NORGES HANDELSHØYSKOLE

Masterthesis submitted for the Master of Science in Economics and Business Administration within the main profile Energy, Natural Resources and The Environment

Bergen, Spring 2012

Vessel Speeds in Response to Freight Rate and Bunker Price Movements -An Analysis of the VLCC Tanker Market

by

Lisa Maria Aßmann

Thesis Advisors: Jonas Andersson & Gunnar Eskeland

This thesis was written as a part of the master program at NHH. Neither the institution, the supervisor, nor the censors are - through the approval of this thesis - responsible for neither the theories and methods used, nor results and conclusions drawn in this work. Bergen, 20. June 2012

Abstract

This paper analyzes the empirical relationship between vessel speeds, freight rates and bunker prices in the VLCC tanker market. The empirical model and the related hypotheses are inferred from the formulation of a theoretical optimal speed model, taking the perspective of a ship owner who operates in the spot market. A regression analysis is conducted with the use of data of VLCC vessel trips from the Arabian Gulf to Japan during 2006 to 2011. The results are found to be inconsistent with the relationship proposed by theory. As a consequence, the data generating processes of the single variables are analyzed more intensively and several explanations for the findings are discussed. Special attention is paid to the theoretic modification of the cost function, where inventory costs are considered as and additional determinant of vessel speed. Against the background of the theoretic modification, the observed speeds appear to be more consistent with speed optimizing behavior. Another regression analysis, including also inventory cost, did however not confirm systematic speed optimizing behaviour. Moreover, possible other reasons for the results and potential shortcomings of the present analysis are reviewed.

Foreword

First and foremost, I would like to thank my supervisors Gunnar Eskeland and Jonas Andersson for their great support and the efforts undertaken to help me with the progress of this work. Furthermore I would like to thank Siri Pettersen Strandenes and Jan Arthur Norbek for their helpful advice on the specifics of the shipping industry. Moreover I would like to thank Matthias Fiedler and Nils Gudat for their helpful comments and all the other people who supported me during the work with this thesis!

Lisa Aßmann, Berlin, June 2012

Contents

1	Intr	oduction	2
2	The	e Shipping Industry & Slow Steaming - A Review	4
	2.1	Basic Definitions in the Shipping Industry	4
		2.1.1 The three Main Cargo Segments	4
		2.1.2 The Tanker Market	6
		2.1.3 How is the Cargo Transport Handled? - Shipping Freight Contracts \ldots	7
		2.1.4 Emissions in the Shipping industry	9
		2.1.5 Slow Steaming	10
	2.2	Literature Review on Speed optimization and slow steaming $\ldots \ldots \ldots \ldots$	10
		2.2.1 Theoretic Speed Optimization	11
		2.2.2 Empirical Speed optimization and actual slow steaming observations	13
3	Wh	en do ships go slow? - A Theoretic Determination of Vessel Speed	15
	3.1	Assumptions & Decision Environment	15
	3.2	Basic Profit Maximizing Model - Vessels on Voyage Charter	15
	3.3	Cost Minimizing Model- Vessels under Time Charter	17
4	Em	pirical Analysis - Is Speed Actually Determined by The Relative Movement of	f
4	Em Frei	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices?	f 19
4	Emı Frei 4.1	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses	f 19 19
4	Em Frei 4.1 4.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses Data Description	f 19 19 21
4	Em Frei 4.1 4.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses Data Description 4.2.1 Speeds	f 19 19 21 21
4	EmI Frei 4.1 4.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement of Sight Rates and Bunker Prices? Model Specification and Hypotheses Data Description 4.2.1 Speeds Freight Rates	f 19 19 21 21 22
4	Emp Frei 4.1 4.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement ofight Rates and Bunker Prices?Model Specification and HypothesesData Description4.2.1Speeds4.2.2Freight Rates4.2.3Bunker Prices	f 19 19 21 21 22 22
4	Emp Frei 4.1 4.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement ofight Rates and Bunker Prices?Model Specification and HypothesesData Description4.2.1Speeds4.2.2Freight Rates4.2.3Bunker PricesData Analysis and Interpretation of Results	f 19 21 21 22 22 23
4	Emp Frei 4.1 4.2 4.3 4.4	pirical Analysis - Is Speed Actually Determined by The Relative Movement ofight Rates and Bunker Prices?Model Specification and HypothesesData Description4.2.1Speeds4.2.2Freight Rates4.2.3Bunker PricesData Analysis and Interpretation of ResultsTime Series Obstacles and Underlying Data Generating Processes	f 19 21 21 22 22 23 26
4	Emp Frei 4.1 4.2 4.3 4.4 A Q	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses Data Description 4.2.1 Speeds 4.2.2 Freight Rates 4.2.3 Bunker Prices Data Analysis and Interpretation of Results Time Series Obstacles and Underlying Data Generating Processes	f 19 21 21 22 22 23 26 37
4 5 6	Emg Frei 4.1 4.2 4.3 4.4 A Q Vess	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses	f 19 21 21 22 22 23 26 37 40
4 5 6	Emp Frei 4.1 4.2 4.3 4.4 A Q Vess 6.1	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses	f 19 21 21 22 22 23 26 37 40 40
4 5 6	Emp Frei 4.1 4.2 4.3 4.4 A Q Vess 6.1 6.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses	f 19 21 21 22 23 26 37 40 41
4 5 6	Emp Frei 4.1 4.2 4.3 4.4 A Q Vess 6.1 6.2	pirical Analysis - Is Speed Actually Determined by The Relative Movement of ight Rates and Bunker Prices? Model Specification and Hypotheses	f 19 21 21 22 23 26 37 40 41 41

	6.2.3	Results Including Deviations between Crude Oil and Bunker Fuel Prices	
		as Explanatory Variable	44
	6.2.4	Single Ship Analysis	46
7	Other Exp	lanations & Discussion	48
8	Conclusion	1	56
Α	Further Re	egression Results	62
	A.1 OLS o	on logs of weekly Data without Intercept	62
	A.1.1	REG1: Distance Included	62
	A.1.2	REG2: Distance Excluded	63
	A.1.3	Regression on Differences of All Variables	64
	A.2 OLS o	on logs of Trip Data	65
	A.3 OLS of	on NON-OII Including Dummies	65
	A.4 OLS i	ancluding Crude Oil Prices (BRENT) and excluding Freight Rates	66
	A.5 OLS u	using only Speed data from trips to Mizushima	66
в	Dickey Ful	ller Test	66
	B.1 Dicke	y Fuller Test Procedure	66
	B.2 Unit I	Root Test Results	67
	B.3 Dickey	y Fuller Test Results for Freight Rates	67
	B.3.1	Including Trend and Drift	67
	B.3.2	Dickey Fuller Test for Freight rates 1998-2011	68
	B.4 Dicke	y Fuller Test Results for Bunker Prices	68
	B.5 Model	l Including Trend and Drift	68
	B.6 Brent	Unit Root Tests	68
	B.7 Unit I	Root Test for Differenced Brent Crude Oil Prices	69
	B.8 Unit I	Root Test for Differenced Bunker Prices	69
	B.9 Engle	Granger 2 step Cointegration Results	69
С	Plots		70
	C.1 Logs of	of Weekly Speeds	70
	C.2 Logs	of Weekly Freight Rates	70
	C.3 Logs of	of Weekly Fujairah Bunker Prices	71
D	OLS Assur	mptions	71
	D.0.1	OLS-Assumptions	71

E Note On Programming Code

73

List of Figures

1	Bunker Prices and Freight Rates	11
2	3D Scatterplot of Weekly Data	23
3	Freight Rate - Bunker Combinations and Average Speeds	26
4	Weekly Time Series Plot	28
5	ACF Logs of Weekly Speeds	29
6	ACF Logs of Weekly Freight Rates	30
7	ACF Logs of Weekly Bunker Prices	31
8	Residuals and Logs of Speeds	34
9	Differenced Logs of Bunker Prices	35
10	Bunker and Crude Oil Prices 2006-2011	44
11	Histogram Ship IDs	47
12	Most Frequent VLCC Route observed between 2006-2011	49
13	Fuel Consumption as a Function of Speed	51
14	Speed as a Function of Hull Fouling	52
15	Fleet seperated by Ship Owners	54
16	ACF of Residuals REG1	62
17	ACF of Residuals REG2	63
18	Logs of Weekly Speeds 2006-2011	70
19	Logs of Weekly Freight Rates 2006-2011	70
20	Logs of Weekly Bunker Prices 2006-2011	71

1 Introduction

The shipping industry has always been characterized by an extreme cyclical development, exposing its actors to periods of boom and bust(Stopford, 2009). In order to survive in this volatile business, vessel speeds have always played an important role.

When ships were only powered by wind, sailing fast was a unique selling point and simultaneously saving manning cost-hence it was already a matter of success. But ever since ships have been powered by a motorized propulsion system, varying speeds incurred also different costs, namely fuel costs. Thus, varying speeds in order to be the best provider or the cheapest, is an old hat so to say. Especially during low markets, indicated by high fuel oil prices and low freight rates, sailing slower is a popular measure to reduce costs. This has been amplified by the fact that fuel consumption is approximately related to speed through a cube law - which means that slowing down by 20 %, reduces fuel costs by approximately 50 % (Corbett et al., 2009). In addition, since anthropogenic emissions of greenhouse gases and environmental aspects of doing business have gained strong importance over the last decades, vessel speed decisions are closely intertwined with yet another dimension. As fuel consumption is directly related to CO_2 emissions, slowing down reduces emissions. The New York Times (February,2010) put it aptly by stating "Slow Trip Across Sea Aids Profit and Environment" pointing at a possible win-win situation evoked by Slow Steaming (sailing relatively slow).

The Maritime Industry has so far slipped the Kyoto emission target for CO_2 emissions and other Greenhouse Gas(GHG) emissions, although producing approximately twice as much emissions as the aviation industry (Harilaos N. Psaraftis and Christoph Kontovas, 2009; John Vidal, 13.02.2008). But as awareness of climate change and environmental consequences increases, emission reduction regulation in shipping is not a long way off. In the course of discussing possible regulatory measures to force ship operators to sail slow, some market based measures aiming at the mentioned win-win situation are considered among others. In order to be able to evaluate the effects and effectiveness of considered measures it is important to have a look at the market conditions and the related economic incentives determining vessel's speeds. Therefore, the motivation behind this master thesis is to analyze the economic incentives which guide ship operators to sail slower. And thereby even more important, to detect if the well-established relationship between speeds, freight rates and bunker prices can actually be observed empirically.

This is done with an empirical investigation in the form of a regression analysis of the relationship between vessel speeds, freight rate and bunker prices. This empirical part is built on a theoretic economic optimal vessel speed formulation which underlines the well known view that vessel speeds should respond to changes in bunker prices and freight rates (see for example(Norman and WergelandTor, 1979; Ronen, 1982; Stopford, 2009; Corbett et al., 2009)). The theoretic speed optimization takes the view of a shipowner operating his ship on the spot market and is based on a model of Ronen (1982). Although speed optimization (and related to that also Slow Steaming) is a well-established concept in the maritime economic literature only little research has been conducted on this issue empirically. Some empirical work on slow steaming vessels has been done in the Container market, as Container vessels have the largest speed range and hence the largest potential to reduce speeds. But given that Very Large Crude Oil Carriers (VLCC) account for a large total share in the world fleet, and consequently contribute to a major share of emissions of ships, the VLCC tanker market is subject of the analysis at hand. The empirical part is conducted with the help of observations on VLCC vessel speeds between 2006 to 2011 on the main VLCC route from the Arabian Gulf to Japan. The data was provided by IHS Fairplay and included observations of 258 vessels on 13 routes.

