weekly frequency. In the period prior to 2011, we do not have fixtures from Clarksons. Hence it is hard to compare the number of fixtures in the period prior to 2011 with the period from 2011 onwards. We see a relatively high number of fixtures around the violation period during the Oil Glut. Table 2.5 shows storage profits for profitable fixtures for the individual charterers. The charterers with profitable storage trades can be characterized as shipping companies, commodity traders, oil companies and a commercial bank. We think that the commodity traders, oil companies and the commercial bank observed in table 2.5 are firms which are able to set up the arbitrage strategy outlined in equation (2.4), because they have access crude cargoes and also have the funding relationships needed to carry out the trade. Table 2.6 shows the implied funding rates as a spread above LIBOR for which the storage profit will be zero. For instance, a value of 5 in Table 2.6 implies that the agent will only be able to profit from the arbitrage if her funding rate is below the prevailing LIBOR rate plus five percentage points. We note that some of the implied no-arbitrage rates have a considerable spread above LIBOR of more than 3 percentage points. The implied no-arbitrage rates gives additional information regarding the size of the storage profit relative to the length of the storage period. We note that most of the charterers are also chartering vessels when the storage trade is unprofitable. We do not find this controversial as commodity traders and oil companies also demand transportation services or store crude oil temporarily for logistical reasons.

Table 2.4: **Time-charter fixtures summary statistics**
This table shows summary statistics from time-charter fixtures collected from Clarksons Shipping Intelligence Network (2011-2017) and Bloomberg (2008-2017). The earliest reported fixture is from the 9th of June 2008 and last is from the 2nd of May 2017. The extension option indicates whether a time-charter contract contains an extension option.

Characteristic	Unit	N	Average	St. Dev.	Min	Max	Yes	No
Vessel	DWT	317	307,900	19,347	265,500	442,000		
TC period	Months	317	17.16	14.35	1	96		
TC rate	$/day	291	34,705	12,945	10,750	98,000		
Vessel age	Years	317	8.707	5.358	0	21		
Extension option	yes/no	317					72	245

Table 2.5: **Floating storage profits**
This table shows summary statistics for profitable floating storage trades for a LIBOR funded agent. We label a trade as a profitable floating storage trade when the profit in equation (2.4) is positive. The table shows the profits in million USD. Numbers in parentheses indicate the total number of time-charter fixtures made by the specific charterer within our sample period.

Charterer	Number of profitable trades	Average floating storage profit	Minimum	Maximum
SK Energy	1(2)	6.687	6.687	6.687
Koch	6(30)	5.643	0.514	12.203
Trafigura	5(11)	4.870	2.218	7.494
BP	1(21)	3.441	3.441	3.441
Clearlake	5(10)	3.122	0.134	7.472
Unipec	3(15)	2.758	0.805	4.781
Shell	9(29)	2.499	0.404	5.888
Euronav	1(4)	2.146	2.146	2.146
Morgan Stanley	2(3)	1.810	0.913	2.708
Core Petroleum	2 (6)	1.120	0.851	1.548
Blue light	1(2)	0.788	0.788	0.788
ST Shipping	3(10)	0.710	0.277	1.124
Reliance	1(10)	0.570	0.570	0.570
Litasco	1(6)	0.341	0.341	0.341

Table 2.6: **Implied no-arbitrage funding rates**
This table shows summary statistics for profitable floating storage trades for a LIBOR funded agent. We label a trade as a profitable floating storage trade when the profit in equation (2.4) is positive. The table shows how many percentage points above LIBOR the funding rate needs to be in order for the profit of the storage trade to equal zero.

Charterer	No arbitrage LIBOR spread	Average	Minimum	Maximum
Shell		8.146	0.241	33.936
SK Energy		5.877	5.877	5.877
Koch		7.586	0.990	16.371
Clearlake		4.475	0.507	8.832
Morgan Stanley		4.426	0.573	8.278
Trafigura		4.193	1.671	6.610
Unipec		3.800	1.323	7.776
BP		2.580	2.580	2.580
Euronav		1.332	1.332	1.332
Reliance		1.287	1.287	1.287
Core Petroleum		1.259	1.149	1.369
ST Shipping		1.223	0.529	2.394
Blue light		1.000	1.000	1.000
Litasco		0.597	0.597	0.597

2.5 The floating storage decision

2.5.1 The FFA hedged time-charter trading strategy

We will now look further into the floating storage decision of charterers. We compare the storage profits with the alternative strategy of using the vessel for transportation and hedging the market exposure using FFAs. We set forth the alternative trading strategy as a possible explanation for why vessels on time-charter are sailing when they would have had positive storage profits during the Oil Glut. The alternative trading strategy consists of three steps. First, the charterer time-charters a vessel and pays the time-charter rate. Second, the charterer employs the vessel in the voyage charter market earning voyage charter freight rates. Third, the charterer hedges the voyage charter freight rate exposure from the second step by entering into the paper-based freight derivatives Forward Freight Agreements. The charterer receives a cash-flow from this trading strategy which has a present value of:

$$\pi_t^{FFA-TC} = e^{-r_{t,T}(T-t)}(T-t)\mathrm{E}_t\left[FFA_{t,T} - FR.Baltic_{t,T} - (TC_{t,T} - FR_{t,T})\right], \tag{2.5}$$

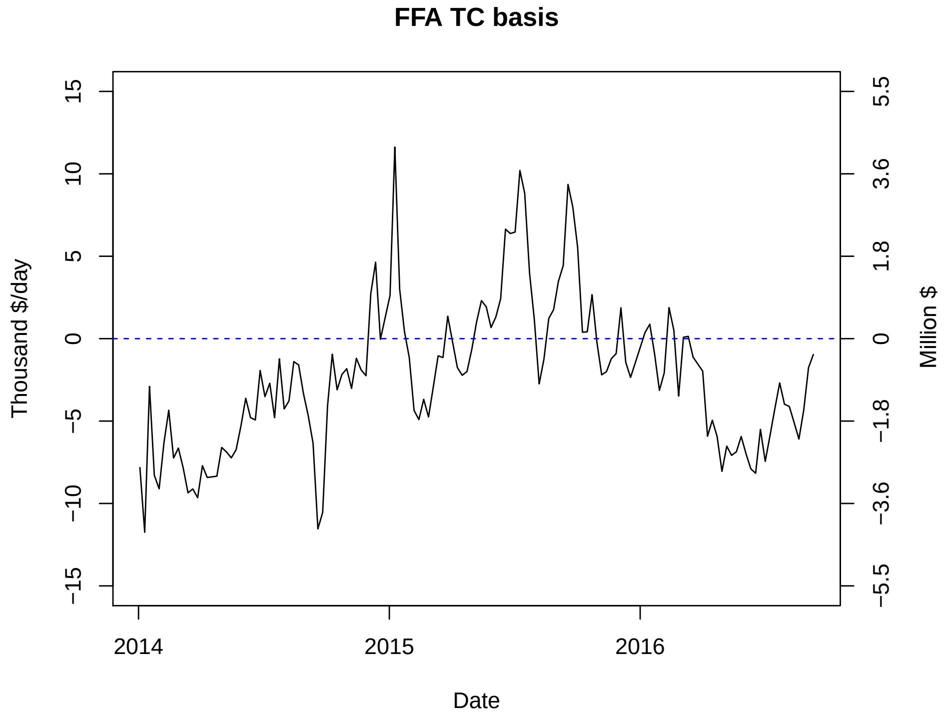
where $FFA_{t,T}$ is the time-charter equivalent FFA rates, $FR.Baltic_{t,T}$ is the average of the time-charter equivalent settlement rates for the FFAs published by the Baltic Exchange, and $FR_{t,T}$ is the average freight earnings over the period from time t to time T. In the case, where there is no basis risk between the Baltic spot assessments and the freight income of the vessel the charterer earns the FFA TC basis: $FFA_{t,T} - TC_{t,T}$.

Time-charter agreements and FFAs are two possible ways agents can hedge their freight rate exposure. A time-charter gives the charterer possession of a vessel whereas FFAs are cash-settled contracts. This implies that FFAs are purely linked to the future realizations of spot freight rates. FFAs do therefore not reflect the value of real options such as the floating storage trade. If FFAs and time-charter agreements were perfect substitutes an agent would be able to make an arbitrage profit by time-chartering a vessel, hedging the freight rate exposure with FFAs, and employing a vessel in the spot market. FFA hedging is, however, associated with considerable basis risk and the arbitrage strategy outlined above is not a risk-free arbitrage strategy (Adland and Jia, 2017; Alizadeh and Nomikos, 2009). The basis risk can be attributed to a number of factors. To mention a few, vessels fix at discrete time-points roughly two months apart whereas the FFA settles against the average of daily spot assessment throughout the period. Another source stems from differences between vessel characteristics of the reference vessel of the FFA and the vessel on time-charter. Similarly, basis risk can arise if the time-chartered vessel is employed on routes different from reference route of the FFA. The time-charter is also associated with unemployment risk which is not captured by the FFA[12]. The above mentioned features are all reasons why the FFA hedged time-chartering strategy need not represent an arbitrage opportunity in the true risk-less sense. Nevertheless, if deviations between time-charter rates and FFA rates become sufficiently large the trading strategy might still be attractive to charterers.

[12]FFAs settle against the broker assessed settlement rates published by Baltic Exchange. The settlement rate should reflect the prevailing spot rate for vessels trading. Unlike a time-charter, the FFA contract therefore does not hedge an operator against vessel unemployment risk.

Figure 2.6: **Time-charter FFA basis**

This figure shows the spread between the time charter equivalent from FFAs and the time-charter rate with a horizon of one year. The spread can be denominated either in $/day or in million $ over the one year period.



In a recent paper, Adland and Alizadeh (2018) look at what determines the difference between time-charter rates and FFAs in dry bulk. They find that on average the time-charter rates exceed the equivalent rate from FFA contracts. They argue that part of the positive difference can be explained by a risk premium associated with default risk inherent in the bilateral time-charter agreements. Another factor is the convenience yield associated with the commercial control of the vessel. From Adland and Alizadeh (2018), we know that time-charter rates on average exceed FFA rates in the dry bulk market. Interestingly, Figure 2.6 shows that the period where the floating storage arbitrage is open coincides with the period where time-charter rates are lower than the equivalent rate from FFAs[13]. The deviation of $11,620/day which corresponds to $4.24m over the one year storage period is substantial. Time-charter rates are therefore not only low compared to the oil futures contango spread but also compared to the corresponding FFA prices. This suggests that time-charter rates are generally too low when they are related both to the storage trade and the FFA hedged time-charter trading strategy.

[13]We use FFA prices for the TD3 route between Saudi Arabia and Japan

2.5.2 The excess storage profit

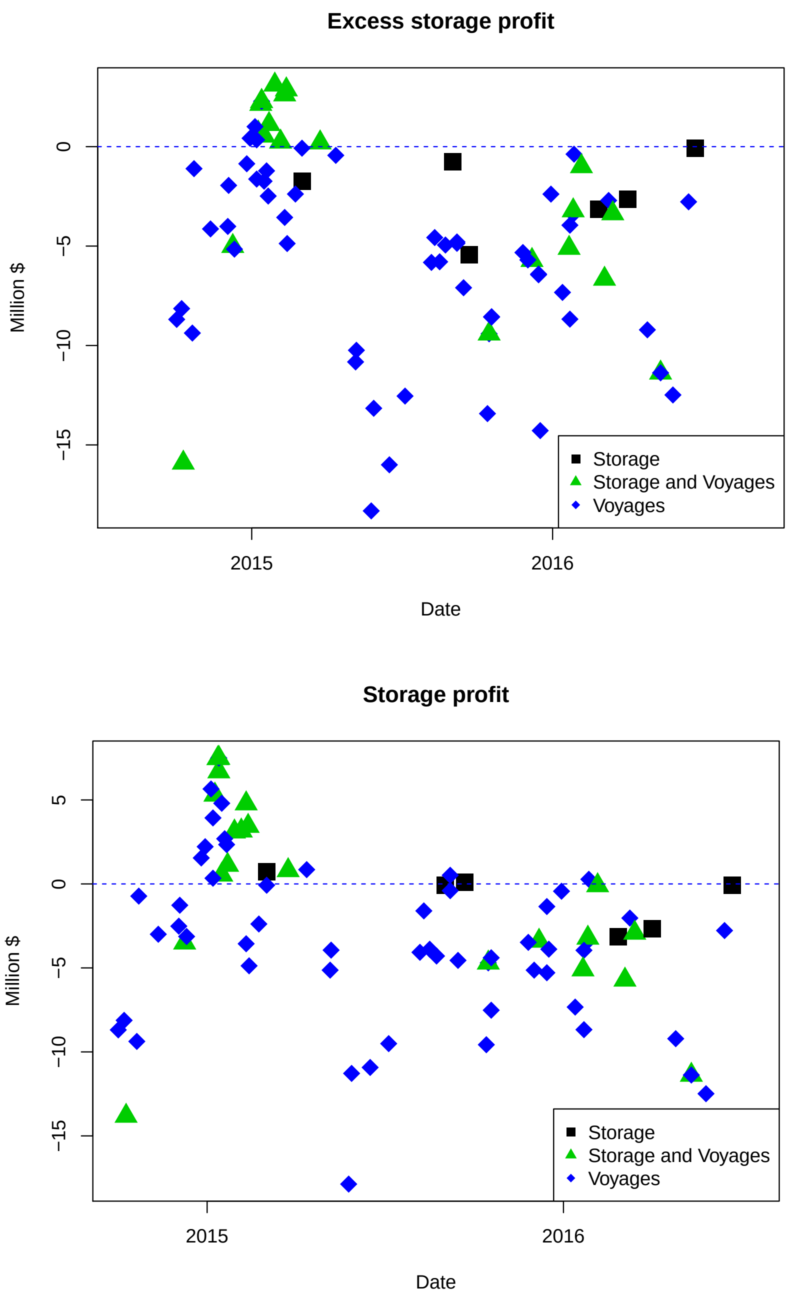
A rational charterer should pursue the most profitable trading strategy. A charterer should therefore only pursue the floating storage trade if the profit exceeds the profit of the alternative trading strategy. Ignoring the FFA hedging basis risk, a vessel will be used for floating storage when:

$$\pi_t^{Excess} = \left(F_{t,T} - e^{r_{t,T}(T-t)}\left(S_t + INS + TRC_t\right)\right)w - e^{r_{t,T}(T-t)}\left(TC_{t,T}(T-t) + MGO_{t,T} + PC\right) - \max\left\{e^{r_{t,T}(T-t)}(T-t)\left(FFA_{t,T} - TC_{t,T}\right), 0\right\} \geq 0 \quad (2.6)$$

We will now use information from vessels' AIS to test the hypothesis that vessels will be used for floating storage when the excess profit from equation (2.6) is positive. We use information from vessels' AIS to look at the behaviour of vessels on time-charter. We utilize AIS information provided by MarineTraffic on vessel positions, speeds, and self-reported draughts for a period from October 2014 to August 2016.

We then look at which vessels that were actually used for floating storage. We categorize vessels on time-charter into vessels used as floating storage, vessels used for transportation, and vessels used for a combination of storage and voyages. In order for a vessel to be put in the combination of storage and voyages category, it has to be laden and stationary (i.e. have a draught above 15 meters and a speed below 6 knots) for at least 20 consecutive days within the time-charter period. We do not observe all vessels through their entire time-charter period. Also, some vessels' time-charter period exceed our AIS sample period. However, for most vessels we are able to get a reasonable view of how the chartered vessel is utilized. We make two samples. The first sample consists of time-charter contracts where we are able to reasonably classify the behaviour of the vessels on time-charter. The second sample consists only of time-charter contracts where the entire time-charter period is contained in our AIS sample period. Figure 2.7 consists of two panels showing the storage profit and excess storage profit for the first sample. Panel (a) shows excess storage profits above the FFA TC basis given by equation (2.6) for each of the individual fixtures. For positive values, the floating storage profit exceeds the value of the alternative trading strategy. Panel (b) shows the storage profit measured by equation (2.3). The shape of the points indicate whether vessels are used for floating storage, transportation or a combination of the two. The figure shows that only a few trades relate to floating storage for the entire period of the time-charter.

Figure 2.7: **Storage profit excess of the FFA TC basis and storage profit**
In Panel (a), this figure shows the storage profit excess of the time-charter FFA basis which is set forth in equation (2.6). Panel (b) shows the storage profit set forth in equation (2.2).



2.5.3 The storage decision logistic regression results

We estimate a logistic-regression where the dependent variable equals one if the vessel is involved in any form of floating storage within the time-charter period and zero if it is purely used for transportation. A limitation of our work is that we cannot properly evaluate the storage decision for long-term time-charter contracts within our sample window of 1 year and 10 months. Another limitation is that our approach compares two static choices made when the time-charter is fixed. Hence our method does not factor in charterers' dynamic responses to realizations of uncertainty during the time-charter period. We use two specifications. In the first specification, we include a vessel age dummy for vessels with an age above 15 years. In the manual for panellists, panellists are instructed to make their freight rate assessment for vessels with a maximum age of 15 years. Hence we expect a higher level of basis risk for vessels older than 15 years due to a higher risk of unemployment in the spot market. We also include the TC period in months, vessel size in dwt and a dummy equal to one if the storage profit is positive and exceeds the FFA-TC basis from equation (2.6). In our second specification, we replace the excess storage profit dummy from equation (2.6) with a dummy equal to one if the storage profit from equation (2.4) is positive.

The regression results are shown in table 2.7. The first column shows the specification using the storage profit in excess of the FFA TC basis as a covariate. We notice that it as a positive and significant coefficient, indicating that the probability that the vessel is used for floating storage increases with the excess profit. Column two and three shows the second specification with the pure storage profit as a covariate. The third specification only uses observations for which we were able to calculate the FFA TC basis. Hence, column three and column one are estimated on the same data. The size of the storage profit has a positive and significant impact for both the sample with 128 and 81 observations. In all specifications, the vessel age dummy has a significant effect suggesting that old vessels on time-charter are more likely to be used for floating storage. This is intuitive as older vessels should have higher basis risk and unemployment risk than younger vessels, and thus a lower value of the alternative use in the spot freight market. A key result of our paper is the significant coefficient of the storage profit excess of the FFA TC basis. We interpret this as charterers being reluctant to use the vessel for storage purposes when the storage profit is smaller than the alternative chartering strategy. Table 2.8 shows similar results when we restrict our sample to time-charter contracts where we are able to track the vessels through the entire storage period, though we acknowledge that our result is dependent on our classification of our outcome variable.

As a further check, we therefore estimate another logistic regression where we adapt a more restrictive classification of vessels used floating storage. If we do not label observations where time-chartered vessels are used for a combination of storage and voyages as storage outcomes, we can not explain the storage decision of charterers. The logistic regression results, when we adapt the restrictive definition of storage outcomes, show that neither excess storage profits, storage profits or vessel age are able to explain charterers' storage decision. In the sample with 128 observation, we find a negative effect with respect to the time-charter period using the restrictive characterisation of storage outcomes. The estimated logistic regression results for the restrictive definition of storage outcomes are shown in appendix 2.11. We believe that it is sensible to label vessels that are used for a combination of storage and voyages as storage outcomes. We are nevertheless aware that our results are sensitive to our classification of storage outcomes.

Table 2.7: **Floating storage logistic-regression**
This table shows results from logistic regressions. The dependent variable is a floating storage dummy. The dummy takes a value of one if the vessel is used for floating storage during the time-charter period.

	Dependent variable:		
	Outcome		
	(1)	(2)	(3)
$1_{\{\text{Excess Storage Profit}>0\}}$	3.930**		
	(1.427)		
$1_{\{\text{Storage Profit}>0\}}$	−1.068	1.306*	1.454*
	(1.153)	(0.567)	(0.633)
$1_{\{\text{Vessel age}>15\}}$	3.203***	2.594***	2.899***
	(0.806)	(0.634)	(0.723)
Extension Option Dummy	−1.686	−1.157	−1.318
	(0.906)	(0.767)	(0.848)
Dwt	−0.029	−0.009	0.003
	(0.038)	(0.028)	(0.036)
TC period	−0.167	−0.073	−0.107
	(0.085)	(0.040)	(0.078)
Constant	8.455	1.703	−1.956
	(11.716)	(8.553)	(11.071)
Observations	81	128	81
Log Likelihood	−31.071	−48.256	−34.598
Akaike Inf. Crit.	76.142	108.512	81.195
Note:	*p<0.05; **p<0.01; ***p<0.001		

Table 2.8: **Floating storage logistic-regression using only non-censored observations**
This table shows results from logistic regressions. The dependent variable is a floating storage dummy. The dummy takes a value of one if the vessel is used for floating storage during the time-charter period. The data sample is restricted to vessels on time-charter where the entire time-charter period is contained in our AIS sample period.

	Dependent variable:	
	Outcome	
	(1)	(2)
$1_{\{\text{Excess Storage Profit}>0\}}$	4.841*	
	(1.886)	
$1_{\{\text{Storage Profit}>0\}}$	−2.271	0.858
	(1.612)	(0.702)
$1_{\{\text{Vessel age}>15\}}$	4.612**	3.407**
	(1.706)	(1.196)
Extension Option Dummy	−1.406	−0.820
	(1.402)	(1.206)
Dwt	−0.062	−0.020
	(0.047)	(0.040)
TC Period	−0.047	−0.007
	(0.120)	(0.103)
Constant	17.473	4.391
	(14.204)	(12.097)
Observations	56	56
Log Likelihood	−20.636	−26.317
Akaike Inf. Crit.	55.272	64.633
Note:	*p<0.05; **p<0.01; ***p<0.001	

2.5.4 Economic explanations for the oil market arbitrage

The violations of the no-arbitrage condition occur during the recent Oil Glut and the Financial Crisis. During the Financial Crisis, arbitrage opportunities have been documented for multiple markets e.g. deviations from the covered interest rate parity in foreign exchange markets and the CDS-corporate bond arbitrage, (Mancini-Griffoli and Ranaldo, 2011; Mitchell and Pulvino, 2012; Garleanu and Pedersen, 2011). The idea of slow moving capital, as described in Mitchell et al. (2007) and Duffie (2010), states that arbitrageurs are dependent on available capital in order to fund their arbitrage activities. When arbitrageurs are capital constrained they are unable to correct the mispricing and violations persist. We see that during the Oil Glut the violation is short-lived compared to the violations during the Financial Crisis.

During the Oil Glut, we have no reason to expect that arbitrageurs (commodity traders, oil companies, and commercial banks) were capital constrained. This raises the question why we observe violations during the Oil Glut? We start by noting that the majority of shipowners cannot do the floating storage trade themselves as they are not able finance the trade and do not have access to oil cargoes. Firms such as commodity trading houses and oil companies are better positioned, and the heterogeneity in the ability to finance the trade and access cargoes creates an incentive to trade. The amount funding needed to finance the trade is substantial. With a crude oil price of 46.59$ per barrel[14] and a cargo size of 2 million barrels, the principal on the floating storage trade is $93.18m for the crude oil alone. In comparison, the price of a 5 year secondhand 310,000 dwt VLCC was $80m in the same period[15]. Furthermore, the magnitude of voyage charter costs are typically between $0.5m and $2m for a voyage between Saudi Arabia and Japan. For instance the total voyage costs from the Baltic Exchange TCE amounted to $970,770, in October 2016 for a voyage from Saudi Arabia to Japan. The financing costs associated with the trade substantially exceeds shipowners working capital.

Second, we argue that the time-charter rates accepted were low in the violation period in January, 2015. In section 2.5, we compare time-charter rates with the time-charter equivalent rate from FFAs. The comparison suggests that time-charter rates were not only low compared to the level of contango, but they were also low compared to the prevailing FFA prices. The deviation from both the level of contango and FFA prices suggests that shipowners were accepting too low time-charter rates. We are not able to establish the exact cause which made shipowners accept the relatively low time-charter rates. Possible rational explanations are; (a) shipowners were liquidity constrained and therefore willing to accept lower time-charter rates, (b) shipowners were risk averse and therefore willing charter out their vessels at a discount or (c) a combination of (a) and (b). Alternatively, there is the behavioural explanation[16] that the shipowners' perception of the

[14]This is the observed Brent Crude oil future price on the 13th of January 2015.

[15]Source: Clarksons Shipping Intelligence

[16]Greenwood and Hanson (2014) argues that shipowners' investment decisions are subject to behavioural biases. They argue that shipowners over-extrapolate past returns and neglect competitors' investment decisions. If shipowners investment decisions are subject to behavioural biases then their chartering decisions are possibly also subject

attractiveness of the time-charter rate is reference dependent, a general concept from behavioural economics, (see for instance, Kahneman (2003)). In January 2015, the one-year time-charter rate reached its highest level since 2009[17] which potentially made them attractive compared to the shipowners' reference point of rates from the previous five years.