The paper starts out with an introduction into the specifics of the shipping industry and furthermore develops a theoretical model of optimal speed. Second, on the basis of the theoretical optimal speed relationship, a hypothesis for the empirical relationship is formulated and tested empirically. As a third step the data and results are analyzed more closely and eventual modifications are introduced. Finally the outcomes and related explanations are discussed.

2 The Shipping Industry & Slow Steaming - A Review

Being the major transport mode for manufactured goods and raw materials, the shipping industry always facilitated world trade. Not only because world trade grew strongly over the last decades but also because major advances in ship technology made shipping an increasingly cost effective transport mode (Alizadeh and Nomikos, 2009, p. 25), seaborne trade has been growing significantly. And the emissions from shipping did as well.

However, the maritime industry has so far not been controlled proportionally to its share in emissions. Especially CO_2 emissions are not regulated in any way, as the shipping industry could opt out of the Kyoto Protocol emission target(Harilaos N. Psaraftis and Christoph Kontovas, 2009; Kontovas and Psaraftis, 2011a).

As one measure to reduce emissions is slow steaming, the following section has the aim to provide basic insights in the specifics of the shipping industry and the role of slow steaming and speed optimization in this context. Initially some characteristic concepts and definitions about the specifics of the shipping industry are provided. A short literature review will deal with what concepts and research exists on the topic of optimal vessel speed and slow steaming.

2.1 Basic Definitions in the Shipping Industry

The maritime industry is a complex industry which can be divided into different markets and different segments. Generally there are four markets in shipping, the Freight Market, the Newbulding Market, the Demolition Market and the Secondhand Market. The analysis at hand deals with the Freight Market as the core product of the maritime industry, where the transportation of goods or raw materials is the center of attention. This core product can be divided into different segments, which are defined by the product to be transported. The main three categories are bulk shipping, specialized shipping and liner shipping and each has distinct characteristics (Stopford, 2009, p. 61).

2.1.1 The three Main Cargo Segments

Bulk Shipping

Bulk Shipping constitutes the largest segment accounting for three quarters of the world merchant fleet. Bulk shipping is characterized by the homogeneity of the transported good. As the word Bulk already suggests, Bulk shipping comprises mainly raw materials which can be shipped in large amounts. The bulk segment can be further divided into liquid and dry bulk markets. The major bulks in the dry bulk category are iron ore, grain, coal, phosphates and bauxites and are mostly shipped in large standard consignments. Minor bulks in the dry bulk category are for example steel products, steel scrap, cement, gypsum non-ferrous metal ores, sugar, salt, forest products and chemicals, and are shipped in smaller amounts. Liquid bulks are typically crude oil, oil products, liquid chemicals, vegetable oils and wine and require tanker transportation.(Stopford, 2009)

Liner Services

This segment provides very different services, characterized by smaller and less homogeneous goods which would not justify using bulk shipping modes (Stopford, 2009, p. 64). Goods transported through Liner Services cannot be generalized, but they are often of high value and cannot be easily stowed. Here it is important that the goods can be delivered on a regular basis were shippers may value security and rather willing to pay fixed tariffs than to depend on volatile spot rates. Typical examples for goods handled by liner services are containerized cargo, palletisized cargo and individual items such as pieces of machinery.

Specialized Shipping

This third category inherits characteristics of both other sectors, but ships are specifically designed to carry one special kind of cargo.

The following table from Alizadeh and Nomikos (2009) depicts a classification of vessels typically employed in the three sectors and corresponding typical speeds.

The lin	iner and container shipping market		
Vessel type	Ship size (TEU)	Approximate speed (knots)	
Feeder	100-499	15-20	
Feedermax	500-999	15-20	
Handy	1000-1999	15-20	
Sub-Panamax	2000-2999	20-25	
Panamax	3000-3999	20-30	
Post-Panamax	>4000	20-30	
The dry bulk shipping market			

2 The Shipping Industry & Slow Steaming - A Review

Post-Panamax	>4000	20-30	
The dry bulk shipping market			
Vessel type	Ship size (dwt)	Approximate speed (knots)	
Handysize	20,000-35,000	12-16	
Handymax	35,00-45,000	12-16	
Supramax	45,000-55,000	12-15	
Panamax	60,000-75,000	12-15	
Capesize	80,000-300,000	12-14	
	oing market		
Vessel type	Ship size (dwt)	Approximate speed (knots)	
Handysize	20,000-45,000	14-16	
Panamax	50,000-70,000	14-16	
Aframax	70,000-120,000	13-15	
Suezmax	130,00-160,000	12-14	
VLCC-ULCC	160,000-500,000	12-14	
Source:Alizadeh	and Nomikos (200	9, p. 30)	

Table 1: Vessel Classification and Typical Speeds

2.1.2 The Tanker Market

Since crude oil tankers are the subjects of the analysis, the specifics of the crude oil tanker market are outlined shortly.

As indicated in the above table, there are several classes of ships which operate in the tanker market. The focus of this master thesis is however the largest class of tanker vessels, namely the VLCC market, where VLCC stands for Very Large Crude Oil Carriers which typically carry around 2 million barrels of crude oil. Approximately 60 % of the seaborne crude oil trade is handled by this vessel type, the other 40% are mostly handled by Suezmax and a few Aframax vessels. Due to the fact that oil reserves and production are heavily concentrated in a few regions around the world, the crude oil trade routes are also limited to a few typical routes. The most frequent route for VLCC vessels is the route between the Arabian Gulf to Japan and is therefore used in this work. Besides, there are few other routes, of which Middle-East is unsurprisingly the major starting point. From there, typical routes go to US East Coast, Western Europe and the Far East. Apart from that, routes from the North Sea to the US East coast and from West Africa to the US and Europe, are the major crude oil trading routes. According to the UNCTAD Maritime Transport Review from 2011 (United Nations Conference of Trade and Development, 2011), 1.8 billion tons of crude oil, representing a share of 45 % of the world's crude oil production are shipped with tankers. As a consequence of their deep draught of around 20 meters, they are restricted to sail on routes where this draught is possible. According to Stopford (2009, p.441), the speed of a VLCC vessel is 15,8 knots, which differs from the approximate speed given in the above table 1 from Alizadeh and Nomikos (2009). But this reflects the so called design speed, which is according to Clarkson (2012) the speed, the vessel was originally designed for. The VLCC vessel fleet is owned by different actors in the market. As opposed to earlier times (1890-1975), nowadays the fleet is not mainly owned by oil companies anymore. Today traders also play a substantial role, and much of crude oil transport is handled through the market (Stopford, 2009, p. 436).

2.1.3 How is the Cargo Transport Handled? - Shipping Freight Contracts

The settlement of the transaction to ship crude oil from one port to another, involves several actors and can be conducted in different ways. The simplest case is the case when an oil company owns its own fleet. In such a case there is no market transaction involved, the oil company "just" ships the crude from on port to another, where it has to handle its further clearing, i.e. when to get a slot in port, how to discharge the cargo, where to store it or to sell it and so on. But since this is not important for the analysis at hand, those procedures are ignored. Starting from a very general market situation, i.e."carry crude oil from A to B", there is generally one individual who wants to sell the product and one individual who wants to buy it. For a successful market transaction to happen, both parties have to agree on a price, which is called freight rate. In the shipping market this seemingly straight forward procedure can be a rather complex. Therefore it is important to be familiar with a certain vocabulary in order to understand common market transactions in the crude oil shipping market. The following definitions follow the glossary from Stopford (2009, p. 176).

Shipper

The Shipper is the individual or company who wants to ship cargo

Charterer

The Charter is the individual or company who hires a ship

Charter-party

Contract defining the terms of the transaction, i.e. on which terms the cargo of the shipper is transported or on which terms the charterer hires a vessel.

Voyage Charter

Is a transaction where the shipping of cargo is settled for one voyage. The ship earns a routespecific freight rate per ton of transported cargo on terms set out in the charter party. The latter specifies the nature and volume of the cargo, the discharging and loading ports and laytime and demurrage. Example: An oil company wants to transport 200,000 tons of Crude Oil from Ras Tanura to Chiba. It involves a broker who is assigned to organize a ship that carries the crude from Ras Tanura to Chiba. If it finds one, s/he "fixes" the ship, i.e. charters the ship at a negotiated freight rate, which could be perhaps 20 US \$ per ton shipped on this route. The details of how long the ship is "allowed" to be in port to load the Crude Oil (laytime), and a period of when it should arrive at the other port are set out in the charter party. If the ship needs longer time than specified in the charter party to load the cargo, the shipowner claims a daily so called demurrage fee. If it is the other way around, the fee the charter receives from the owner is called despatch. On a voyage charter operation, the master of the ship is instructed by the shipowner and all operational cost and voyage costs, i.e. fuel costs and port charges are paid by the shipowner.

Contract of Affreightment (COA)

The shipowner agrees on carrying specified quantities of a specific kind of cargo on a special route or routes over a given time period. S/he can use ships of his choice within specified restrictions.

Time Charter

An arrangement where the ship earns a freight rate per time unit, i.e. monthly or semimonthly. This freight rate is called time charter rate. The master of the ship is instructed by the charterer, so the charter has operational control, even if the ship is still owned and managed by the shipowner. The shipowner still pays operating costs, but all voyage costs are paid by the charterer.

Spot Rate

The spot rate is the freight rate, the shipowner receives per ton of transported cargo when he operates his ship under voyage charter. For VLCC tankers the spot rates is reported in Worldscale.

World Scale

World Scale is a worldwide nominal tanker scale intended to be used as a reference for individual market transactions. It is a reference freight rate which should be equal to a fixed daily hire element, when considering a standard vessel and route specific voyage costs(Worldscale.co.uk, ????). As bunker prices and other voyage cost change, this freight rates is adjusted every year in order to represent the same fixed daily hire element. This reference freight rate is reported

as World Scale 100, also called flatrate. The rate at which a single ship is fixed is reported as a percentage of Worldscale 100.¹Nowadays there exist different Worldscale reference rates for different general routes, as for example the one used for this analysis from Arabian Gulf to Japan for VLCC tankers.

Time Charter Rate

The freight rate the shipowner receives per day when operating his vessel under a time charter agreement. It is reported in US \$ per day.

Which contract type is used to settle the transport of the cargo depends on the strategy and needs of the shipowners and charterers.

2.1.4 Emissions in the Shipping industry

Although being popular for being relatively environmentally friendly compared to other transport modes, world shipping still accounts for 2.7% global CO_2 emission as of 2007 according to International Maritime Organization (2010). Besides emitting CO_2 , vessels also emit other Greenhouse Gases (GHG) as Methane (CH_4) and Nitrous Oxide $(N2_0)$ and other non-GHGs, mainly sulfur dioxide (SO_2) and nitric oxide (NO_x) . But for the purpose of this work, the focus is on CO_2 emissions. It is known that CO_2 emissions are exponentially related to speed, in a similar way as speed and fuel consumption are related. The other emissions do not necessarily depend on vessel speed in a similar uncomplicated manner. Moreover, the other main emissions, apart from CO_2 emissions, have been more in the focus of regulatory institutions such as the International Maritime Organization (Kontovas and Psaraftis, 2011b). Generally speaking, there are three categories of measures which aim at reducing CO_2 emission. One way to achieve Co_2 emission reduction in shipping are technological measures, such as to include more efficient ship hulls and engines, the use of alternative fuels such as cells, biofuels and others, electric support in port from shore sources, devices to capture exhaust emissions and even the use of sails. A second category of measures are market based mechanisms which include emission trading and carbon tax schemes (Psaraftis and Kontovas, 2011). The third category are operational measures, such as reducing speed and to further optimize routing and scheduling. The first two categories can be assumed to be implemented only in medium/long term. In contrast, operational measures can almost immediately be applied. As such reducing speed, also known as slow steaming is one of the most popular measures in the discussion on how to reduce CO_2 emissions.