During the violation period in the Oil Glut, we have argued that time-charter rates were not just low compared to the degree of contango but also relative to the equivalent FFA rates. The literature on FFAs contains some evidence that the FFA curve reflects market participants' expectation of the future voyage charter rate and thereby the excess storage profit will reflect the expected value of the floating storage relative to the value of operating the vessel in the voyage charter market. The positive spread between the FFA rates and the time-charter rate can furthermore serve as a trading signal for a risky time-chartering strategy without the FFA hedge. This is an even simpler albeit even riskier trading strategy which is open to a wider set of market participants e.g. shipowners.

This implies that the firms which are able to exploit the floating storage arbitrage might be beaten to the punch by firms who employ risky trading strategies which can be carried out right away. Given that the time-charter rates generally seem too low, the number of shipowners who are willing to hire out their vessels at discount should be limited to liquidity constrained, risk averse or behavioural biased shipowners. Furthermore, it can be argued that the floating storage is not completely risk-free as the arbitrageur might receive margin calls during the storage period. The arbitrage is open when oil prices are low and the degree of contango is high. When oil prices are low there is potentially an increased likelihood that the oil price will mean-revert towards a higher level in the future. Hence the arbitrageur might have an increased likelihood of receiving margin calls on the short futures position during the storage period. If oil prices increase sufficiently the arbitrageur needs sufficiently deep pockets to cover the potential margin calls.

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to behavioural biases.

[17] See the time-series plot of the one-year time-charter rate in appendix 2.8

2.6 Concluding remarks

We investigate the floating storage trade. The floating storage trade causes additional demand for tanker vessels in excess of the demand for transportation services. We evaluate a cash-and-carry trading strategy and the corresponding no-arbitrage relation. We find violations of the no-arbitrage condition both using time-series of time-charter rates and time-charter rates from fixtures.

We investigate storage profits across storage horizons. We find that in the aftermath of the Financial Crisis profits for short storage horizons exceeded profits for longer horizons. During the Oil Glut, we see the opposite picture such that storage profits for storage horizons above one year exceed short-term storage profits. We attribute the difference to the distinction between oil supply and demand shocks. The Financial Crisis served as a negative oil demand shock and pushed down both the short end of the oil futures curve and spot freight rates. In contrast, the Oil Glut served as a positive demand shock to oil which pushed down the short end of the oil futures curve but stimulated spot freight rates through increased demand for transportation services.

Our findings are of interest to maritime economists and oil market participants alike. As floating storage activity can be an important driver of tanker demand at the margin, an improved understanding of the behaviour market participants in this regard can assist in better forecasts of the market. Our findings also illustrate empirically how the tanker freight and oil futures market are integrated through the floating storage arbitrage, with the oil futures spread effectively putting a floor on tanker time-charter rates. However, we show that this constraint has been effective only rarely, notably in the Financial Crisis of 2008-2009 and subsequently in the Oil Glut of 2014-2015.

Finally, we evaluate the ex-post usage of chartered ships using geospatial ship-tracking data. We find that charterers are reluctant to use vessels for floating storage even in cases when they would have had positive profits. We derive the excess storage profits above the FFA time-charter spread and find that it is a significant predictor of charterers' storage decision. A possible explanation for this finding is that the charterer simply chooses the most profitable trading strategy. However, the FFA hedged time-chartering strategy is subject to basis-risk. We also find that vessels with an age above 15 years are more likely to be used for floating storage. An alternative explanation is that market participants who are not able to exploit the storage arbitrage still find time-chartering a vessel and operating it unhedged in the voyage charter market attractive. This would also lead to an significant effect of the excess profit covariate.

A natural continuation of this research would be to look at volatility spillover effects and the lead-lag relationship between crude oil tanker time-charter rates, the FFA curve and contango spreads.

2.7 Acknowledgements

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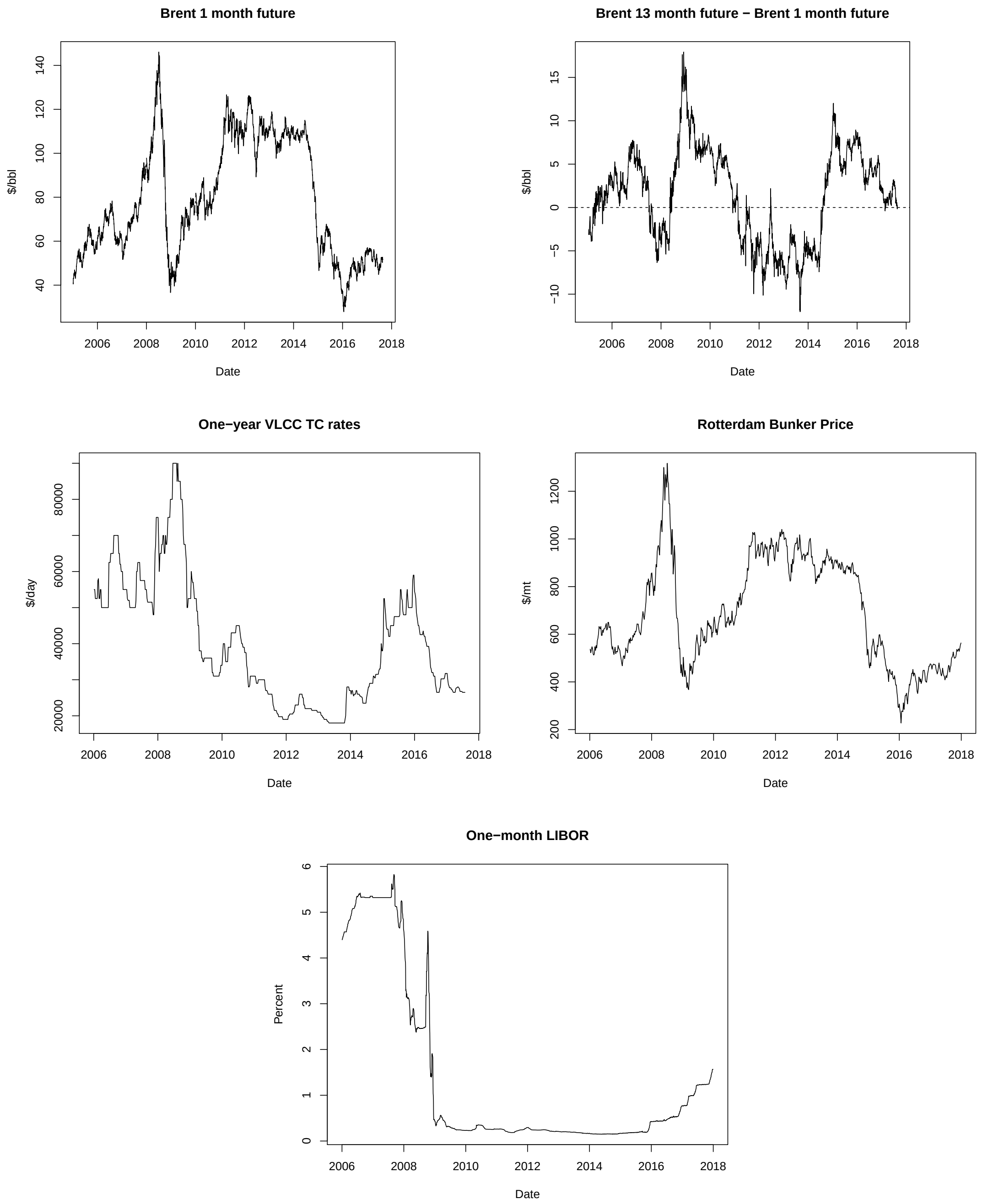
2.8 Appendix: Time-series plots

Figure 2.8.1: **Time-series plots**



2.9 Appendix: Method of Koekebakker and Adland (2004)

We create a smooth time-charter rate curve using the method of Koekebakker and Adland (2004). The the time-charter rate between time t (today) and a future time-point time T is modelled such that the smooth forward rate $f(s,s)$ satisfy the value matching condition:

$$\mathrm{E}_t^{\mathcal{Q}}\left[\frac{1}{T-t}\int_t^T e^{-r(s-t)}(TC_{t,T} - f(s,s))ds\right] = 0. \tag{2.7}$$

Rearranging equation (2.7) and accepting the approximation $e^{rs}/(\int_t^T e^{rs}ds) \approx 1/(T-t)$ gives us an expression for time-charter rates:

$$TC_{t,T} = \frac{1}{T-t}\int_t^T f(t,s)ds, \tag{2.8}$$

The forward time-charter rate is then defined as the rate at which a charterer at time t can charter a vessel between two future time-points T_1 and T_2. The forward time-charter rate is then

$$FTC_{t,T_1,T_2} = \frac{1}{T_2 - T_1}\int_{T_1}^{T_2} f(t,s)ds, \tag{2.9}$$

This enables us to bootstrap forward rates from the observed time-charter indices as

$$FTC_{t,T_1,T_2} = \frac{TC_{t,T_2}(T_2 - t) - TC_{t,T_1}(T_1 - t)}{T_2 - T_1}. \tag{2.10}$$

We choose the functional form of $f(t,s)$ as the cubic spline that matches the observed forward charter rates from equation (2.10) and simultaneously satisfies the maximum smoothness criteria of Adams and Van Deventer (1994).

2.10 Appendix: Brent Bid-Ask spread (% Price)

We obtain an estimate of transaction costs from bid and ask prices for the Brent futures contract. The time-series of bid and ask prices are from Bloomberg. It is often the case that either the bid or ask price is missing. Table 2.10.1 shows the distribution of the bid-ask spread divided by two measured in percent of the last price. In our base case, we discount arbitrageurs' crude oil sales with 0.05% and put a premium of 0.05% on arbitrageurs' crude oil purchases.

Table 2.10.1: **(Bid-Ask spread)/2 (% Price)**
This table shows half of the bid-ask spread relative to the last price. We use the last price as the mid price such that the bid price is the mid price minus one half of the bid-ask spread. In the table a value of 0.043 corresponds to a Bid-Ask spread of 0.086% of the last price. The bid-ask spread in the period between September 2008 and January 2009 consists of only one value observed on the 14th of September 2008. In our calculation of the storage profits we put a premium and discount of the futures prices of 0.05%.

	5%	15%	25%	50%	75%	85%	95%
Period 1995-Dec-12 to 2017-Aug-23	0.015	0.022	0.028	0.043	0.085	0.134	0.275
Period 2008-Jan-01 to 2009-Jan-01	0.014	0.020	0.029	0.052	0.107	0.193	0.462
Period 2008-Sep-01 to 2009-Jan-01	0.608	0.608	0.608	0.608	0.608	0.608	0.608

2.11 Appendix: Logistic regression results with the restrictive specification of the storage dummy

Table 2.11.1: **Floating Storage Logistic-Regression**
This table shows results from logistic regressions. The dependent variable is a floating storage dummy. The dummy takes a value of one if the vessel is used for floating storage during the **entire** time-charter period.

	Dependent variable:		
	Outcome		
	(1)	(2)	(3)
$1_{\{\text{Excess Storage Profit}>0\}}$	−17.812		
	(3,434.203)		
$1_{\{\text{Storage Profit}>0\}}$	0.081	−0.372	−0.372
	(1.774)	(1.588)	(1.588)
$1_{\{\text{Vessel age}>15\}}$	4.624	4.856	4.855
	(2.920)	(2.886)	(2.886)
Extension Option Dummy	−2.830	−3.156	−3.155
	(2.387)	(2.322)	(2.323)
Dwt	−0.160	−0.154	−0.154
	(0.104)	(0.097)	(0.097)
TC Period	−0.737	−0.822*	−0.822*
	(0.377)	(0.399)	(0.400)
Constant	48.888	47.272	47.262
	(31.964)	(29.814)	(29.809)
Observations	81	128	81
Log Likelihood	−8.776	−9.500	−9.500
Akaike Inf. Crit.	31.553	31.000	30.999
Note:	*p<0.05; **p<0.01; ***p<0.001		

Table 2.11.2: **Floating Storage Logistic-Regression using only non-censored observations**
This table shows results from logistic regressions. The dependent variable is a floating storage dummy. The dummy takes a value of one if the vessel is used for floating storage during the **entire** time-charter period. The data sample is restricted to vessels on time-charter where the entire time-charter period is contained in our AIS sample period.

	Dependent variable:	
	Outcome	
	(1)	(2)
$1_{\{\text{Excess Storage Profit}>0\}}$	−18.278	
	(3,329.399)	
$1_{\{\text{Storage Profit}>0\}}$	−1.210	−1.589
	(1.984)	(1.822)
$1_{\{\text{Vessel age}>15\}}$	5.585	5.756
	(3.053)	(3.082)
Extension Option	−2.873	−3.205
	(2.432)	(2.412)
Dwt	−0.152	−0.144
	(0.111)	(0.103)
TC Period	−0.615	−0.743
	(0.403)	(0.423)
Constant	45.991	44.169
	(34.006)	(31.566)
Observations	56	56
Log Likelihood	−6.810	−7.700
Akaike Inf. Crit.	27.619	27.401
Note:	*p<0.05; **p<0.01; ***p<0.001	

Chapter 3

Bargaining Power in Crude Oil Tanker Markets

Frederik Regli

Abstract

I study the bargaining power of shipowners and charterers in the crude oil tanker market for very large crude oil carriers (VLCCs). I find that the Nash bargaining parameter of shipowners is 24% on average and that the distribution of bargaining parameters is right skewed. This means that, when a shipowner enters into voyage charter agreement, the shipowner extracts approximately one-fourth of the shipowner's and the charterer's joint value of the trade.

Keywords— AIS, Bargaining, Crude Oil, Matching, VLCC

3.1 Introduction

I study the relative bargaining power of geographical traders and shipowners in the crude oil tanker market. Recent studies by Brancaccio et al. (2017), Brancaccio et al. (2018), Parker (2014) and Tvedt (2011) have looked at the equilibrium search and matching between geographical commodity traders(hereafter traders) and shipowners in bulk shipping markets. An important aspect of the search and matching models is the subsequent bargaining process and the relative bargaining power of the involved parties. When exporters and shipowners meet, they start bargaining over the contractual terms of the transportation contract, also known as the charter party. An important feature of the charter party is the price paid for the transportation service, better known to market participants as the freight rate. The contractually agreed upon freight rate reflects the relative bargaining power of the geographical trader and the shipowner. However, the shipowner and the trader will only reach an agreement if the value of entering the trade exceeds the value of their alternatives. The value of the alternatives serves as threat points establishing the agents' participation constraints. Both agents will exercise some bargaining power if they are able to extract an excess value above the value of their outside alternative. The joint value of the trade is the sum of the shipowner's and trader's value in excess of the value of their respective threat-points. The freight rate outcome determines the share of the value which the shipowner and trader are able to extract. The relative bargaining power depends on the agents' valuations of the trade and the value of their alternatives to the trade. The outside option of the shipowner is to remain unemployed and continue searching for employment. The unemployed shipowner dynamically makes a choice of where to sail in ballast to search for orders.

The traders buy crude oil in an oil-producing country such as Saudi Arabia, hire a tanker vessel to transport the oil to the refinery. The refinery will be located in an oil-consuming country such as South Korea. When the crude oil reaches the refinery, it is refined into oil products such as gasoline, diesel and fuel oil. Introducing refineries into my model, allows me to use the profit of refineries, better known as the refining margin, to determine the profit obtained by a trader[1]. In general the charterer need not be a refinery as it could also be an oil major reallocating oil reserves. The idea of jointly modelling oil tanker markets and refining markets is not new. Kennedy (1974) sets forth a static long-run model of crude oil production, transportation, refining, and consumption of oil products. Mayr and Tamvakis (1999) show that US crack spreads lead crude oil import volumes in the United States of America. My specification of geographical traders' valuations is an important distinction from the papers by Brancaccio et al. (2017) and Parker (2014). This allows me to get an estimate of the relative bargaining power of the shipowners and charterers through their profit sharing.

The freight market is often characterized as a perfectly competitive market in which the freight rate reflects the transportation cost of the marginal vessel. However, freight rates often exceed the marginal cost of transportation, (Adland and Strandenes, 2007), which suggests that shipowners

[1] In a more general model, the profit will be shared between a shipowner, a trader and a refinery. My main interest is on shipowners' bargaining power and I therefore treat the the trader and refinery as one agent.

are in possession of bargaining power. The bargaining power enables shipowners to extract some of the value which would otherwise have accrued to the trader.

Brancaccio et al. (2017) estimate a fixed bargaining coefficient of drybulk shipowners equal to 0.3. Their estimated bargaining coefficient depends on the exporters' valuation of the freight. They estimate exporters' valuations as a weighted average of the prices of iron ore, coal, grain, steel, and urea. The average is weighted by the relative frequency of the commodities in their sample of shipping contracts. However, geographical traders profit from the geographical spread in commodity prices rather than the price level of the commodities. In their model, exporters are oil producers with unobserved production costs. In the model by Parker (2014), the traders' valuation of a freight is the revenue arising from the geographical spread in oil prices. In the estimation of the model, it is assumed that the geographical traders' expectation of the future oil price is independent of the destination region. Furthermore, the traders' expectation of the crude oil price evolution is based on a binomial model. In the model, there is an 80% chance that the crude oil price will increase by 10%, and a 20% chance that the oil price will decrease by 5%.

In this paper, I set up a simple matching model where shipowners make dynamic ballasting choices. The matching model set forth in Brancaccio et al. (2017) and Brancaccio et al. (2018) is, to my knowledge, the only existing empirical matching model in bulk-shipping markets. Their model does not account for unobserved matches which arise through unreported fixtures. I estimate the spatial matching function using an expectation maximization (EM) algorithm to account for matches which are not reported in the fixtures data, (Dempster et al., 1977). Another contrast is that I allow shipowners to dynamically update their ballasting choices during their ballast legs. I estimate a stylized regime shifting process for the freight rate earnings. The regime shifts are governed by a Markov chain. This allows me to estimate a shipowner's steady state continuation value associated with accepting the terms in the voyage charter party, but also the continuation value of the shipowner's alternative to remaining unemployed. The shipowner's continuation value associated with remaining unemployed serves as the shipowner's disagreement point. I find that the shipowners' bargaining parameter is 24% on average, e.g., if a trade has an excess value (above the values of the threat points) of $100,000 the shipowner $24,000 and the trader would get $76,000 on average.

The rest of the paper is structured as follows: Section 3.2 presents the model, section 3.3 describes the data, section 3.4 presents the empirical estimation approach, and section 3.5 concludes.

3.2 Model

3.2.1 Environment

My model is inspired by the spatial matching frameworks of Brancaccio et al. (2017) and Buchholz (2015). Rather than estimating my model using a structural dynamic discrete choice model, I specify a stochastic freight rate process and estimate my matching function parametrically. Furthermore, I allow the shipowners to match with geographical traders prior to their arrival to the loading region. This is reasonable as the number of days between the contract signing and the loading date is roughly 21 days in the VLCC segment, according to Prochazka (2018, chapter 1). The model is a discrete-time infinite horizon and finite location model with L locations such that $l \in \{1, 2, ..., L\}$ and $t \in \mathcal{T} = \{0, 1, ...\}$. Time periods should be thought of as weekly periods and locations as both geographical regions and ocean regions. Geographical regions are, for instance, the Arabian Gulf, Europe, the Far East, the Caribbean, the United States of America, West Africa, India, and Southern Asia. The distance between location l and k is $\delta_{l,k}$ miles, and the average transportation time is $\tau_{l,k} = \dfrac{\delta_{l,k}}{7 \cdot 24 \cdot v_{l,k}}$ weeks, where $v_{l,k}$ is the average speed between location l and location k in knots. The model contains two types of agents: traders and shipowners. Both agent types are risk-neutral and have time-additive utility. The discount factor is given by β. Traders profit from refining crude oil into oil products. Traders buy crude oil in oil-producing regions (e.g., the Arabian Gulf, West Africa and the Caribbean) and transport it to oil-importing regions (e.g., the Far East, the United States of America and Europe). In the oil-importing country, refineries refine crude oil into oil products such as gasoline, diesel oil and fuel oil, which are sold to consumers.

3.2.2 Ship owners' freight revenue and voyage costs

In my model, shipowners earn freight rate income when they supply tanker services to the traders. There are N_s vessels in the merchant tanker fleet. Vessels are sailing either loaded or in ballast. Sailing between location l and location k is associated with a cost of sailing equal to $c^s_{l,k,t}(Ballast)$

when the vessel sails in ballast and $c^s_{l,k,t}(Loaded)$ when the vessel is loaded.

When a shipowner forms a match and enters into an agreement with a trader, she earns freight revenue and pays voyage costs. I let time t denote the time when the shipowner and trader enter into the agreement. At time t, the vessel is located at position i, which has a distance to region l of $\delta(i, l)$. The shipowner is responsible for paying voyage costs, such as port charges and fuel expenses. The shipowner's profit from entering into a voyage charter with a load in location l and discharging in location k is the freight revenue net of canal dues, fuel- and port costs[2] given by:

$$\pi_{i,l,k,t} = \underbrace{r_{l,k,t} \cdot q}_{\text{Freight Revenue}} - \underbrace{bp_t \cdot \left(c^s_{i,l,t}(Ballast) \cdot \tau_{i,l} + c^s_{l,k,t}(Loaded) \cdot \tau_{l,k}\right)}_{\text{Fuel expenses}} - \underbrace{c_{port}(l, k)}_{\text{Port charges}}. \tag{3.1}$$

The shipowner's freight revenue is $r_{l,k,t} \cdot q$ where q is the cargo size (measured in tonnes or barrels), and $r_{l,k,t}$ is the freight rate (measured in dollar per ton or dollar per barrel) which the shipowner receives for transportation of the crude oil from location l to location k. First, the shipowner needs to sail the vessel to loading region l from the vessel's current location i. The cost of sailing in ballast to the loading region depends on the bunker price and the bunker consumption. c_{port} is the exogenous port charges in dollars. The freight rate is assumed to be governed by a discrete Markov chain. For each loading region l, the freight rate can be in one of three discrete states: low, medium or high. The freight rate transitions are governed by a Markov chain probability transition matrix Π.

3.2.3 Searching and matching

Shipowners and traders search for each other in the shipping market. Searching vessels can either be vessels sailing in ballast towards a loading region or employed vessels searching for their next voyage charter. When a shipowner and trader match, they start bargaining over the terms of the charter party agreement. In practice, brokers will intermediate trades and form matches between buyers and sellers of transportation services (Strandenes, 2000). In the model, the matching process between traders and shipowners is modelled by the matching function:

$$m_{l,t} = m_l(s_{l,t}, f_{l,t}) \tag{3.2}$$

[2] I ignore the foreign exchange element in port charges which are often denominated in local currency.

where $f_{l,t}$ is the number of cargoes, and $s_{l,t}$ is the number of unmatched ships searching for freights in location l. In the model of Brancaccio et al. (2017), ships can only match with traders when they are within the same region. However, the number of days between the contract signing and the loading date is 21 in the VLCC segment compared to an average of six days in the sample of dry-bulk contracts of Brancaccio et al. (2017). This implies that, in most cases, tanker vessels search and match with traders before reaching the loading region. The probability that an unemployed vessel matches with a trader is $p_{l,t} = m_{l,t}/s_{l,t}$.

3.2.4 Traders

The trader buys crude oil at location l and hires a tanker vessel to carry out the transportation between location l and location k. The refinery transforms crude oil into oil products. I focus on $N = 4$ oil product types: gasoline, diesel, fuel oil and liquefied pressured gas (LPG). When the refinery refines one barrel of crude oil, it obtains w_n barrels of oil product n. The table shows the oil product yields obtained from refining one barrel of Brent and WTI crude oil respectively.

Table 3.2.1: This table shows product yields from refining a barrel of Brent and WTI crude oil, source: Bloomberg.

	Brent	WTI
LPG	6	5
Gasoline	54	58
Diesel	37	34
Fuel Oil	12	11

The profit of the refinery is the refining margin. The refining margin is the revenue on the oil products sold to consumers after expenses associated with purchasing the crude oil, transportation costs, and operational costs. The refinery considers the prices of crude oil, oil products, and operational costs as exogenous. The freight rate is determined through Nash bargaining between the shipowner and refinery. The crude oil price at location l at time t is given by $P_{l,t}$. The exogenous oil product prices at location $k \in \{1, 2, ..., L\}$ are denoted by the price vector $[P_{k,1,t}, P_{k,2,t}, ..., P_{k,N,t}]$, and the marginal operational costs of the refinery is c_t^r. The profit[3] of the refinery on a cargo size

[3] Parker (2014) specifies the trader's profit from matching with ship i as the discounted expected value of selling the crude oil at location k at time $t + t_{l,k}$ less transportation costs and the cost associated with purchasing of the crude oil at location l at time t:

$$\mathrm{E}_t[\pi_t^G] = \left(\beta^{t_{l,k}} \mathrm{E}_t[P_{k,t+t_{l,k}}] - P_{l,t}\right) q - r_{l,k,t} \cdot q$$

It is seen that using a oil futures price has similar appeal as using refinery margins as a measure of a trader's profits.

of q is:

$$\pi^r_{l,k,t} = q\Bigg(\underbrace{\sum_{n=1}^{N} w_n P_{n,k,t}}_{\text{Revenue from oil products}} - c^r_t - r_{l,k,t} - P_{l,t}\Bigg). \tag{3.3}$$

If the trader does not match with a tanker vessel, the trader does not buy the crude oil and receives his outside value equal to zero.