Therefore one could think that it is also soon to be regulated if related stakeholders allow or want this to be happening. Therefore it is crucial to analyze the underlying incentives to do so,

 $^{^{1}}A$ detailed example is given in 4.2.2

which is apart from the environmental perspective, mainly an economic analysis if stakeholders involved are assumed to be rational individuals in the sense of rational choice theory.

2.1.5 Slow Steaming

There is no general definition of slow steaming, but it is used as a synonym for reducing vessel speed. However, it is hard to discern slow steaming when original speed is unknown. Intuitively, slow steaming applies to sailing speeds that are lower than "normal" speeds. The latter can either be assumed to be the average speed or the so called design speed, for which the ship was designed. The latter is a technical measure and is based on the specific demands a vessel should satisfy² and technical limits. Optimal speed relates to an economic point of view, such that optimal speed is the speed which gives the highest profit to the decision maker. This optimal speed is however not environmentally optimal, since this would imply to go as slow as possible if only the CO_2 emissions are considered. Therefore slow steaming speed can simultaneously be the optimal speed, if the original speed was non optimal and higher than optimal speed. This has to be noted with caution when dealing with literature on this topic, since different perspectives are taken. The literature review to be followed is separated into a theory part which mainly deals with optimizing speed economically and into a more empirical part, which deals with observed or expected slow steaming as a speed reduction measure(compared to before or expected speeds).

2.2 Literature Review on Speed optimization and slow steaming

Speed optimization implies that speed can be changed upwards or downwards to be optimal under certain conditions and restrictions. However it seems to be more popular to pick slow steaming as a theme to deal with speed optimization and it is less often heard of "fast steaming" if at all. Since oil prices soared and freight rates were partly very low in the last years, conditions and decision environments have not been favorable for relatively fast speeds.

²nowadays high speeds are less important in the tanker market, instead fuel efficiency is more decisive according to MAN (2009)



Freight Rates BTDI T3 (US\$) and Bunker Prices

Figure 1: Bunker Prices and Freight Rates

This development might be also a reason for a large share of literature dealing primarily with the influence of oil price on speed and fuel consumption, where oil price and linked to that, bunker price, is negatively influencing vessel speed. From an economical point of view speeds should be adjusted in order to maximize profits under the assumption that ship operators are rational individuals. From an environmental point of view speeds should be adjusted to cause least environmental damage, which mainly means going slower if CO2 emissions are considered here in first place. If bunker prices are high and freight rates low, those two perspectives might have the same normative impetus to go slower in order to reduce fuel consumption. Hence there is more literature on discussing benefits if vessels would go slower (Harilaos N. Psaraftis and Christoph Kontovas, 2009; Cariou, 2011) but not much on if they actually are slow steaming.

2.2.1 Theoretic Speed Optimization

The literature on speed optimization in response to the relative movement of freight rates and bunker prices can be considered to be relatively small(Ronen, 2011, p. 211). Most literature dealing with the relationship between vessel speed, bunker prices and freight rates arose in the wake of sharp increases in bunker prices at different point in times, and hence often analyzes the impact of an increase in bunker prices on vessel's (economically optimal) speed as for example Ronen (2011, 1982); Beenstock and Vergottis (1993) or on freight rates as in Norman and WergelandTor (1979) and United Nations Conference of Trade and Development (2011). Only very little literature is available on a simultaneous exogenous influence of freight rates and bunker prices on speed in a microeconomic context.³. The paper from Ronen (1982) which is central to the analysis at hand formulates a theoretical speed optimization as a response to oil price and freight rates movements, considering the tradeoff between saving fuel cost through slow steaming and making income losses because of prolonged trip time. Ronen (1982) develops different theoretical models for the determination of the vessel's optimal speed per leg on the basis of three different decision environments: An income generating -laden leg, a positioning -empty leg and a speed related leg which includes penalties for being late and boni for being early. Most recently Ronen (2011) extended his original model formulation with the inclusion of a fixed service frequency which has to be maintained when considering the container market. He models the trade off between the cost of adding more vessels to the fleet to be able to maintain the service frequency when going slower, and the fuel cost savings from slow steaming. He also presents cost savings estimations with the use of published real vessel data. Besides there is extensive literature on the supply of vessel capacity which, to different extents, also includes optimal speed analysis. As such, Stopford (2009, p. 162) for example, describes the supply curve to be characterized by the shipowner maximizing his profits through operating at speeds where marginal costs equal freight rates. The cost of providing one more tonne mile, depends on speeding up, and speeding up results in exponentially higher bunker costs. Consequently he also models optimal speed to be indirectly depended on a ratio of freight rates and bunker prices. In a similar way Norman and WergelandTor (1979) defines the optimal speed to be simply given by the equality between the extra freight rate income of speeding up and the extra fuel costs of speeding up. In order to estimate possible CO_2 reductions at specific higher bunker price levels, Corbett et al. (2009) also sets up a profit maximizing equation depended on speed. As opposed to Ronen (1982), his equation maximizes profits on a trip basis and includes freight rate revenue only as independent of speed. As a result, his optimal speed is only dependent on bunker prices through fuel consumption of main and auxiliary engines. Based on a data set providing observed average speeds and specific vessel characteristics on Container routes to the US, optimal speeds (and corresponding reduced CO_2 emissions) at given static bunker price levels are estimated. Norstad et al. (2011) introduces speed as a decision variable to tramp ship routing and scheduling problems, where speed traditionally was treated as a fixed variable. It is shown that profit is improved when taking speed into account as a variable which can be adjusted to some extent, either to take on additional spot cargo or to use less fuel per distance unit.

³Freight rates are considered to be exogenous under the assumption to take single ship owner's perspective

2.2.2 Empirical Speed optimization and actual slow steaming observations

Most of the literature on actual observed speed optimization behaviour deals with container ships, as those are the fastest ships and hence have the highest speed and fuel reduction potential when looking at single ships, and not on the relative share of fuel consumption of container ships in total. As such, Notteboom and Vernimmen (2009) analyzed the container industry response to increasing bunker prices on the basis of AXS Alphaline data which provides the fuel consumption characteristics of different ship categories at different specified speeds.

According to this analysis, some measures have been implemented by introducing larger vessels, more vessels and lower speeds at the analyzed liner services. But it is also stated that the causality of these measures and bunker price increases is somewhat blurred due to port congestion and resulting schedule integrity concerns (Notteboom and Vernimmen, 2009, p.336). Also Cariou (2011) states that slow steaming became an increasingly common strategy in liner shipping as fuel prices have been rising. His article tries to measure how much CO2 emissions have been saved by those slow steaming measures undertaken, based on data of 2051 container vessel with a minimum capacity of 1000 TEU. The data included route, frequency, rotation in number of days and port calls, and moreover information on the slow-steaming status of the services. According to this database, 42.9% of those vessels were slow steaming in January 2010 (Cariou, 2011, p. 262).

The work of Corbett et al. (2009) analyes possible reactions to higher bunker prices of container ships as well as theoretical optimal speed. The estimations are based on information on 2000 unique container ships on 1066 unique routes identified with the help of the US Entrance/-Clearance dataset and Lloyd's Maritime Information System (LMIS). It was observed, that the speeds of container ships were consistent with estimations based on a 150 US \$ per ton bunker fuel price⁴. Furthermore it was observed that the speed varied to a much lesser extent than the varying potential given from power conditions. Besides the scientific literature, slow steaming is widely believed to be applied by the majority of vessels and has often been subject to opinions in specialized press. As such, various articles like "Slow Speed Ahead!" from FearnleysSvenning (2007),"Ocean Shipping Lines cut Speed to Save Fuel Costs"' (White, 2010) and "A Chief Engineers Concern Regarding Slow Steaming of Ships"' are discussing the impact of bad market conditions and different reactions of expected regulation on slow steaming. The world's largest shipping companyMAERSK (21.12.2011) states about their own slow steaming behavior:

[...] Cutting energy consumption through slow steaming, optimal hull designs and Waste Heat

⁴According to Corbett et al. (2009) this price was a usual price per metric ton at the time the observations were made(2001-2002)

Recovery systems to name a few initiatives has lowered the entire Maersk Groups bunker fuel use to 10.7 million tonnes in 2010, down from 13.8 million in 2007 (MAERSK, 21.12.2011)

3 When do ships go slow? - A Theoretic Determination of Vessel Speed

3.1 Assumptions & Decision Environment

For the following theoretic formulation of a vessel's speed optimization, it is first assumed that the shipowner is the individual who decides about the speed of a vessel. This is due to the assumption that voyage charter arrangements are the starting point of the analysis at hand. According to Beenstock and Vergottis (1993)[p. 101] it can assumed that there is perfect competition in the shipping market and that market participants behave rationally and hence optimize speed. It is also assumed that the ships are laden and for simplicity reasons, that there is no congestion at the ports and ships can load and unload their cargo instantaneously.

3.2 Basic Profit Maximizing Model - Vessels on Voyage Charter

The following model is based on the first model in Ronen (1982) and the takes a profit maximizing view of a ship owner chartering out his ship on the spot market. In the spot market the ship owner receives a route and direction specific freight rate in Dollar per ton of cargo to be transported from port A to B. Let this freight rate received per ton of shipped cargo be denoted by R and the amount of cargo to be transported by W. A transport leg of length D is completed in d days at the speed V, which is bounded below by some minimum V_{min} which the vessel has to maintain in order to be able to maneuver and above by V_{max} . It is assumed that fuel costs, which are the product of daily fuel consumption F and bunker cost of the fuel, P_B , are to be the only cost factor, due to the assumption that fixed cost to operate the ship are relatively small and do not change with speed. It is furthermore assumed that the shipowner does not own the cargo and hence does not include any depreciation or discounting calculus for the value of the cargo.

Notation:

R =Spot freight rate in Dollar/ton transported from A to B.

W = Weight of cargo which is needed to be transported in tons

 $W_{max} =$ Maximum cargo capacity of ships under time charter or owned by cargo owner

- D = Distance from port A to port B
- d =days it takes the vessel to sail from port A to port B
- V =Vessel speed

 $V_{min} =$ Minimum vessel speed

 $V_{max} =$ Maximum vessel speed

 F_d = Fuel consumption at design speed VV_d

 $P_B =$ Price of Bunker fuel in Dollar/ton

- $P_O =$ Price of Crude Oil/ton
- r =interest rate
- T = Time Charter Rate per day

Furthermore are fuel costs assumed to depend on the ship's speed in the following way:

$$F = \left(\frac{V}{V_d}\right)^3 F_d \tag{1}$$

Daily profit can be written as

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

Hence, the speed optimizing daily profits is given by

$$\frac{\partial \frac{\pi}{d}}{\partial V} : \frac{24RW}{D} - 3P_B F_d \left(\frac{V}{V_d}\right)^2 \frac{1}{V_d} \stackrel{!}{=} 0 \tag{3}$$

s. t. $V_{min} \leq V \geq V_{max}$

$$\Rightarrow V^* = \sqrt{\frac{8RWV_d^3}{P_B DF_d}} \tag{4}$$

Thus, the profit maximizing speed V^* is increasing in the revenue per ton R, weight transported W and design speed V_d and decreasing in trip length D, bunker cost P_B and fuel consumption at design speed F_d .