3.2.5 Shipowners' states, values and decisions

In this section, I will describe the behaviour of a shipowner. The state variables of the shipowner are the vessel's location and employment status. The shipowner's dynamic decision problem is where to ballast her vessel when it is unemployed. When a vessel enters employment, it will ballast to the loading region and carry out the voyage specified by the voyage charter contract. However, the employment status of vessels is not perfectly observed by the econometrician since not all contracts are reported[4]. This implies that for parts of the data, the true underlying employment state of the vessels is unobserved. When fixtures are unreported the employment state of the vessels is coarse[5]. However, I observe a change in the vessels' loading conditions. For vessels that load oil without a contract being observed, I can create an interval in which the vessel entered the contract. The exact event time is unknown but falls within a certain time interval. It should be noted that some vessels may never enter into a voyage charter for natural reasons, for instance, if the vessel is owned or time-chartered by an oil company. In other words, the exact time of employment is interval censored. Within each location, the vessel can be

1. *unemployed* when it is sailing in ballast and the shipowner has not entered a new agreement with a trader.
2. *employed* when it is sailing in ballast, but the shipowner has signed a new contract with a trader. The vessel will also be employed when it is sailing loaded.

The vessel's employment status can transition accordingly: an unemployed vessel will transition to the employed state when it enters into an agreement with a trader. It can also remain in unemployed state if it does not enter an agreement with a trader. Whenever a vessel in the data makes a

[4]Not all voyage charter agreements are reported. Some charterers omit to report their fixtures, see Parker (2014) chapter 5. Furthermore, in some of the fixtures, the vessel is not specified. This implies that only a fraction of the realized matches is observed in the fixtures data in practice.

[5]Coarse data is when: *"data are neither entirely missing nor perfectly present. Instead, we observe only a subset of the complete-data sample space in which the true, unobservable data lie"*, Heitjan and Rubin (1991)

direct transition from unemployed to employed without an fixture being observed, I interval censor the entire ballast leg.

3.2.6 Timing

Within each period, the timing is as follows:

1. Unemployed vessels make ballasting choices d_t based on their current position i_t and the current freight rate state x_t.
2. Traders and shipowners match.
3. Matched vessels will bargain over the freight rate and become employed. In the next period, they will start to ballast towards the loading region.
4. Unmatched vessels will start the next period unemployed at their new location i_{t+1} and with a new freight rate state x_{t+1}, which is governed by the probability transition matrix Π.

Ballasting ships' valuations

Unemployed vessels will make ballasting choices based on their assigned continuation values. The shipowner's optimal ballasting choice is given by:

$$d_t^*(x_t, i_t) = \arg\max_{d_t} \Bigg\{ \mathrm{E}_t \Bigg[-c(i, d_t) + \overbrace{\sum_l p_l(i_t) \sum_k M_{lk} \left(q \cdot r_{l,k,t}(x_t) - c(i_{t+1}, l, k) + \beta^\tau V(x_{t+\tau}, k, d_{t+\tau}^*) \right)}^{\text{Expected value of a voyage charter}} \\ + \underbrace{\left(1 - \sum_l p_l(i_t) \right) \cdot \beta \cdot V(x_{t+1}, i_{t+1}, d_{t+1}^*)}_{\text{Expected value of remaining unemployed}} \Bigg] \Bigg\}. \quad (3.4)$$

The value associated with being at location i_t, when the freight rate state is x_t and the ballasting choice made by the shipowner is d_t is:

$$V(x_t, i_t, d_t) = \mathrm{E}_t \Bigg[-c(i_t, d_t) + \overbrace{\sum_l p_l(i_t) \sum_k M_{lk} \left(q \cdot r_{l,k,t}(x_t) - c(i_{t+1}, l, k) + \beta^\tau V(x_{t+\tau}, k, d_{t+\tau}^*) \right)}^{\text{Expected value of a voyage charter}} \\ + \underbrace{\left(1 - \sum_l p_l(i_t) \right) \cdot \beta \cdot V(x_{t+1}, i_{t+1}, d_{t+1}^*)}_{\text{Expected value of remaining unemployed}} \Bigg]. \quad (3.5)$$

The expected value of a vessel depends on the vessel's current location i_t and the current freight rate state. The expected value consists of the following components: $-c(i_t, d_t)$ is the cost associated with the vessel's ballast choice, d_t. $p_l(i_t)$ is the probability of entering into a voyage charter with a trader, which will load in region l. For simplicity, I assume that $p_l(i_t)$ is independent of the freight rate state x_t. In reality, I expect a positive dependence, i.e., a positive covariance between the fraction of available ships that matches and the freight rate level[6]. Conditional on a match with a load in location l, the probability of getting a voyage to location k is $M_{l,k}$. When the vessel matches with a trader, it earns the freight rate $r_{l,k,t}$ and pays voyage costs of $c(i_{t+1}, l, k)$. The voyage costs $c(i_{t+1}, l, k)$ consist of bunker costs and port charges. Bunker costs are the costs associated with sailing in ballast from the vessel's position at time $t+1$, i_{t+1}, to the loading region l plus the cost for the voyage between location l and location k. The vessel will be travelling for τ periods after time t before it reaches location k, i.e. $\tau = \tau_{i_{t+1},l} + \tau_{l,k}$. For notational convenience, I have suppressed the dependence of τ on i_{t+1}, l and k. The continuation value associated with being in region k is given by $V(x_{t+\tau}, k, d^*_{t+\tau})$ which is discounted by β^τ. With probability $(1 - \sum_l p_l(i_t))$, the vessel does not match with a trader. The vessel will then continue in the next period from its prevailing location. The new location at time $t+1$ is i_{t+1} which is determined by the vessel's previous location i_t and its ballast choice d_t. The continuation value from the vessel's new position is given by $V(x_{t+1}, i_{t+1}, d^*_{t+1})$, which is discounted one period by β.

3.2.7 The freight rate bargaining power

When a trader and a shipowner match they bargain over the freight rate and split the surplus via Nash bargaining. The shipowner's bargaining power is determined by the Nash bargaining parameter γ. The freight rate outcome of the bargaining process $r_{l,k,t}$ maximizes the Nash (1950) product:

$$r_{l,k,t} = \arg\max \left(V_{\text{Ship match}} - V_{\text{Ship no match}}\right)^{\gamma} \left(V_{\text{Trader match}} - V_{\text{Trader no match}}\right)^{(1-\gamma)}, \tag{3.6}$$

where $V_{\text{Ship match}} = q \cdot r_{l,k,t} - c(i_t, l, k) + \beta^\tau \mathrm{E}_t \left[V(x_{t+\tau}, i_{t+1}, d^*_{t+\tau})\right]$ is the shipowner's value associated with the match for the freight rate $r_{l,k,t}$. The shipowner only enters the voyage charter if the value of the match exceeds the value of remaining unemployed. The value of remaining

[6]When there are few(many) available vessels the freight rate level is expected to be high(low) and the fraction of available vessels that matches is also expected to be high(low) for a fixed level of transportation demand.

unemployed is the threat point of the shipowner. The threat point is given by $V_{\text{Ship no match}} = \beta \cdot \mathrm{E}_t \left[V(x_{t+1}, i_{t+1}, d^*_{t+1})\right]$. The trader's value of a match is given by the refining margin, i.e., $V_{\text{Trader match}} = \pi^r_{l,k,t}$. If the trader does not match with a shipowner, the trader receives a value of zero. The shipowner's bargaining power parameter $\gamma = \gamma_{shipowner}$ is determined from:

$$
\begin{aligned}
(1-\gamma_{shipowner})\left(q \cdot r_{l,k,t} - c(i_t,l,k) + \beta^\tau \mathrm{E}_t\left[V(x_{t+\tau}, i_{t+1}, d^*_{t+\tau})\right] - \beta \cdot \mathrm{E}_t\left[V(x_{t+1}, i_{t+1}, d^*_{t+1})\right]\right) = \\
\gamma_{shipowner}\left(q\left(\underbrace{\sum_{n=1}^{N} w_n P_{n,k,t}}_{\text{Revenue from oil products}} - c^r_t - r_{l,k,t} - P_{l,t}\right)\right)
\end{aligned}
\tag{3.7}
$$

Equivalently, the shipowner's bargaining power is given by proportion of the total value which the shipowner is able to extract:

$$
\gamma_{shipowner} = \frac{V_{\text{Ship match}} - V_{\text{Ship no match}}}{(V_{\text{Ship match}} - V_{\text{Ship no match}}) + (V_{\text{Trader match}} - V_{\text{Trader no match}})} \tag{3.8}
$$

Before I get to the estimation of the matching function and describe how I calculate continuation values, I will describe the data.

3.3 Data description

3.3.1 Data sources

I combine datasets from different sources. First, I have information from ships' AIS tracking systems for VLCCs from MarineTraffic from November 2014 to August 2016. The AIS data contains information on vessels' speed, self-reported draughts and positions in the form of longitude and latitude coordinates. Second, I employ time-series information on route-specific, time-charter equivalent (TCE) earnings and bunker prices. I use the TCE and bunker price series to estimate the choice-specific continuation values. I merge the AIS dataset with the fixtures dataset by the vessel-specific IMO numbers. Furthermore, I have information on bilateral fixtures between charterers and shipowners from Clarksons Shipping Intelligence Network. In the fixtures data, I observe the name of the shipowner and charterer, the agreed upon freight rate, the date the fixture entered, the cargo size, and the IMO number of the vessels. The freight rates are predominately denominated in World Scale. I am in possession of the flat rate (i.e., the conversion rate from

World Scale to dollars per metric ton) for the route between the Arabian Gulf and the Far East. I am only able to evaluate the bargaining power on the route from the Arabian Gulf to the Far East.

I have information on refinery margins from Bloomberg. The refining margin data consists of time-series of the revenue from sold oil products, variable refinery costs, and crude oil spot prices. Table 3.3.1 shows the summary statistics for the oil product revenue in South Korea for a barrel of the Dubai Fateh grade, the crude oil spot price for the Dubai Fateh grade, and the variable refinery costs which are all from Bloomberg.

Table 3.3.1: **Refinery-related time-series**
This table shows summary statistics for the three refinery-related time-series which are all measured in $/bbl. The first time-series is the oil product revenue in South Korea. The second time-series is the crude oil spot price for the Dubai Fateh grade, where one mt corresponds to 7.232 barrels. The third time-series is the variable refinery costs.

Statistic	N	Mean	St. Dev.	Min	Max
Oil product revenue in South Korea for Dubai Fateh	718	73.56	26.97	34.37	118.18
Crude oil spot price Dubai Fateh	718	64.40	27.00	22.49	111.28
Variable refinery costs	711	3.89	1.73	1.68	7.68

3.3.2 Voyages and employment status

In order to determine the vessels' employment status, I have compiled voyages for each vessel using the AIS data. I compile voyages by filtering through the AIS data in order to determine loading and discharge dates. The loading and discharge dates are determined based on the vessels' speeds, draughts and locations. As an example, the vessels' reported draughts are not always up to date, e.g., vessels change their draughts while sailing after they have departed from a port in a loading region. Table 3.3.2 shows the distribution of interregional voyages. The primary loading region is the Arabian Gulf where 66.57% of the voyages are initiated. The Arabian Gulf is followed by West Africa (16.30%) and the Caribbean (9.24%).

Table 3.3.2: **Compiled voyages**
This table shows the distribution of the hand compiled voyages from the AIS sample. The sample period is from November 2014 to August 2016.