The penalty (payment) for being late(early) agreed upon in the charter party is not included for simplicity reasons, but potentially matters to the ship owner. But since beeing early/late fees are also relatively small and the travel time expected at the date of the fixture should include the hindsight of choosing an optimal speed, those fees are not included in this basic model.

3.3 Cost Minimizing Model- Vessels under Time Charter

Given that some trips made in the VLCC tanker market are conducted under time charter agreements, the aforementioned assumption that the vessel which is subject to the speed optimization is operating under a voyage charter agreement, is modified. This second model tries to set up a theoretic optimal speed formulation for a vessel under time charter agreement. Recalling that a time charter agreement implies that the shipowner rents out his ship over a certain time period in exchange for a daily fee (time charter rate), and more important that the shipowner does not cover fuel costs and port charges, reveals that the shipowner is no longer taking the speed decision. Instead the charterer has to pay for the fuel costs and hence is assumed to decide over the vessel speed. Due to the fact that the charterer is not generating any profits from this operation, a cost minimizing view is taken to formulate optimal speed. This is similar to the model of Ronen (1982) and cost minimization problem formulated in the appendix of Devanney (2009). The daily costs the charterer faces are the daily time charter rate, the bunker fuel costs and the spot rate per day for the share of the cargo the charterer cannot handle with his time chartered transport capacity. According to Devanney (2009) the charterer can either be short tonnage or long. If freight rates are high, he would speed up to free tonnage to gain from subletting it for high spot rates. If freight rates are low he might go slower and charter in his short tonnage at low spot rates. Fixed operating costs, are not considered due to the assumption that they are relatively small and do not depend on speed. Starting from the basic model approach for voyage charter agreements also the inventory cost, i.e. the value of the cargo is ignored since it is assumed that the charterer does not necessarily own the $cargo^5$. But this assumption might be not very realistic and has to be modified eventually. Thus, the daily cost function used to optimize speed can be described by the following equation, where the term T denotes the daily time charter rate and $W_d i f f$ denotes the difference between maximum capacity transportable with the vessel(s) under time charter agreement and the amount needed to be transported W.

$$MinC: \left\{ \frac{RW_{diff}}{\frac{D}{24V}} + T + P_B \left(\frac{V}{V_d}\right)^3 F_d \right\}$$
(5)

s. t. $V_{min} \leq V \geq V_{max}$

this leads almost to the same optimal speed as the optimal speed from the voyage charter model, apart from the fact that instead of W only a smaller absolute amount $W_d iff$ is determining the optimal speed. If $W_d iff$ is positive, i.e. the charterer has to charter in tonnage, the costs are minimized, else the the income from chartering out the free tonnage is maximized

⁵Also following assumptions made in the literature available on optimal speed, compare Ronen (1982); Devanney (2009)

(Devanney, 2009).

$$\Rightarrow V^* = \sqrt{\frac{8RW_{diff}V_d^3}{P_B DF_d}} \tag{6}$$

The same is valid for oil company owned vessels, apart from the fact that they do not have to pay a daily time charter rate. But since the daily time charter rate is not depended on vessel speed, it is irrelevant for the optimal speed.

4 Empirical Analysis - Is Speed Actually Determined by The Relative Movement of Freight Rates and Bunker Prices?

The empirical analysis forcuses on the VLCC tanker market. There are two main reasons why the VLCC tanker market was chosen to be the subject of the analysis. Firstly, ships operating in this market have very similar characteristics since they come with basically two engine types.⁶ Not only the ships are very similar, but also the goods transported have the same characteristics (always Crude Oil as the name VLCC (Very Large Crude Oil Carrier) suggests). The homogeneity of ships and cargo simplifies a comparative analysis and justifies generalizing assumptions that have to be made in order to conduct the analysis. The second reason why the VLCC tanker market was chosen is, that there is no empirical analysis on the speeds of VLCCs published so far.

4.1 Model Specification and Hypotheses

In order to specify a model and its functional form for the empirical analysis at hand, the theoretic optimal speed formulation from above is used to impose the structure on the empirical model. The optimal speed for vessels under voyage charter is used to set up a relationship between the variables that can be tested. Therefore the model formulated in equation (4), is used as a starting point. The hypotheseses for the coefficient signs evolves from the partial derivatives of the variables in this optimal speed relationship.

$$V^* = \sqrt{\frac{8RWV_d^3}{C_B DF_d}}$$

This theoretic relationship is the result of economic theory (optimizing behaviour) and may not be able to explain the observations made on its own. But it provides an impression about the relationship of the main determinants of the observations under review, assuming that decision takers are rational individuals which seek to optimize their profits. In reality there might exist other speed determining elements which are not measurable, such as weather conditions and currents for example. Furthermore measurement errors can occur, which lead to wrong observations. In addition to that, there are also other stochastic elements which enter into the realizations of a variable (Cramer, 1969, p. 4) due to random variation not present in theory. Each observation can be seen as a random realization of an underlying sample of possible realizations. Therefore, the economically optimal speed has to be complemented with a stochastic element. This very element can be introduced with an error term which accounts for the deviation from the optimal

⁶typically M.A.N B&W and Wartsila, see Vessel Peer Group analysis in Clarkson Shipping Intelligence Network (2012)

relationship and the observed relationship. This is done by multiplying the theoretic optimal speed by an error term μ , where $\mu = e^{\varepsilon}$

$$V^* = \sqrt{\frac{8RWV_d^3}{C_B DF_d}} e^{\varepsilon} \tag{7}$$

According to the assumptions under which an OLS regression can be conducted and is moreover an efficient and unbiased estimator, the empirical model equation has to be linear.⁷ Taking logs of the above equation one gets

$$lnV^* = \frac{1}{2}ln8 + \frac{1}{2}lnR + \frac{1}{2}lnW + \frac{3}{2}lnV_d - \frac{1}{2}F_d - \frac{1}{2}lnP_B - \frac{1}{2}lnD + \varepsilon$$
(8)

which describes a log-linear relationship.

This could be used as basis for an empirical investigation of the form:

$$lnV = \alpha_0 + \beta_1 lnR + \beta_2 lnW + \beta_3 lnV_d + F_d + \beta_4 lnP_B + \beta_5 lnD + \varepsilon$$
(9)

Where α_0 is the intercept term, which should be equal to $\frac{1}{2}ln8$ according to theory. β_1 to β_5 are the coefficients which should represent the influence of the explanatory variables on the dependent variable. The goal should be to test if the regression coefficients from this model specification are significant and furthermore if they have the right signs according to the theory. That would mean, that β_4 and β_5 should be negative, indicating that speed is decreasing in bunker prices and distance, and increasing in freight rates and weight transported. Due to lack of information on the actual carried weights the variable W is not included as explanatory variable. This could lead to an omitted variable bias if the vessels are loaded very differently. A not fully loaded vessels would probably only occur in low markets, when freight rates are low. One the one hand, this implies that vessels would not speed up to earn on high freight rates. On the other hand however, they have the option to speed up with less fuel consumption compared to full load. Moreover shipowner might still expect to be able to get a next full-load cargo. Therefore it is hard ascertain in which direction a bias of partly loaded vessels would go. Thus the omitted weight variable has to be kept in mind when looking at the results.

Since there is also no information on the design speed of a specific ship and consequently its fuel consumption at design speed given in the data, also these two variables have to be excluded from the empirical model. But since the ships have very similar characteristics (Adland and Strandenes, 2007), those variables should not have significant influence on speeds as the ratio of those variables can rather be treated as a constant.

 $^{^7\}mathrm{see}$ a more detailed description of the OLS assumption in the Appendix D

Thus, a model to be estimated could look like that:

$$lnV = \alpha_0 + \beta_1 lnR + \beta_4 lnP_B + \beta_5 lnD + \varepsilon$$
⁽¹⁰⁾

If the OLS assumptions⁸ hold for the model above, the model can be estimated and tested with the help of a standard OLS regression.

4.2 Data Description

Before the empirical model is estimated, the Data and its sources are shortly presented in the following section.

4.2.1 Speeds

The data and information on VLCC vessel speeds is obtained from IHS Fairplay, an international information service company which is able to provide past geographic vessel position data from AIS (Automatic Identification System). For the most frequent VLCC route, which goes from the Arabian Gulf to Japan, single vessel's departure and arrival dates were extracted from January 2006 to December 2011. The departure and arrival times where given dead on time. The trip time was given in hours needed per trip. The corresponding average speeds were recalculated using distance tables from portworld.com⁹ and reported at the time the trips started. The more general route AG-JAPAN could be separated into more exact routes starting from Ras Tanura and Ju'amayah in the Arabian Gulf to 13 ports in Japan. The destination ports in Japan were Chiba, Kashima, Kiire ¹⁰, Kinwan ¹¹, Mizushima, Muroran, Oita, Senboku, Sendai, Shimotsu, Tomakomai ¹², Yokkaichi and Yokohama. Ras Tanura and Ju'amayah were assumed to be the same starting point due to their very close location.

The data is skimmed for outliers, meaning that speed observations which are smaller than the minimum speed (determined by the speed a vessel has to sail in order to be able to maneuver ¹³), were replaced by the speed value of the last observation given¹⁴ In total, the dataset included 259 different vessels with similar characteristics operating on the above described 13 routes. Some ships which were only observed once and others were observed up to 20 times on different routes.

⁸see Appendix D

⁹Available from:http://www.portworld.com/map/

¹⁰here the distance to Kagoshima was obtained from the distance table since it was the closest port available and used as a synonym

 $^{^{11}\}mathrm{here}$ the distance to Naha City port was used

 $^{^{12}\}mathrm{here}$ the distance to Muroran was used

 $^{^{13}}$ at approximately 8 knots according to IMO (03.06.2011)

¹⁴In a first step outliers were reported as missing values, and as a second step missing values were replaced by the value of the last given observation.

From the outset, the data was provided in form of a very irregular panel, ie. speed observations of 259 vessels along the 13 routes from Arabian Gulf were observed over time, but in very irregular time intervals. ¹⁵ Even for single routes with a satisfying amount of observations over time, the observations were highly irregular such that interpolation seemed not an appropriate option. To be able to conduct a regression analysis with this data, it was transformed to a weekly time series, where the average speeds of the single trips were averaged over weeks. Since the data is a time series as a consequence, special attention is paid to possible time series characteristics in the Results Section 4.3.

4.2.2 Freight Rates

The freight rate data is obtained from the Clarkson Shipping Intelligence Network(Clarkson, 2012), one of the worlds leading providers of shipping information services. For the spot freight rate, Baltic Index data for the route Arabic Gulf - Japan¹⁶ is collected on a daily basis reported in World Scale (January 2006 until December 2006).

Based on a publication of historic flatrates from McQuilling Services (McQuilling Services, 2011)¹⁷ Worlscale spot freight rate data was recalculated to US\$ per ton transported on the route Arabic Gulf to Japan. The following example explains the transformation from Worldscale measures to US\$ per ton measures: If the spot freight rate on the route was given as **121.61** Worldscale, and the Worldscale 100 for the route was given by

 $100WS=15.16\;\mathrm{US}\$$

, the freight rate used on this data for the analysis at hand was equal to:

1.2161 * 15.16 US = 18.4360 US

After this transformation this daily figures were also averaged over weeks. The averages were taken over the same dates as the speed data, starting 07.01.2006 and ending 24.12.2011.

4.2.3 Bunker Prices

Data on bunker prices is also obtained from the Clarkson Shipping Intelligence Network database. Here weekly Fujairah 380bst bunker prices are used since they are the geographically closest price available, and furthermore the cheapest price available if the shipowner has to choose between destination and departure port to fill up his tanks.

¹⁵Some routes were observed once (Kinwan), the most frequent route was observed 149 times (Mizushima). Similarly, a large share of vessels has been observed only once, and the most frequently obsverved ships 15 times.

¹⁶called BDTI TD3 in SIN

¹⁷Available from:http://www.mcquilling.com/reportviewer.aspx?fname=No.+11+Flat+Rate+Forecast-2011-Oct-14-11-32-86.pdfrender=1

The weekly bunker prices were matched to the same week dates as freight rates and speeds. The IHS Fairplay dataset furthermore contained information on whether the vessels were owned by oil companies or not. In table **??** the descriptive statistics of the variables are summarized.

	Speed	Freight Rate	Bunker Prices
Min	7.87(14.10.2006)	6.54(18.04.2009)	214.0 (27.12.2008)
1st Qu	11.65	10.34	333.9
Median	12.40	12.43	447.8
Mean	12.35	14.79	448.0
3rd Qu	13.04	16.70	513.6
Max	14.83 (27.09.2008)	$53.51 \ (22.12.2007)$	$736.0\ (19.07.2008)$
StD	1.14	7.61	138.01

Table 2: Descriptive Statistics

4.3 Data Analysis and Interpretation of Results

Looking at the data with the help of figure 2 gives a first impression:



3D Scatterplot

Figure 2: 3D Scatterplot of Weekly Data

The first impression prevailing is, that it is hard to detect any kind of meaningful relationship from the plot. It seems as if on the one hand there are obviously some quite high speed observations at around 15 knots, when at the same time Bunker prices are very high and freight rates are very low. On the other hand vessels seem to go slow even if freight rates are very high and bunker prices are relatively low.

However, since the objective of this work is to test if the theoretical determinants of speed can be observed to significantly influence vessel speed in practice, the above described data is used in a regression analysis. As it is suggested by the empirical model from equation (18) the logs of the observed speeds are regressed on the logs of freight rates, bunker prices and the distances. Given the model from equation (18)

$$lnV = \alpha_0 + \beta_1 lnR + \beta_2 lnP_B + \beta_3 lnD + \varepsilon$$

the hypotheses induced from theory are:

- the bunker price coefficient β_2 is negative
- the freight rate coefficient β_1 is positive
- the distance coefficient β_3 is negative

The results of the regression above are presented in the table below.

	Estimate	Std. Error	t value	$\Pr(> t)$
0	-7.7292	2.3002	-3.36	0.0009 ***
$\beta_1(lfr)$	0.0004	0.0140	0.03	0.9773
$\beta_2(lfujbunk)$	0.0257	0.0178	1.44	0.1513
$\beta_3(ldist)$	1.1498	0.2600	4.42	0.0000 ***
Residual stand	ard error: 0	0.09428 on 30	8 degrees	of freedom
Multiple R-squared: 0.06143				
Adjusted R-squared: 0.05229				
F-statistic: 6.719 on 3 and 308 DF p-value: 0.0002096				02096
Signif. codes:	0 ***	0.001 **	0.01 *	0.05 .

Table 3: OLS on Logs of Weekly Data

The results clearly fall short of the expectations raised by the theoretic considerations. Except for freight rates, the coefficients do not have the expected signs. Everything else equal, an increase of one percent in Bunker price should lead to a 0.02 percent increase in speed. That would mean that higher bunker prices would lead to increased speed of ships, and that is not reasonable on

4 Empirical Analysis - Is Speed Actually Determined by The Relative Movement of Freight Rates and Bunker Prices?

the basis of the theory introduced before. The very small coefficient for freight rates of 0.0004, indicates that if freight rates change by one percent, speeds change by 0.0004 percent, which might be the right sign but reflects very little influence on speed. Note furthermore, that only the intercept term and the distance coefficients are significant when looking at the t- and pvalues. This reflects the fact that bunker prices and freight rates have no explanatory power for the determination of vessel speed, at least according to this results. The coefficient for distance however is strongly significant and suggests that a one percent change in distance increases speed by 1.15 percent. This result is also inconsistent with the theoretic formulation of optimal speed from equation (4). But it could be explained by the fact, that the speeds are calculated without the notice of possible waiting times as a consequence of port congestion. The longer the distance, the smaller the share of waiting time (which implies a speed of close to 0 knots) distorting the average speed over the complete trip. The highly significant intercept coefficient of -7.73 is not very meaningful, as considering a zero percentage change in freight rates or bunker prices would indicate a -7.73 percentage change in speed already. However, the results using a model without intercept after substracting the constant $\frac{1}{2}ln8$ as implied by theory, does not give any more promising results (Results can be found in Appendix A.1.1).

Figure3 gives a more intuitve impression about the outcomes of the above regression results. Freight rates and bunker prices were plotted against each other and the squares indicate the pairwise combination of high, medium and low freight rates and bunker prices. The upper left square indicates for example that the freight rate observation is in the highest third of the observed freight rate range, and in the lowest third of the observed bunker prices ¹⁸. As one can see especially in this upper left square, the combination of high freight rates and low bunker prices could not be observed in the time period under review. The red figure represent the means of the observations made during each of the nine bunker-freight combinations.

 $^{^{18}}$ The thirds were defined by the observed range of the variable during the period 2006-2011 and divided by three.





Figure 3: Freight Rate - Bunker Combinations and Average Speeds

Those average speeds might not be very reliable as for example for the combination of medium high freight rates and low bunker prices, only two observations are registered. So it might not be very representative that the vessels will sail with an average speed of 12.25 knots given this combination. This rather qualitative analysis suggests that the VLCC vessels on the route AG-JAP do not follow a relative movement of freight rates and bunker prices, instead, it looks as if they would sail at approximately the same speeds no matter what happens to the market conditions.

4.4 Time Series Obstacles and Underlying Data Generating Processes

Given that the data analyzed here is time series data, the method applied should take the special properties of time series data into account. Since the prior goal was to test the relationship implied by theory, these considerations have been secondary. But given the rather poor outcomes

it is important to also analyze the underlying data generating processes of the single series and to pay attention to how and if the time series properties might affect the relationship between the single variables. If time series data is used for a regression analysis it is assumed that the realizations of the involved variables have the same underlying distributions over time (Hayashi, 2000)[p. 98]. This property is also called stationarity. Mostly a weaker form of stationarity which is called covariance-stationarity is used in time series analysis, only requiring the first and second moments of the variables to be stable over time. This can formally be described by the following (Enders, 2010)[p54]:

if for all points in time s and t-s

$$E(y_{t}) = E(y_{t-s}) = \mu$$
$$E\left[(y_{t} - \mu)^{2}\right] = E\left[(y_{t-s} - \mu)^{2}\right] = \sigma_{y}^{2}$$
(11)
$$E\left[(y_{t} - \mu)(y_{t-s} - \mu)\right] = E\left[(y_{t-j} - \mu)(y_{t-j-s} - \mu)\right] = \gamma_{s}$$

where μ , σ_y^2 and γ_s are constants.

If the above requirements are not fulfilled, the process is said to be non-stationary. Including such non stationary variables in a regression can lead to wrong inference and spurious results (Granger and Newbold, 1974). Hence, one has to assess the properties of the included time series and either transform them properly, or carefully check if the outcomes of such a regression might be spurious. That the outcomes are spurious is unlikely in the case at hand, because the R^2 is very low already. But still it provides some more insights to analyze the variables seperately in order to obtain a better understanding of their relationships. Hence it is first analyzed if the variables can be considered to be stationary. Apart from inspecting the plots of the single series and their Autocorrelation Functions (ACF), this is done with the help of the Augmented Dickey Fuller Test for Unit Roots (see further details in Appendix B).

As a starting point, figure 4 below gives an impression of the realizations of all three variables over time. 19

¹⁹For Unit Root Tests always the logs are analyzed since logs are suggested to be used from the theoretical model

4 Empirical Analysis - Is Speed Actually Determined by The Relative Movement of Freight Rates and Bunker Prices?



Figure 4: Weekly Time Series Plot

Speeds

Starting out with the analysis of speeds as the dependent variable, the look at the plot (a larger plot of the logs of weekly speeds over time can be found in Appendix C) suggests that speeds are rather mean reverting over time. It is not possible to detect any period of generally higher or lower speeds over certain periods and also the variance seems quite similar over time. It seems as if the technically possible range of speeds, which lies approximately between 8 and 16 knots, is generally not fully exploited. From the speed data under review here, no speeds higher than 15 knots can be observed, and only little can be observed around 10 knots and lower, which would be equivalent to super slow steaming speeds. As there are technical boundaries to speeds, it is unsurprising that speeds do not show any exploding or trending behavior. Nevertheless, one would intuitively think that speeds could be even lower, as the period reviewed displays large

spans of high bunker prices and low freight rates. Inspecting the plot, the impression is that speeds are stationary. Yet a glance at the Autocorrelation Function (ACF) could give further insights.



Figure 5: ACF Logs of Weekly Speeds

It is quite clear from the plot of the series itself, as well as from the ACF, that speeds have to be stationary. Therefore a Unit Root test to test for stationarity is not conducted here.

Freight Rates

Opposed to the weekly speed series, the freight rate series looks far less stable. The plot in figure 4 reveals more variability, particularly between the end of 2007 and the end of 2008, where 2 relatively large spikes can be observed (a larger plot of the logs of weekly freight rates over time can be found in Appendix C). According to maritime economic theory, those spikes can occur if demand for the VLCC transport of crude oil strongly increases in the short term, and supply cannot be equally increased in the short term. Additionally the financial crisis hit maritime trade during 2008, explaining the large drop in freight rates. As is shown by Adland and Strandenes (2007), the spot freight rate is always bounded below by some minimum level because there is always the option for ship owners to put their vessels into lay up, if the spot freight rate is equal or lower than cost at lay up (plus layup costs). On the contrary, freight rates can go through the roof in the short term as indicated above. In the long term however, supply is always elastic and can adjust to demand changes, either by building new or scrapping old vessels. Therefore extreme freight rate levels are not sustainable in the long term (Steen et al., 2006)[p.450]. Even if the spot freight rate process looks rather random and not very mean reverting, this is an

argument in favor of stationarity in the long term. However this can be analyzed more detailed with the help of the ACF:



Figure 6: ACF Logs of Weekly Freight Rates

Opposed to the theoretic implication, the slowly decaying ACF suggests that spot freight rates could be also non-stationary or contain a close-to-unit root. This suspicion is tested using the Augmented Dickey Fuller Test (see Appendix B). Neither economic theory, nor the plot suggest that a deterministic time trend should be included in the test equation. However, it could be possible that the data generating process for spot freight rates contains a stochastic drift. If it is assumed that transport costs are rising, it would be reasonable to also expect freight rates to rise over time. But as technology advances steadily, it can rather be expected that transport costs (at least marginal costs) would rather decrease over time, as a consequence of technological progress. On the other hand it is worth noting that the spot freight rates used here, include bunker prices in an unknown way. The spot freight rate is basically the price that is paid by the charterer to the shipper in exchange for the transport. And in the end this price has to at least cover variable costs in the short run in order to maintain the shipper to operate his ship. As bunker prices account for a large share of variable costs, spot prices should include bunker prices plus a markup (Steen et al., 2006). As bunker prices have been steadily increasing over the last years ²⁰ and are expected to rise as well in the future, spot freight rates could also be assumed to inherit an stochastic upward drift term due to bunker cost increases. Another thing worth mentioning is, that the freight rates are reported in nominal terms, which would result also in an upward trending component. Summing up, it would be crucial to know which effect would be larger- cost decreases through technological progress or inflation and bunker price increases (if at all) on order to decide on what direction a drift could imply. (Steen et al., 2006) [p.466].