Load	Discharge	No.	Percentage
Brazil and Uruguay	Far East	28	0.98
Brazil and Uruguay	India	5	0.18
Brazil and Uruguay	SPORE	41	1.44
Brazil and Uruguay	US Gulf	1	0.04
Caribbean	Far East	19	0.67
Caribbean	India	103	3.62
Caribbean	SPORE	141	4.95
Mediterranean	Far East	6	0.21
Mediterranean	India	1	0.04
Mediterranean	SPORE	4	0.14
Other	Far East	7	0.25
Other	India	22	0.77
Other	Red Sea	1	0.04
Other	SPORE	10	0.35
Other	US Gulf	1	0.04
Panama and Ecuador	Far East	14	0.49
Panama and Ecuador	SPORE	5	0.18
Arabian Gulf	Brazil	9	0.32
Arabian Gulf	Canada	24	0.84
Arabian Gulf	Far East	998	35.04
Arabian Gulf	India	222	7.79
Arabian Gulf	Other	2	0.07
Arabian Gulf	Red Sea	42	1.47
Arabian Gulf	South Africa	9	0.32
Arabian Gulf	SPORE	363	12.75
Arabian Gulf	UK and Continent	65	2.28
Arabian Gulf	US Gulf	127	4.46
Arabian Gulf	US West Coast	35	1.23
Red Sea	Far East	9	0.32
Red Sea	India	3	0.11
Red Sea	SPORE	3	0.11
Red Sea	UK and Continent	2	0.07
UK and Continent	Far East	33	1.16
UK and Continent	SPORE	26	0.91
UK and Continent	UK and Continent	1	0.04
West Africa	Canada	1	0.04
West Africa	Far East	261	9.16
West Africa	India	145	5.09
West Africa	Other	1	0.04
West Africa	South Africa	3	0.11
West Africa	SPORE	44	1.54
West Africa	UK and Continent	8	0.28
West Africa	US Gulf	1	0.04
Yemen	Far East	1	0.04
Yemen	SPORE	1	0.04

On aggregate, 92.11% of the voyages load in either the Arabian Gulf, West Africa or the Caribbean. The majority of voyages (88.33%) discharge in either the Far East (48.32%), the Southern Pacific Oceania Region (SPORE) (22.41%) or India (17.60%).

Vessels' employment states

I will now label the employment status for each of the vessels. First, I label vessels which are carrying out a voyage as employed. Second, I look through the periods when vessels' are reported loaded by their draughts but are not carrying out a voyage. These observations consist of vessels which are sitting laden and are either used for floating storage or hindered from discharging due to port congestion[7]. I label the employment status of these observations as vessels involved in floating storage or subject to port congestion. Third, the remaining observations consist of vessels which are sailing in ballast.

I categorize vessels sailing in ballast vessels into three categories unemployed, employed, or either employed or unemployed. On ballast legs where I observe a fixture, I know when the vessel is employed and unemployed. On the part of the ballast leg prior to the fixture is reported, I label the vessel as unemployed. On the part of the ballast leg after the vessel has entered the fixture, I label the vessel as employed. On ballast legs where I do not observe a reported fixture vessels are either employed or unemployed. This is the case when a vessel sails in ballast to a loading region and picks up a cargo without a fixture being observed in the fixtures dataset. In this case, I cannot identify the exact time where the fixture is entered and the match is interval-censored.

3.4 Empirical approach

I will now present the empirical approach. I start by estimating the matching function as a generalized linear binomial model. I assume that unobserved matches are missing at random and employ an EM algorithm to account for the interval censored matches[8]. In my estimation of the matching function, I consider only matches in the Arabian Gulf, West Africa, and the Caribbean. The three loading regions contain 92.11% of all voyages identified in my sample. When I leave out 7.89% of the observed matches I will underestimate the continuation values.

[7] Admittedly, the vessels subject to port congestion should have been classified as still employed on a voyage. This is a consequence of my compilation of voyages, where I have sometimes marked the date of arrival at a port as the discharge date instead of the actual discharge date.

[8] Parker (2014, chapter 5) notes that oil majors Shell and Vitol have a low representation of fixtures in the Clarkson fixtures compared with reports from shipbrokers on their respective market share. This implies that the missing fixtures are potentially charter specific.

3.4.1 Estimation of the matching probability

In this section, I estimate the matching function as a generalized linear model with a complementary log-log link function. My voyage charter data sample does only contain some of the voyages actually conducted. When a vessel loads at a loading region without a voyage charter agreement being present in the data, I treat it as an interval-censored observation. I assume that the vessel entered the voyage charter at some point within its ballasting leg[9]. In this case, I only know that the vessel has entered into a voyage charter agreement prior to its loading date. Thus, I have a missing data problem since, I lack the exact week in which the agreement was made. I deal with the missing data problem by estimating the parameters with an EM algorithm, (Dempster et al., 1977).

First, I initialize the parameters by estimating the model using only data where I observe the matches. I then do an expectation step. In the expectation step, I calculate the expectation of when the vessel matches with a trader. I calculate the expected values using the initial parameters from the estimation where I only use data on ballast legs where fixtures are reported. I then estimate new parameters using both the complete data and the interval-censored data.

Let $Y_{i,l,t}$ be a stochastic variable equal to one if the vessel matches with a trader in location l in week t:

$$Y_{i,l,t} = \begin{cases} 1 & \text{If a 'location } l \text{ match' is observed for vessel } i\text{, in week } t \\ 0 & \text{If no 'location } l \text{ match' is observed for vessel } i \text{ in week } t\text{,} \end{cases} \tag{3.9}$$

Let $T_{i,l}$ be the waiting time until a vessel matches with a trader, i.e., the time until $Y_{i,l,t} = 1$. The discrete hazard[10] is the conditional probability of getting a match in period t, conditional on the shipowner not having matched earlier on the ballast leg. The hazard is given by:

$$\lambda_l(t) = \mathcal{P}\left(T_{i,l} = t | T_{i,l} \geq t\right) = \frac{\mathcal{P}\left(T_{i,l} = t\right)}{\mathcal{P}\left(T_{i,l} \geq t\right)} \tag{3.10}$$

[9]In the data, I observe that shipowners enter into new employment while they are still employed on a voyage charter. I ignore this possibility in my EM-algorithm estimation and assume that all unobserved matches are made when the vessel is ballasting.

[10]Here the hazard is a conditional probability rather than a rate.

I work with the discrete hazard function of the form:

$$\lambda_l(t) = 1 - \exp\left[-\exp\left[\boldsymbol{\alpha}_l + \boldsymbol{\beta}'\boldsymbol{X}_{i,t}\right]\right] \tag{3.11}$$

The complementary log-log link function yields a linear predictor

$$\log\left[-\log\left(1 - \lambda_l(t)\right)\right] = \boldsymbol{\alpha}_l + \boldsymbol{\beta}'\boldsymbol{X}_{i,t} \tag{3.12}$$

The probability of observing a match in week t for a voyage charter which will load in region l is:

$$\mathcal{P}\left(T_{i,l} = t\right) = \lambda_l(t) \prod_{k \in \mathcal{L}} \prod_{j=1}^{t-1} (1 - \lambda_k(j)), \tag{3.13}$$

where the probability that the vessel still has not matched in period $t-1$ is:

$$\mathcal{P}\left(T_{i,l} > t-1\right) = \prod_{k \in \mathcal{L}} \prod_{j=1}^{t-1} (1 - \lambda_k(j)) \tag{3.14}$$

The joint likelihood function for all vessels is then:

$$\begin{aligned} \mathit{Likelihood} &= \prod_t \prod_i \prod_l \left[\mathcal{P}\left(T_{i,l} = t\right)\right]^{y_{i,l,t}} \left[\mathcal{P}\left(T_{i,l} > t\right)\right]^{1-y_{i,l,t}} \\ &= \prod_t \prod_i \prod_l \left[\frac{\lambda_l(t)}{1 - \lambda_l(t)}\right]^{y_{i,l,t}} \prod_{j=1}^{t} (1 - \lambda_l(j)) \end{aligned} \tag{3.15}$$

where $y_{i,l,t}$ is a dummy equal to one if the vessel enters into a voyage charter with a loading port in region l for the complete observations. The log likelihood becomes:

$$\mathit{LogLikelihood} = \sum_t \sum_i \sum_l y_{i,l,t} \log \lambda_l(t) - y_{i,l,t} \log(1 - \log \lambda_l(t)) + \sum_j^t \log(1 - \log \lambda_l(j)) \tag{3.16}$$

In the EM algorithm's expectation step number n, I take the expectation of the log likelihood conditional on the current parameter estimates $\boldsymbol{\theta}^{(n)} = [\boldsymbol{\alpha}^{(n)}\ \boldsymbol{\beta}^{(n)}]$. As the log-likelihood function is linear in $y_{i,l,t}$, this corresponds to finding the expected value of $y_{i,l,t}$ conditional on the current parameter values $\boldsymbol{\theta}^{(n)}$ and the observed data.

For the interval-censored observations, I do not know the exact event time $y_{i,l',t}$, but I do know that the vessel will eventually load in region l' and that the week when the vessel matches lies between two time points t_0 and $t_0 + \kappa$. In the expectation step, the observations are replaced by their expected values $\tilde{y}_{i,l',t'}$. The expected value $\tilde{y}_{i,l',t}$ for $t \in \{t_0, t_0 + 1, ..., t_0 + \kappa\}$ is equal to probability that the event occurs at time t' conditional on the event occurring in one week between time t_0 and time $t_0 + \kappa$, i.e., $\tilde{y}_{i,l',t'} = \mathcal{P}\left(Y_{i,l',t'} = 1 \middle| \sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right)$, where t_0 is the week the vessel journeys out on its ballasting leg and $t_0 + \kappa$ is the week where the vessel loads a cargo. The probability that the vessel enters a match in a week between t_0 and $t_0 + \kappa$ is:

$$\mathcal{P}\left(\sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right) = \mathcal{P}\left(Y_{i,l',t_0} = 1\right) + \sum_{t=t_0+1}^{t_0+\kappa} \mathcal{P}\left(Y_{i,l',t} = 1\right)\left(\prod_{v=1}^{t-t_0} \mathcal{P}\left(Y_{i,l',t-v} = 0\right)\right),$$

Furthermore, the joint probability of a match occurring during the ballast leg and the match occurring exactly in week t' is given by:

$$\mathcal{P}\left(Y_{i,l',t'} = 1 \cap \sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right) = \begin{cases} \mathcal{P}\left(Y_{i,l',t'} = 1\right) & \text{when } t' = t_0 \\ \mathcal{P}\left(Y_{i,l',t'} = 1\right)\left(\prod_{v=1}^{t'-t_0} \mathcal{P}\left(Y_{i,l',t'-v} = 0\right)\right) & \text{when } t' > t_0 \\ 0 & \text{when } t' > t_0 + \kappa \end{cases}$$

and the expected value $\tilde{y}_{i,l',t'}$ is then given by:

$$\mathcal{P}\left(Y_{i,l',t'} = 1 \middle| \sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right) = \frac{\mathcal{P}\left(Y_{i,l',t'} = 1 \cap \sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right)}{\mathcal{P}\left(\sum_{u=t_0}^{t_0+\kappa} Y_{i,l',u} = 1\right)} \tag{3.17}$$

I estimate parameters for four covariates. The covariates consist of three loading region indicator variables, one for each loading region. The fourth covariate is the distance to the loading region. This specification gives the distance covariate and equal influence for all loading regions. The parameters for the complete data are shown in Table 3.4.1, and the converged EM algorithm parameters are shown in Table 3.4.2. The matching probabilities for the converged EM algorithm are also illustrated for the Arabian Gulf in Figure 3.4.1, West Africa in Figure 3.4.2, and the Caribbean in Figure 3.4.3. The figures show how the probability of getting a match increases as the vessel approaches the loading region. The matching probabilities are evaluated in the observed vessel position closest to the data's centroid of each locational tile.

Table 3.4.1: **Initial matching function estimates from the complete data**
This table shows the regression results for the generalized linear model for the sample without the interval-censored observations. The dependent variable is a match dummy which is equal to one when the ship matches within a given loading region. The matches are assumed to follow a binomial distribution with a complementary log-log link function.

	Dependent variable:
	$1_{\{\text{Match}\}}$
$1_{\{\text{Arabian Gulf}\}}$	-0.363^{***}
	(0.046)
$1_{\{\text{West Africa}\}}$	-1.188^{***}
	(0.098)
$1_{\{\text{Caribbean}\}}$	-2.401^{***}
	(0.156)
Distance	-0.0002^{***}
	(0.00001)
Observations	13,083
Log Likelihood	−3,892.175
Akaike Inf. Crit.	7,792.349
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 3.4.2: **Matching function EM algorithm estimates**
This table shows the results for EM algorithm for the generalized linear model. The dependent variable is a match dummy which is equal to one when the ship matches within a given loading region. The matches are assumed to follow a binomial distribution with a complementary log-log link function.

	Dependent variable:
	$1_{\{\text{Match}\}}$
$1_{\{\text{Arabian Gulf}\}}$	0.759
$1_{\{\text{West Africa}\}}$	−0.452
$1_{\{\text{Caribbean}\}}$	−0.923
Distance	−0.0003
Observations	48,717

Figure 3.4.1: **Matching probabilities for voyages loading in the Arabian Gulf**
This figure shows the probability that an unemployed vessel matches with a trader at each locational tile for a voyage loading in the Arabian Gulf.