²⁰this is discussed in the next pragraph on the data generating process of bunker prices
But this it is not clearly detectable from a priori economic knowledge. Eyeballing as a last resort suggests however that there is no deterministic time trend obvious. But after considering the aforementioned influences on freight rates, there could be reason to include an intercept term, reflecting a stochastic drift. The results for the Dickey Fuller Test on the basis of a model including the drift term and no trend is presented below. Test results of test with the other model specifications can be found in Appendix B.2.

Model	Hypothesis	Test Statistic	Crit Value $95^{21}\%$
$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-4.57	-2.87

Note: the lag length of the model in the test equation is determined by the Bayes information criteria

Table 4: Augmented Dickey Fuller Test for Logs of Spot Rates

The results²² suggest, that freight rates can be considered to be stationary. This result is furthermore supported by ??, who finds that spot freight rates are stationary using non-linear model specifications.

Bunker Prices

According to figure 4, Bunker Prices could be suspected to contain a positive trend over time. Despite of the large spike and fall in 2008, bunker prices seem to be steadily increasing.(a larger plot of log of bunker prices is available in AppendixC). Apart from the suspicious increase over time the plot of the ACF in figure 7 suggest that the series is not stationary since the autocorrelation is decaying only very slowly.



Figure 7: ACF Logs of Weekly Bunker Prices

 $^{^{22}\}mathrm{A}$ longer freight rate series from 1998-2011 could also be tested to be stationary, the results can be found in Appendix B.2

4 Empirical Analysis - Is Speed Actually Determined by The Relative Movement of Freight Rates and Bunker Prices?

On the basis of economic theory, and the assumption that the bunker market is perfectly competitive and demand and supply are elastic to some degree, bunker prices should revert to some long term mean (Maslyuk and Smyth, 2008). This long term mean could be trending upwards, if marginal costs for production of bunker prices are expected to rise as a consequence of higher extraction costs (Pindyck, 1999; Hotelling, 1931). Additionally, demand can be expected to rise due to world economic growth, since economic growth implies a growing demand for seaborne trade and therefore also for bunker oil. On the other hand vessels become more effective and less fuel consuming, which in turn should decrease demand for bunker. But the latter effect might be smaller in comparison. However, this argumentation would conclude to model bunker prices including a time trend, where the time trend reflects the long-term mean, bunker prices tend to revert to. But this view would ignore persisting effects of random demand and supply shocks, which can be present in reality. Examples for those kind of shocks could be new oil discoveries and alternative technology for example (Pindyck, 1999). Assuming therefore that bunker prices are subject to random influences and high uncertainty, bunker prices can be a modeled more appropriately with a random walk plus drift to test for unit roots. It is worth noting that there is not much literature on the stochastic properties of bunker prices, but since bunker prices are closely related to crude oil prices, much can be inferred from the analysis of crude oil prices. As such, many papers analyzing crude oil prices, concluded that the hypothesis for a unit root could not be rejected, whether ordinary ADF tests were applied or other test procedures including structural breaks (see for example Alizadeh and Nomikos (2004); Gülen (1998)). Postali and Picchetti (2006) argue for example, that crude oil prices can be best modeled by a Geometric Brownian $Motion^{23}$, which is a continuous random process. Moreover, studies from Kumar Narayan and Smyth (2007) and others have examined that energy demand can be considered as nonstationary. As a result, also crude oil prices and therefore also bunker prices can be assumed to inherit this nonstationary property of energy demand as well. Summing up the above considerations, the bunker price series analyzed in the work at hand is tested with the model specification including a drift term and no trend.

Model	Hypothesis	Test Statistic	Crit Value 95%
$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-1.3284	-2.87
	$a_0 = \gamma = 0$	1.3248	4.61
$\Delta y_t = \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	0.8696	-1.95

Table 5: (Augmented)Dickey Fuller Test for Logs of Bunker Prices

²³see for example Hamilton (1994, p. 477) for further details on Geometric Brownian Motion

The above test results suggest that bunker prices contain a unit root, since the H_0 of a unit root cannot be rejected at the 5% significance level. Given this result, also the hypothesis that the data generating process does not contain a drift term (a_0 in the above specification) can not be rejected. As a consequence, also the model containing no drift and no trend is tested, here the H_0 of a unit root can neither be rejected. Therefore it can be concluded that bunker prices are non stationary. A test including a trend and a drift term, indicating that the trend term should not be included either, can be found in Appendix B.4.

After inspecting all three weekly average series separately, a clearer picture of the structure of the single series appears. It is evident, that bunker prices violate the condition for stationarity and therefore also indirectly violate the assumptions under which an OLS estimation would be reliable. Therefore the results of the regression from equation (18) should be treated with care. As already indicated before, the results are not suspicious to be spurious, since they do not indicate any strong relationship which could be mistrusted anyway. However, the hypothesis that one series which inherits possible exploding behavior (bunker prices) should explain a very stationary series (speeds) is suspicious in the way that it is unprobable to be approved.

A look at the residuals in figure 8 gives the insight, that the residuals look rather stationary which favors the reliability of the regression outcomes (ACF of residuals in Appendix C. On the other hand, if it is compared with the plot of the dependent variable (speeds) itself, it becomes obvious that the residuals display almost the same pattern as the dependent variable, reflecting the fact that the explanatory variables have no explanatory power at all.



Figure 8: Residuals and Logs of Speeds

Still, there are normally two remedies for dealing with nonstationary variables. One remedy would be to transform the nonstationary variable in order to make it stationary. Two ways can be considered for this. Depending on whether the nonstationary variables is assumed to contain a time trend or a stochastic drift, it can either be differentiated or detrended. The latter is done if the series inherits a deterministic time trend (Enders, 2010, p. 189). Since it was concluded from economic theory and the unit root test that bunker prices do not entail a deterministic time trend, detrending can be ignored as a possible measure. Instead, bunker prices could be differenced in order to become a stationary series. Bunker prices were differenced one time in order become stationary. The results of the Dickey Fuller Test for the first difference in bunker prices can be found in Appendix B.8. Series which are differenced d times in order to become stationary are also called integrated of order d, or I(d). Using the new stationary differenced bunker price variable in a regression is statistically more valid since inference is reliable again. But theoretically, including the differenced bunker prices as regressors, has a different meaning. A regression of the form

$$lnV = \alpha_0 + \beta_1 lnR + \beta_2 dlnP_B + \beta_3 lnD + \epsilon \tag{12}$$

could be interpreted as follows: An increase by one percent in the change of bunker prices would increase speed by β_2 percent. Looking at figure 9





Figure 9: Differenced Logs of Bunker Prices

indicates, that speed therefore should have been slowest around the time of the financial crisis since then the negative changes were largest. However, even a regression using the first differenced bunker prices has not more explanatory power. (Results can be found in Appendix A.1.2).

Taking differences of all variables, would not be very consistent with the theory either.

$$dlnV = \alpha_0 + \beta_1 \frac{1}{2} dlnR + \beta_4 \frac{1}{2} dlnP_B + \beta_5 \frac{1}{2} dlnD + \epsilon$$
(13)

Here an increase of one percent in the change of bunker price would increase the change of speed by β_4 percent. The outcomes of this regression are not more promising either.(Results can be found as well in Appendix A.1.3).

The other remedy is the possibility that the two explanatory variables could be connected through a cointegration relationship which could explain the movement of speeds. This remedy is ruled out by the different orders of integration of the variables included.²⁴.

Conclusion of the Data Analysis

To sum up the outcomes of the data analysis, it can be said that vessel speeds do not respond in any obvious way to the movements of bunker prices and freight rates. Given the statistical properties of the single series, it is neither very reliable to conduct a regression analysis in the sense of the proposition of economic theory on optimal vessel speeds, nor very promising. Apart from the regression analysis and the analysis of the underlying data generating processes, also the

²⁴For further details on the issue of cointegration please see for example Chapter 6 in Enders (2010).

more qualitative analysis of the observed mean speeds during different combinations of bunker prices and freight rates(figure 3) gives the impression hat the vessels considered rather sail like a regular bus line than optimizing speed in response to different market conditions. The conclusion is therefore, that the theoretic optimal speed relationship could not be observed empirically in the VLCC tanker market for the analyzed routes and vessels. To preclude the suspicion that the averaging over weeks could have distorted the actual sailed speeds, also the irregular trip data has been used for a OLS regression analysis, assuming that the data was collected all at the same time. The results were very similar to the outcomes from the weekly data analysis. Results are given in Appendix A.1.1.

5 A Quote from the Industry

The findings of the statistical analysis on the relationship between the speed, freight rate and bunker price observations are on the one hand quite disillusioning, and on the other hand quite strong. It is astonishing that it is not possible to find any response in speed to the relationship between bunker prices and freight rates, as it is explained by theory- which is often taken as a given by the industry. Are shipowners not behaving like rational individuals at all? Or are there just too many unobservable other factors such as weather conditions and port congestion which determine vessel speeds? Are the assumptions too restricting?

In June last year (2011) the tanker report of McQuilling Services LLC, an international marine services company specialized on tankers, reports that at the current state of the market, slow steaming has become *"the center of attention"* particularly in the VLCC sector. Looking at the actual observed speeds in the analyzed data set here, this quote does not seem to be resembled.

Apart from the above statement, the same report furthermore specifies

"...While the potential of double savings by slow steaming round trip would be of interest to owners; charterers are not likely to settle for such slow laden trips "McQuilling Services (2011)

The implication of this statement is, that shipowners and charterers who do not own the laden cargo themselves, might think about going slower as a good measure to save money. Opposed to them, cargo owners might think about it as a money loosing undertaking. The cargo, in the case of VLCCs approximately 300000 tons of crude oil, has to be discounted invalue per day the ship is arrives later due to going slower. That is equal to a value decrease. These dynamics have so far been excluded from the theoretic model, since it was assumed that the shipowner is the individual deciding over vessel speed and that s/he has enough bargaining power to decide about this on his own. But this might not necessarily be the case.

Given the constellation where it would be favorable for a shipowner to sail slow – high bunker prices and low freight rates—the cargo owner would probably enjoy some significant bargaining power. A large spread between freight rates and bunker prices indicates that shipowners are not able to press for equally higher spot rates. The occurrence of this situation is probable if there is an oversupply of vessels. As a consequence, the demand side, the cargo owners in this case, have the power to select between different suppliers and threaten shipowners to choose another shipowner if they would not go fast enough. If this is actually the case, is hard to measure, but could be one possible explanation for observed speeds which tend to be (still) too high for the mostly unfavorable market conditions during the analyzed period. If the market is in equilibrium and ship and cargo owner have equal bargaining power, there might still be a difference between the behavior of vessels operated by cargo owners and vessels operated by ship owners. Even if it was shown in the time charter model that all possible ship operators would- to different extents- respond to the changes of freight rates and bunker prices in a similar way, the value of the cargo was so far not included in the model. The following analysis therefore takes the view of a cargo-owner controlled ship. The cargo owner might be a time charterer chartering in a vessel, or an oil company owing their own vessels. Based on this assumption, the cargo value is included as an explanatory variable, and freight rates are excluded for now. The latter is due to the simplifying assumption that a time charterer or an oil company is not required to charter in or out any cargo on the spot market as it was assumed in the time charter model in section 3.3.

The following example should make the consideration of cargo value clearer: Suppose the Oil Company wants to transport 300 000 tons of crude oil from Arabic Gulf to Japan. Assume furthermore that the Oil Company owns a VLCC which can carry exactly 300 000 tons of crude oil. This is important and relates to the above statement on the exclusion of freight rates, since otherwise the oil company had to charter capacity in or out and would hence again depend to a smaller extent on freight rate levels. But the latter situation is not considered for the example at hand. Given furthermore the following features:

Tons of crude oil to be transported	300.000			
Barrel conversion factor	7,33			
Barrel of crude oil to be transported	2.199.000			
Crude oil price/barrel	US \$ 100			
annual risk free rate	0,04			
daily interest rate	0,000261158			
daily alternative value of the cargo: US \$ 23.631				

If the vessel slows down with the objective to save fuel costs, these savings should be larger than the accumulated alternative value of the cargo over the period the vessel arrives later due to the slow steaming action. Given the following characteristics of a 289 000 DWT tanker built in 2010 with a MAN B.&W.engine, 25

a similar vessel would save approximately 16.000 US \$ per day by slowing down from 15 to 11 knots, and simultaneously loose approximately 24.000 US \$ of alternative cargo value per

²⁵retrieved from Clarkson Shipping Intelligence Network (Clarkson, 2012)

5 A Quote from the Industry

Bunker Price	US $$275 \text{ per}$	
	15,40 knots	11 knots
	(design speed)	(slow steaming)
Fuel Consumption	92 tpd	$33,53^{26}$
daily fuel savings fr	om slow steaming: US\$ 16.109,12	

day. As one can easily see, the cargo value loss might under certain conditions outweigh the fuel saving benefits.

6 Vessel Speeds on Behalf of Cargo Owners

6.1 Theoretical Modification

The above example can also be described more formally. In doing so, the cost minimization model from Ronen (1982) is taken as a starting point, but instead of using the alternative value of the ship, the alternative value of the cargo is used as a cost element. In addition to the notation given from the basic model, P_o is introduced as the price of the cargo. In the case analyzed here, this price is the crude oil price, optimally at destination. Furthermore r denotes the interest rate, the cargo owner would earn per day on the value of his cargo. If the cargo owner wants to handle his cargo himself, he has to consider a trade off between the additional costs from cargo value decrease and savings from bunker fuel cost decrease of slowing down. Assuming that the cargo owner wants to ship exactly the maximum amount of cargo he can carry with his own ship (meaning that he does not have to charter in additional capacity on the spot market or charter out free capacity on the spot market; $W = W_{max}$) the cost function for a laden trip could be described by the following:

$$C:\left\{WP_o\left(1+r\right)^{\frac{D}{24V}} + P_B\left(\frac{V}{V_d}\right)^3 F_d \frac{D}{24V}\right\}$$
(14)

minimzing costs with respect to speed

$$MinC: \left\{ \underbrace{WP_o}_A (1+r)^{\frac{D}{24V}} + \underbrace{P_B\left(\frac{1}{V_d^3}\right)F_d\frac{D}{24}}_B V^2 \right\}$$
(15)

s. t. $V_{min} \leq V \geq V_{max}$ gives

$$\frac{\partial \frac{C}{d}}{\partial V} : \underbrace{-\frac{D}{24V^2}A * (1+r)^{\frac{D}{24V}} \ln W (1+r)}_{-} + \underbrace{2VB *}_{+} \stackrel{!}{=} 0 \tag{16}$$

where the first summand is negative, indicating a cost decrease with increasing speed. The opposite is true for the second summand. Thus, it is shown, that with only including crude oil and bunker prices, speed is already pulled in opposite directions in order to minimize costs. The total derivative with respect to speed is therefore dependend on the single parameters in A and B. Solving equation 15 for V in order to obtain an optimal speed relationship, similar to the optimal speed from 4 is a more complicated procedure. However, it is ovious that the optimal speed depends on the specific parameters involved, i.e. if the effect of cargo value decrease or bunker cost increase is larger. So even if crude oil and bunker price could be assumed to be

the same price, it would not be clear what the total derivative is without considering the other parameters. Therefore the observed results might not be as puzzling as before. If additionally some cargo has to be chartered in- or out, the Spot Freight Rate can also be included as an explanatory variable which increases speed. If the cargo owner has freespace on the owned ship and the freight rate is high, s/he can sail faster and make even more money per day with chartering out space. If S/he has to charter in cargo, s/he could sail faster because s/he can transport more per day on his own.

6.2 Empirical Modification

Given the theoretical modification of optimal vessel speed, the data is further explored considering implications of the theoretical modification.

6.2.1 Results from Seperated Data

One implication of the above modification is, that the inclusion of speed data of oil companies could distort the results. On the basis of the above formulation, vessels owned by oil companies probably sail faster, since they own the cargo and would definitely like to avoid inventory costs.²⁷ As illustrated by the aforementioned example, those inventory costs might be larger than the cost increase from increased bunker fuel consumption. This assumption is only realistic, if it is furthermore assumed that oil companies can sell their cargo immediately. Related to that, it could also be the case that oil companies would sail more regular because they probally also sell parts of their cargoes on a regular basis. As a consequence, the results could be biased in the direction of too fast and too regular speeds. Therefore, the data is analyzed using only speed data from non-oil company owned vessels. The result is presented below:

²⁷Even if it was shown that other vessels can also be guided by the incentive to avoid inventory costs, yet it is not definite to which extent. As a consequence the probability that non-oil company owned vessels optimize their speeds like in the basic theoretic model ?? is higher.

	Estimate	Std. Error	t value	$\Pr(>\! t)$	
(Intercept)	-3.1714	2.2070	-1.44	0.1517	
lfr	0.0102	0.0140	0.73	0.4645	
lfujbunk	0.0252	0.0177	1.42	0.1571	
ldistwother	0.6264	0.2497	2.51	0.0126^{*}	
Residual standard error:0.09406 on 308 degrees of freedom					
Multiple R-squared: 0.02825					
Adjusted R-squared: 0.01879					
F-statistic: 2.985 on 3 and 308 DF, p-value: 0.03148					
Signif. codes:	0 ***	0.001 **	0.01 *	0.05 .	

Table 6: OLS on Logs of Non-Oil Company Owned Speed Data

The outcome is not very different from the outcome including speed data of all vessels, and still bunker prices and freight rates have almost no explanatory power. Moreover the sign of bunker prices and distance is still wrong compared to the theoretic suggestion.

But not only oil company owned vessels could be guided by the incentive to avoid inventory cost, also time chartered vessels operated under the control of cargo owners could distort the results in a similar way. Those vessels would like to sell the cargo as fast as possible and hence speed up more than expected by the before theoretical outset (comp. 4). Moreover, in low markets even vessels controlled by shipowners might be forced to go faster than they would optimally do, because the cargo owners have enough bargaining power to force them to do so. Unfortunately in the scope of this work it was not possible to also obtain information on the freight contract terms (i.e. if it was time charter or voyage charter), such that only vessels under voyage charter could have been analyzed. However, given that the dataset contains high irregularities in the occurance of single vessels, the assumption that a large share of the observed speed data is generated by vessels under voyage charter arrgangements seems reasonable. Results of a regression including dummies for the market situation, i.e. a dummy for low markets indicated by a large spread between bunker prices and freight rates can be found in Appendix A.3. Also here, logs of bunker prices and freight rates are tested to be insignificant for the determinantion of logs of the observed speeds. Moreover, the dummy variable coefficient implies that speeds are 0.2 percent higher when the spread between bunker prices and freight rates is large. However, this coefficient is insignificant as well according to the test statistics. The slope dummy implies that speed is decreasing in bunker prices during low markets, as opposed to other

market situations where it is increasing in bunker price. Apart from the fact that the latter is a doubtful outcome from a theoretic perspective, the slope dummy coefficient is insignificant too.

6.2.2 Results including Crude Oil As Explanatory Variable

Another implication of the theoretical modification, and maybe the most impotant, relates to the value of the cargo. The cargo value and its decrease could be important for the speed of the vessel, even if the cargo is no sophisticated and very expensive high tech product. When analyzing the VLCC tanker market, the crude oil price should therefore be included as an explanatory variable, as it is suggested by the theoretical modification. For this purpose crude oil price series could be obtained from the Energy Information Agency (EIA)²⁸. Unfortunately only West Texas Intermediate and Brent Crude Oil Prices were available for the scope of this work. Since Bhar et al. (2008) states in his analysis of oil prices that the Dubai-Oman Crude has the higest correlation with Brent (Bhar et al., 2008, p. 974), Brent is used for the analysis at hand. One thing worth mentioning is, that crude oil and bunker prices are highly correlated²⁹, which in turn causes a multicollinearity problem. The high correlation is not surprising since bunker fuel is the less valuable byproduct of crude oil production and is hence related to crude oil supply. The demand side might be slightly different, since it can be expected that demand for crude oil is mainly dependent on economic growth, bunker fuel demand however is dependent on seaborne trade. But since the latter is dependent on economic growth to a large share as well, in the end both prices reasonably follow similar patterns. The graph below shows the movements of bunker prices and crude oil:

 $^{^{28}\}mbox{Available from: http://www.eia.gov/dnav/pet/pet_{p}ri_{s}pt_{s}1_{d}.htm$

 $^{^{29}}Cor(Bunker, Brent) = 0.889)$



Figure 10: Bunker and Crude Oil Prices 2006-2011

Both series obviously display very similar patterns, highlighting the occurance of a multicollinearity problem if both variables should be included in the regression. One remedy for multicollinearity, is the exclusion of one of the highly correlated variables (Gujarati, 1995, p. 341). That would represent the situation from before, where crude oil prices were not inclduded. Excluding bunker prices would mean that the variable in favor of slowing down would be excluded, which would turn around the analysis completely. Besides, it is unrealities that two variables moving very similar would lead to different coefficient signs, as it is proposed by the theoretic modification.

However, the results of a regression including crude oil prices can be found in Appeendix A.4.

6.2.3 Results Including Deviations between Crude Oil and Bunker Fuel Prices as Explanatory Variable

Indicating the relative movement of bunker prices and crude oil prices, the deviation between the two variables could be decisive. A deviation represents a disequilibrium of the normal relationship between the two variables. A positive deviation means that the difference between crude oil and bunker price is higher than normal, consequently cargo owners would like to sell their cargo even faster. Therefore a positive deviation should increase speed. Given that both series were tested to be I(1) (see Appendix B.2), there could potentially be a stationary cointegrating relationship, reflecting the deviations and hence partly explain speed developments. If the cointegrating relationship between bunker prices and crude oil prices can be estimated as follows

$$P_O = \beta_0 + \beta_1 P_B + \varepsilon \tag{17}$$

a deviation from the cointegrating relationship is characterized by the residuals of the above estimation ϵ . If the residuals of the estimation are stationary, there exists a cointegrating relationship. In the case at hand, using the Augmented Dickey Fuller Test Equation with no trend and no drift and Engle Granger Critical Values³⁰, the residuals of the above estimation can be found to be stationary (results are given in Appendix B.9).