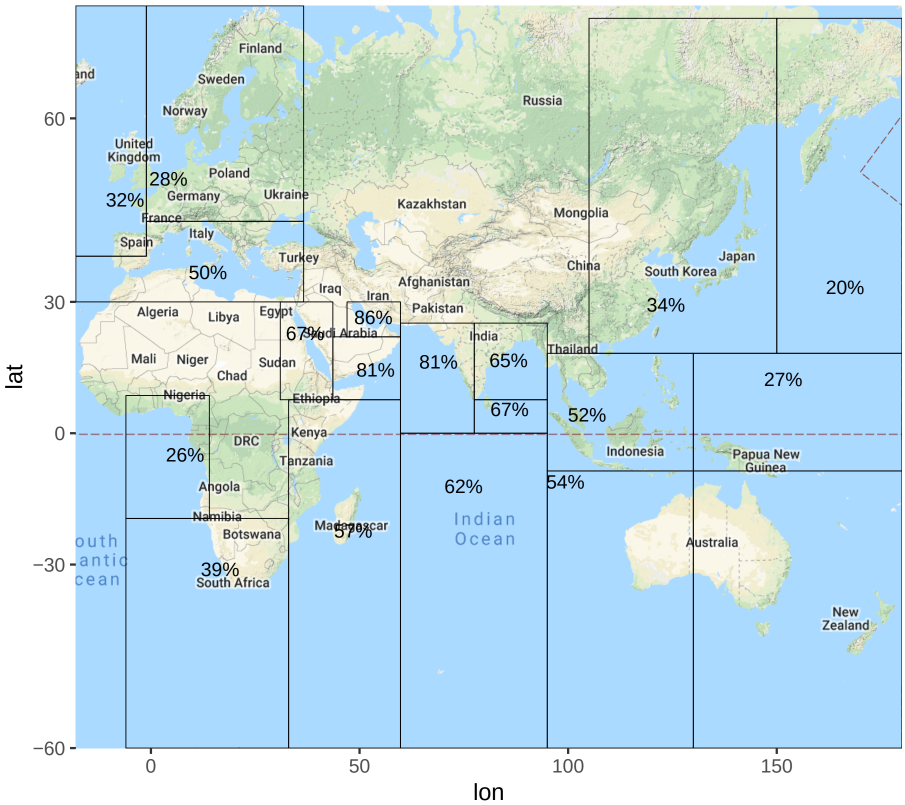


Figure 3.4.2: **Matching probabilities for voyages loading in West Africa**
This figure shows the matching probabilities for an order out of West Africa for different locational tiles.

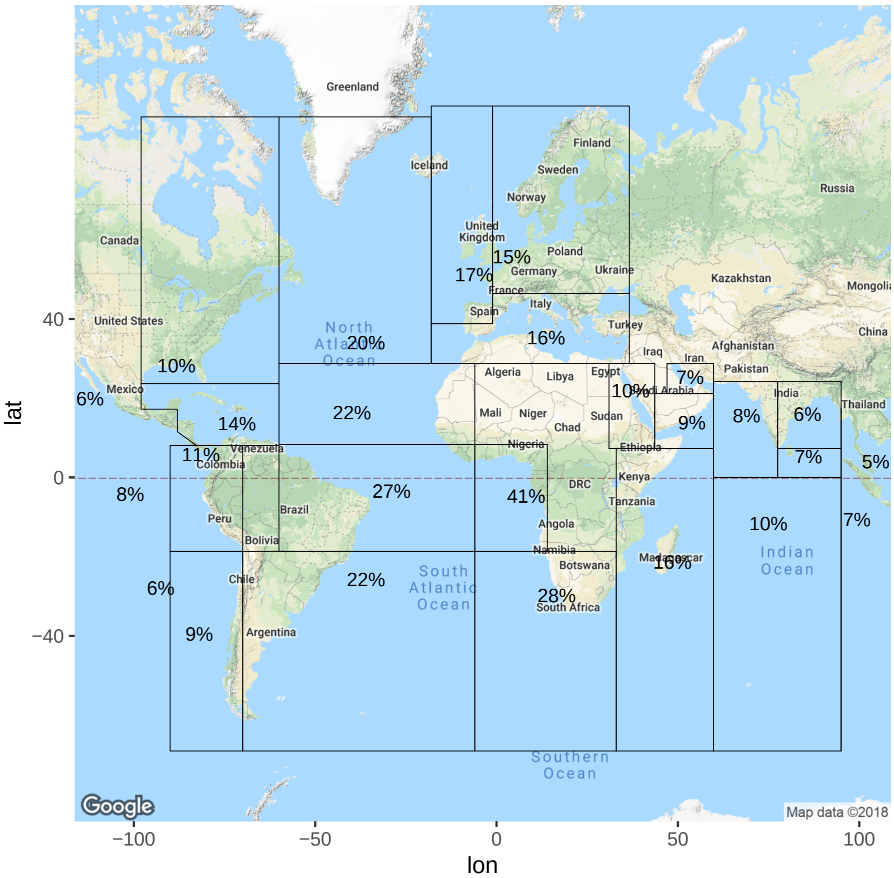
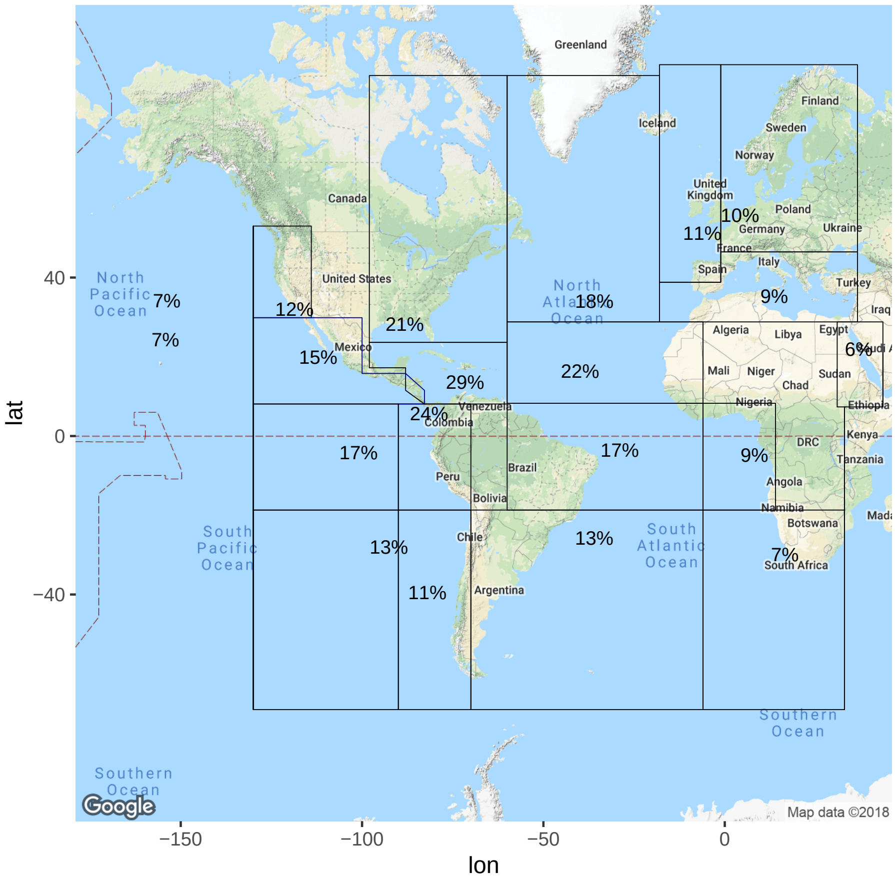


Figure 3.4.3: **Matching probabilities for voyages loading in the Caribbean**
This figure shows the matching probabilities for an order out of the Caribbean for different locational tiles.



3.4.2 Freight rate process

In this section, I specify the freight rate earnings process which I use to estimate the continuation values associated with the shipowners' ballasting choices. I model the freight rate process as a regime-shifting process, the transitions are governed by a Markov chain. This is admittedly somewhat simplistic and stylized. The regime-shifting approach is a convenient process to work with, however. Before I specify the model, I will present the earnings time series.

TCE earnings

I will now present the TCE earnings series which I use to estimate the freight rate process. The earnings series is denominated in thousand dollars per day for the round trip. The TCE calculation is given by:

$$\text{TCE} = \frac{r \cdot q \cdot (1 - \text{brokers fee}) - \text{port costs} - \text{bunker costs}}{\text{voyage time}}. \tag{3.18}$$

I am interested in the earnings before the bunker costs for the ballasting leg are subtracted. I get the earnings by multiplying the TCE series with the number of voyage days. I then add back the bunker costs for the ballasting leg. I calculate the bunker costs for the ballasting leg using the prevailing bunker price and the assumed bunker consumption in ballast of 55 mt/day, see table 3.4.3. I use the bunker price index closest to the loading port of the voyage. Specifically, I use the Fujairah 380cst bunker price for voyages which load in the Arabian Gulf, the Gibraltar 380cst bunker price for voyages loading in West Africa, and the Panama 380cst bunker price for voyages out of the Caribbean[11]. An earnings series is given as:

$$\text{Earnings} = \text{TCE} \cdot \text{voyage time} + \text{ballast leg bunker costs} \tag{3.19}$$

I will now set up the simplistic Markov chain model. I group the earnings series by loading region. I then compute average earnings within each of the three loading regions. I subdivide the loading region average series into tertiles, i.e., I find the 33.33% and the 66.67% quantiles such that the earnings in each loading region can be in either a low, medium or high state. I take the average value within each tertile as the discrete value of the earnings in that state. This leads to $3^3 = 27$ potential states for the freight earnings process. I only observe 13 out of the 27 possible combinations of states in the data. When the freight rate level is high for voyages out of the Arabian Gulf, freight rate levels are also predominately high for voyages out of West Africa and the Caribbean. This is not surprising as freight rates are cointegrated across regions (Berg-Andereassen, 1996; Berg-Andreassen, 1997; Veenstra and Franses, 1997; Kavussanos, 2003). The freight rate regimes can be seen in Table 3.4.4.

I face the issue of having fewer freight rate route indices than there are routes in the observed matches. I replace unobserved route indices with the observed index, which constitutes the closest geographical substitute. For the matches with a loading port in the Arabian Gulf, the earnings index from Ras Tanura to LOOP (Louisiana offshore oil port) is used for voyages which discharge in the US Gulf, Canada and Brazil. The earnings index from the Arabian Gulf to Chiba in Japan is used for voyages from the Arabian Gulf to the Far East. Likewise, I match the earnings indices to the observed voyages in parentheses accordingly: voyages from Ras Tanura (the Arabian Gulf)

[11]The bunker price series could be changed such that the bunker price series for Singapore is used for voyages out of West Africa, and the bunker price for Houston is used for voyages out of the Caribbean.

to Rotterdam (UK and Continent), Ain Sukna (Red Sea), Singapore (SPORE), and Jamnager (India). I match the indices from West Africa to the observed voyages in parentheses accordingly: Bonny Offshore (West Africa) to LOOP (Canada and US Gulf), to Ningbo (Far East), to Kaohsiung (SPORE), to LOOP (US Gulf), to Jamnager (India). For the Caribbean, I only have a single earnings index series from Bonaire to Singapore which then also serves as an earnings proxy for voyages to India and the Far East.

The distribution of voyage destinations conditional on a match, M_{lk}, is shown in Table 3.4.5 for each of the three loading regions. For voyages out of the Arabian Gulf, I discard voyages in Table 3.3.2 to South Africa and the US West Coast. For these voyages, I do not have an appropriate index to use. For voyages out of West Africa, I discard voyages to South Africa and the UK and Continent region.

Table 3.4.3: **Freight Rate TCE series**

This table shows the assumptions of the TCE earnings series. The index vessel is built around 2010. The columns show the assumptions regarding the voyages' loading port, discharge port, voyage distances, voyage speeds and bunker fuel consumption. Source Clarksons Shipping Intelligence Network.

ID	Load Port	Discharge Port	Distance Laden	Distance Ballast	Sea Time	Sea Margin	Port Time	Total Time	Speed Laden	Speed Ballast	Fuel Cons. Laden	Fuel Cons. Ballast
T120	Ras Tanura	Rotterdam	11,170	4,475	50	2.50	4	56.50	13.50	12	80	55
T121	Ras Tanura	Chiba	6,654	6,654	43.60	2.20	4	49.80	13.50	12	80	55
T122	Ras Tanura	Ain Sukna	3,121	3,121	20.50	1	4	25.50	13.50	12	80	55
T125	Ras Tanura	LOOP	12,225	6,011	58.60	2.90	4	65.50	13.50	12	80	55
T126	Ras Tanura	Singapore	3,702	3,702	24.30	1.20	4	29.50	13.50	12	80	55
T127	Bonny Offshore	LOOP	5,912	5,912	38.80	1.90	4	44.70	13.50	12	80	55
T128	Bonny Offshore	Kaohsiung	9,440	9,440	61.90	3.10	4	69	13.50	12	80	55
T129	Bonny Offshore	Jamnagar	7,075	7,075	46.40	2.30	4	52.70	13.50	12	80	55
T131	Bonaire	Singapore	10,767	3,730	46.20	2.30	4	52.50	13.50	12	80	55
T133	Bonny Offshore	Ningbo	10,196	10,196	66.90	3.30	4	74.20	13.50	12	80	55
T134	Ras Tanura	Jamnagar	1,184	1,184	7.80	0.40	4	12.20	13.50	12	80	55

Table 3.4.4: **Freight earnings regimes**
This table shows the freight rate regimes for voyages out of the Arabian Gulf, West Africa and the Caribbean. Freight rate regimes are measured in thousand dollars.

	Rotterdam	Chiba	Ain Sukna	LOOP	Singapore	Jamnagar
Arabian Gulf low	962	1,141	527	1,166	858	230
Arabian Gulf medium	1,729	1,960	956	2,259	1,420	469
Arabian Gulf high	3,584	3,846	1,824	4,800	2,089	938

	LOOP	Kaohsiung	Jamnagar	Ningbo
West Africa low	1,390	1,807	216	1,680
West Africa medium	2,187	2,940	479	2,876
West Africa high	3,730	5,191	939	5,037

	Singapore
Caribbean low	1,390
Caribbean medium	2,581
Caribbean high	5,533

Table 3.4.5: **Distribution of voyage destinations conditional on a match**
This table shows the relative frequency of voyage destinations in percent for the three loading regions for the voyages compiled from the AIS data: the Arabian Gulf, West Africa and the Caribbean. The relative frequencies are used as estimates of M_{lk}, e.g., the probability of getting a voyage to the Far East conditional on having matched with a loading port in the Arabian Gulf is 53.9%.

	The Far East	India	Red Sea	SPORE	UK and Continent	US Gulf
Arabian Gulf	53.9	12	2.3	19.6	3.5	8.6
West Africa	57.7	32.1	0	9.7	0	0.4
Caribbean	7.2	39.2	0	53.6	0	0

3.4.3 Continuation values

I will now calculate the continuation values. I fix the discount factor at 0.99. I set the bunker price[12] used to calculate the ballasting sailing costs equal to 280$/mt. The price of 280$/mt is close to the average bunker price for 380cst Fujairah of 281.285$/mt in the period from October 2014 to October 2016. I solve for the continuation values using the following approach: First, I initialize the continuation value matrix EV. The EV matrix contains an element for each pair of the location and freight rate states. In my setup, the EV matrix has 32 rows and 13 columns,

[12]The model could be extended with a bunker price process.

Table 3.4.6: **Summary Statistics**
This table shows the summary statistics for the earnings series measured in thousand dollars. The sample period is from January 2010 to October 2016.

Index	Load	Discharge	N	Average	St. Dev.	Min	Max
T120	Ras Tanura	Rotterdam	347	2,105	1,324	−272	7,351
T121	Ras Tanura	Chiba	345	2,335	1,298	664	6,888
T122	Ras Tanura	Ain Sukna	342	1,116	625	275	3,320
T125	Ras Tanura	LOOP	343	2,789	1,752	452	8,937
T126	Ras Tanura	Singapore	351	1,465	720	189	4,073
T127	Bonny Offshore	LOOP	354	2,423	1,116	944	6,016
T128	Bonny Offshore	Kaohsiung	346	3,329	1,604	1,059	8,354
T129	Bonny Offshore	Jamnagar	330	523	324	26	1,269
T131	Bonaire	Singapore	351	3,168	1,917	514	7,940
T133	Bonny Offshore	Ningbo	334	3,188	1,532	869	7,421
T134	Ras Tanura	Jamnagar	330	523	324	26	1,269

where 32 is the number of distinct locations, and 13 is the number of distinct freight rate states. I solve for continuation values accordingly:

1. I make an initial guess at the values in the continuation value matrix EV.

2. For each freight rate location state, I evaluate the value of each possible discrete ballasting choice. Let x be a freight rate state, i_t be the vessels current location, and d be a discrete ballasting choice which leads to the new location i_{t+1} in period $t+1$. Then the value of the ballasting choice d is:

$$V(x, i_t, d) = \sum_l p_l(i_t) \sum_k M_{lk} \left(q \cdot r_{l,k,t}(x) - c(i_{t+1}, l, k) + \beta^{\tau(i_{t+1},l,k)+1} \cdot e_x \Pi^{\tau(i_{t+1},l,k)+1} \text{ EV}[k,]' \right)$$
$$+ \left(1 - \sum_l p_l(i_t) \right) \cdot \beta \cdot e_x \Pi \text{ EV}[i_{t+1},]' - c(i_t, d_t), \quad (3.20)$$

where $\tau(i_{t+1}, l, k)$ is sailing time from position i_{t+1} to loading region l plus the sailing time from loading region l to discharge region k. The freight evolution is governed by the (13×13) probability transition matrix Π. If the vessel matches for a voyage from l to k the distribution of the freight rate states at time $\tau(i_{t+1}, l, k)+1$ is $e_x \Pi^{\tau(i_{t+1},l,k)+1}$, where Π^3 is Π to the matrix power 3 and e_x is a unit column vector with element x equal to one. $\text{EV}[k,]'$ is a (13×1) vector of the continuation values associated with each of the 13 freight rate states at discharge location k.

3. Once the values for each of the possible ballasting choices have been calculated in state (i_t, x), I find the value of the ballasting choice which yields the highest value. I store this value in a temporary continuation value matrix $\text{EV}_{tmp}[i_t, x]$.

4. After I have found the value associated with optimal ballasting choices for all states, I update the continuation value matrix setting $\text{EV} = \text{EV}_{tmp}$.

5. Steps 2 to 5 are repeated until the sum of squared differences between the continuation value matrix and the temporary continuation value matrix is smaller than 10^{-6}.

3.4.4 Bargaining power parameters

I will now determine the bargaining power parameters for the bilateral fixtures. I have to restrict my sample to voyages from the Arabian Gulf to the Far East. This is the only route where I know the flat rate and where I am able to convert freight rates from World Scale into dollars per metric ton. Furthermore, I have port charges from a TCE calculation from the Baltic Exchange. I do have the freight rate lump sum payment in dollars for certain voyages, e.g. the majority of voyages which load in the Caribbean. However, I do not know the port charges for these voyages. Hence, I restrict my sample to the route from the Arabian Gulf to the Far East as this is the only route that allows me to make a reasonable estimate of the voyage costs and earnings. I obtain bargaining parameters as:

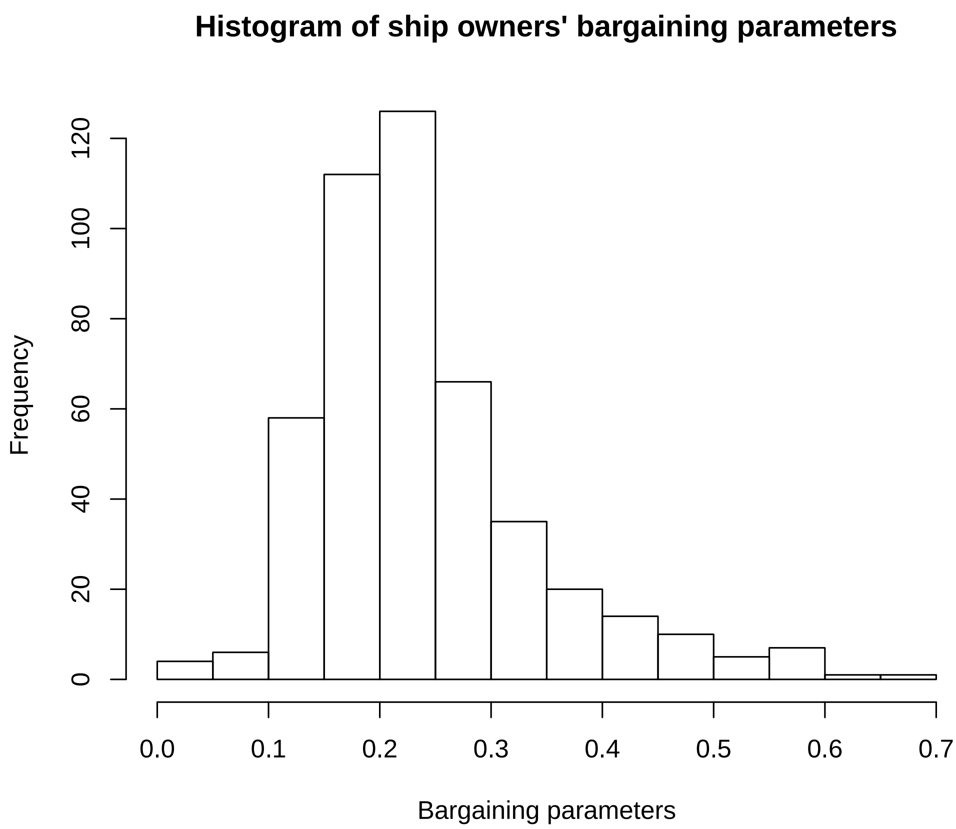
$$\gamma_{shipowner} = \frac{V_{\text{Ship match}} - V_{\text{Ship no match}}}{V_{\text{Ship match}} - V_{\text{Ship no match}} + V_{\text{Trader match}} - V_{\text{Trader no match}}}.$$

The distribution of bargaining power parameters is shown in Figure 3.4.4. The average value is 23.96% which is somewhat close to the 30% used in Brancaccio et al. (2017). This is supportive of the view that charterers are in possession of more bargaining power than shipowners. The distribution of bargaining parameters are right-skewed. The bargaining parameters indicate the freight markets are competitive but that shipowners are able to exert market power and extract part of the traders' value from the trades.

Table 3.4.7: **Summary statistics for bargaining parameters**
This table shows the summary statistics for the estimated bargaining parameters for voyages from the Arabian Gulf to the Far East.

Statistic	N	Average	St. Dev.	Min	Max
NashBargainingParameterShipowner	465	23.960	10.157	3.809	67.076

Figure 3.4.4: **Histogram of bargaining power parameters**



3.5 Conclusion

In this paper, I evaluate the relative bargaining power of shipowners and traders. I set forth a simple model of the matching between shipowners and geographical traders. In the model, shipowners make dynamic ballasting choices to maximize their continuation value. The model differs from the model by Brancaccio et al. (2017) in two important aspects. First, shipowners are able to re-evaluate which loading region to ballast towards along their ballast leg. Second, the matching function is estimated parametrically using an EM algorithm to account for unreported fixtures. Furthermore, I utilize information on refining margins earned by geographical traders to find the relative bargaining power. I find that, on average, geographical traders are in possession of more bargaining power than shipowners. I find that shipowners' average bargaining power coefficient, i.e. the proportion of the total value that the shipowner is able to extract, is approximately 24%.

I acknowledge that my model suffers from (at least) the following limitations: First, the model does not account for dynamic speed choices made by shipowners. Second, the matching function implemented depends only on a loading region dummy, and it is assumed linear in distance. The distance effect is therefore homogeneous across loading regions. This implies that my matching function is neither time varying nor freight rate state dependent. In contrast, Prochazka (2018, chapter 1) shows that the freight rate and distance from the loading region are positively related. Third, the estimation of my matching function, which applies the EM algorithm relies on (a) the missing matches being missing at random, and (b) being able to specify the correct functional form of the matching function. Whether either of the two is satisfied in practice is doubtful. Fourth, I do not have TCE indices for all types of voyages observed in the AIS sample. My replacement of certain routes with the closest substitute will potentially lead to a bias in the estimated continuation values. Furthermore, I make no effort to correct the TCE indices for deviations from the voyage speeds assumed in the calculation of earnings. Fifth, the refining market information I use from Bloomberg is a benchmark series for refineries in South Korea. This implies that I use this as a proxy for all refineries in China, Japan, South Korea and Taiwan. Hence I am not able to capture the heterogeneity in refinery margins. Sixth, the unavailability of flat rates and information on voyage costs limits my examination of the bargaining power to voyages from the Arabian Gulf to the Far East. Seventh, my bargaining power estimate will be biased if my assumption that the trader's alternative value equals zero is invalid.

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Chapter 4

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