Therefore the analyzed residuals are included in a regression of the form

$$lnV = \alpha_0 + \beta_1 lnR + \beta_2 Res + \beta_3 lnD + \varepsilon$$
⁽¹⁸⁾

where the residuals, as the deviation from the normal relationship between bunker and crude oil price, are included instead of the two variables themself. As now every variable is stationary, the results are not as suspicious to be spurious as the other results. The hypothesis is that logs of speed should be increasing in the deviation from the cointegrating relationship between bunker prices and crude oil prices. The hypothesis for Freight Rates and Distances remains the same. However, the presented results (figure 7) indicate that the deviations can not be considered to be a significant determinant either.

	Estimate	Std. Error	t value	$\Pr(> t)$	
(Intercept)	-6.8956	2.1541	-3.20	0.0015 ***	
lfr	0.0000	0.0153	0.00	0.9997	
resregw11.5	0.0012	0.0503	0.02	0.9807	
ldist	1.0728	0.2457	4.37	0.0000 ***	
Residual standard error: 0.0907 on 308 degrees of freedom					
Multiple R-squ	ared: 0.05831				
Adjusted R-squared: 0.04914					
F-statistic: 6.3	57 on 3 and 3	08 DF, p-value:	0.0003413		
Signif. codes:	0.001***	0.01**	0.05 *		

Table 7: OLS Including Cointegration Residuals

The identification of one possible shortcoming in theory, namely the exclusion of inventory cost, could be decisive when looking at the observed speeds. If ship operators include (or are

 $^{^{30}}$ as for example reported in Enders (2010, p. 441)

forced to include) cargo value as a determinant for the vessel speed decision, the observed speeds appear to be more reasonable. However the modification in a regression analysis, inlcuding crude oil price, was not very helpful in identifying some consistency-or inconsistency with theory, as the underlying properties made a systematic statistical analysis inapplicable. Apart from the statistical issues, Devanney (2011)weakens the argument to include inventory costs and points at the non-significance of the cargo value as a speed determinant, stating that "*EEDI Cargo owners are rather cavalier about iventory cost, mostly ingonring them*". Therefore, an exemplary analysis of single ships should give a final impression on the observed speed behaviour.

6.2.4 Single Ship Analysis

The following table gives some further insights on the 3 most frequently observed ships and their mean speeds, the speed range, the according bunker prices and freight rates at the time. "Oil" indicates examples from the set of oil company owned vessel data (only 7 oil company owned ships were observed over the period between AG-JAP), "Other" should indicate data of vessels which are not owned by oil companies (the other 251 vessel).

	Vessel-	no^{31} .	MEAN	MAX	Bunker@Max	FR@max	MIN	Bunker@Min	Fr@Min	Speed Range
	ID									
er	132	15	11.62	12.95	400.50	10.39	8.95	676.50	14.68	4.00
Oth	79	14	12.71	14.13	476.00	8.44	11.65	333.50	12.82	2.49
0	66	14	11.71	13.53	470.50	12.33	10.62	273.00	9.09	2.91
_	62	16	12.21	14.57	495.00	17.19	10.60	281.00	16.78	3.97
0i]	133	8	12.67	14.18	666.50	11.22	9.96	657.50	12.13	4.23
	161	9	12.97	14.65	281.50	10.91	10.31	339.50	10.89	4.35

Table 8: Most frequently observed vessels

It appears that oil company owned vessels seem to sail more simailar to each other, having similar mean speeds and similar speed ranges. Vessel 79 sailed the fastest when freight rates were very low, at around 8 \$ per ton. It does not seem to occur that some vessels sail more rational (in the sense of the basic theory) than others.



Figure 11: Histogram Ship IDs

Figure 11 shows, that there are a a lot of ships which were observed only once or twice and that there are quite some which were observed up to 15 times. The latter indicates that there are maybe more vessels under time charter arrangements than expected. Looking at the most frequent ships, gives a further hint on the suspicion that there are quite some time charter vessels within the observations. The most frequently observed vessels typically sail on the same routes over a certain time period, indicating a time charter arrangement. This result itself gives an explanation for the fact, that speeds might be distorted upwards as a consequence of cargo owner power.

7 Other Explanations & Discussion

Poten & Partners, a global broker and commercial advisor for the energy and ocean transportation industries states as of February 2012:

"The weak freight rate environment in 2011 has seen tanker operators pushing for lower voyage speeds in a bid to cut bunker consumption and increase their earnings. . . 'This past year's tanker market has shown us that even in the non-stop world of global marine transportation there is virtue in slowing down,' said Poten Partners in a report on Friday. 'As low freight rates have been accompanied by high oil prices, tanker owners trading in the spot market have been begrudgingly applying the majority of their voyage revenues towards exorbitant bunker bills.'" (Bunkerworld, 01.02.2012)³²

Manifold quotes alike can be found throughout specialized shipping press and expert opinions. However, when looking at the results of the analysis conducted in this paper, it is doubtful if this logical sounding behavior can be really observed in practice. Tankers sail slow, given that the mean speed in 2011 was 12,09 knots (for non-oil-company owned vessels) and vessels are designed for a speed of 15-16 at calm weathers.³³. But looking at figure 3 again, reveals that this is nothing extraordinary compared to other situations where market conditions were better. Observations registered in the lowest left square for example (indicating the combination of low bunker prices and low freight rates) have the same mean speed (12,07 knots) as mean speed in 2011 (12,09), albeit bunker prices in this square were half as high as the average speed in 2011. This leads to the suspicion that this speed is the lowest VLCC tankers can possibly sail, but according to MAERSK, the word's largest shipping company, super slow steaming speeds of VLCC tankers reach down to 8,5 knots (MAERSK TANKERS, 2012)³⁴. Furthermore, it has to be noted that the observed average speeds per trip do not take into account any port waiting times, which leads to a downward bias of speeds. More specifically speaking, in reality the vessel may go even faster on average. The puzzling thing is not that they go 12 knots on average, but that 12 knots is the average speeds no matter if bunker prices are high or low, dito freight rates.

Why are VLCC vessels observed to sail independent of market conditions? A few thoughts and explanations are given in the following.

Distance Tables

As mentioned in the data descriptions, the data set provided the hours needed per trip, and not average speeds itself. To calculate the average speeds per trip, distance tables were used. Unfortunately, the data did not provide information on the actual sailed distances. This could

 $^{^{32}\}mbox{Available at: http://www.poten.com/Media.aspx?id=21370}$

³³Vessels are built with an extra 15% power sea margin to be able to maintain this desgin speed also in less calm weather conditions (Foreship Ltd., 2009)

 $^{^{34}} Available \ at: http://www.maersktankers.com/Crude/AboutUs/Pages/ShortStories.aspx?SSItemId{=}3$

have led to a distortion because vessels might have sailed longer (or shorter) distances.

But since the distances were taken from one source, if not the levels, the variation in speeds should generally have been representative, given the assumption that the measurement errors are similar for each route. Additionally the most frequent trip (from Ras Tanura to Mizushima) was analyzed separately. Also in this analysis, there was no systematic relationship between speeds, freight rates and bunker prices detectable (Results can be found in Appendix A.5).

Another thought connected to measurement errors from the distance tables is, that vessels could have stopped in Singapore on their way to Japan in order to fill up their tanks. During the period 2006-2011 it occurred that bunker fuel was cheaper in Singapore, (a plot of bunker prices comparison is given in Appendix ??) such that they could have saved costs. On the other hand, filling up the tanks might cost much time which in turn also produces costs. The figure below depicts the route from AG to Japan (in this case Mizushima), where Singapore lies exactly on the way.



Figure 12: Most Frequent VLCC Route observed between 2006-2011

Source: http://www.portworld.com/map/

To take that stop would take some hours, if not even days, which are reported in the trip time and would distort speed calculations. These measurement errors could have led to unreliable speed data, which makes an identifications of a theoretically reasonable systematic behavior very hard. But it has to be kept in mind, that there were around 500 observation over 6 years, which should have made it possible to detect any systematic behavior if present, even if measurement errors can be assumed to have occurred.

Unfavorable Market Conditions 2006-2011 & The Fuel Consumption Curve

As Devanney (2011) puts it in his paper on the discussion of the implementation of the EEDI (Energy Efficiency Design Index),

"At current and likely bunker prices, a well- designed VLCC will be operating at maximum speed only in a full scale boom, less than 10% of the ships life. Most of the time, the ship will be operating at a percentage of full power, often much less than full power."

This statement is perfectly in line with the observations made in the course of this work. The mostly unfavorable market conditions for the tanker market during the years 2006 to 2011 could be another reason for the small amount of variation. As already mentioned in the beginning of this section, the speed range observed, and moreover the mean speeds are located in the already slower part of the possible speed range, which is considered to be slow steaming-speed range. But as mentioned before, there is more downwards variation possible, especially since market conditions were partly really unfavorable, almost at layup-levels. However, the super slow speeds have barely been observed at that time. A closer look at the Fuel Consumption as a function of Speed, gives another insight and possible explanation:



Source: Center for Tankship Excellence 2012 $_{35}$

Figure 13: Fuel Consumption as a Function of Speed

Since the fuel consumption function is exponentially increasing with speed, a decrease in the lowest part of the curve does not have much effect-compared with a speed change at higher speeds. Therefore the shape of the fuel consumption function could be another explanation why vessels might not sail even slower, as the cost benefits from slowing down at the lower part of the speed range are comparably small. Other costs of slowing down, as for example inventory costs might easily have a larger effect (if a welfare maximizing view is taken, counterbalancing shipowners and cargo owners utilities).

Crude Oil Storage Situation

After considering inventory cost as a speed increasing variable, it is worth noting that for this to be decisive, the storage situation for crude oil at destination has to be known. If cargo cannot be sold and used immediately, it has to be stored at destination. If storage is expensive, it might pay out to sail slower in order to pay less for storage, taking the view of a cargo owner. That situation could result in the effect that cargo owners might not push ship operators to sail faster, even if they have relatively high bargaining power. On the contrary, it could occur that they

force them to go even slower if freight rates are low. In extreme cases, cargo owners might even rent VLCCs as storage, given that freight rates are very low. In that case, the vessels can be seen as floating storage and speeds are around zero or very low. As information on the storage situation is hard to obtain systematically, it is (at least in the scope of this work) impossible to include it for a regression analysis, or to sort out vessels which are used as floating storage from any analysis.

Weather And Resistance

Furthermore, weather conditions, basically winds, waves and currents can have significant effects on vessel speeds. Those weather effects mostly increase resistance and require the ship to use higher propulsion power. As a consequence ships sail slower but use an equally high amount of fuel, as if they would use the same propulsion power in calm weather conditions. Resistance is also increased as a consequence of hull fouling, which is a natural matter of time. The figure below depicts vessel speeds as a function of hull fouling.



(Benjamin Pjedsted Pedersen and Jan Larsen, 15.09.2008)

Figure 14: Speed as a Function of Hull Fouling

But given that the VLCC world fleet contains relatively homogeneous vessels (Adland and Strandenes, 2007, p. 197), with similar age, a distortion of speed observations as a consequence of different vessel ages can not be of decisive influence. Furthermore, weather conditions can be considered to be quite random and therefore show no obvious systematics which could be

exploited in an analysis. Therefore weather as a determinant of vessel speed should have no explanatory power as it could be seen as a factor producing random noise in the observations. But maybe this noise is large enough to make all other variables useless.

The issue of whether the vessels under review have been fully loaded is as well connected to vessel speed. A fully loaded VLCC vessel has about 20 meter draft which produces a lot of resistance. Is the vessel only partly loaded, the resistance is reduced and the vessel can either save fuel or go faster. Since there is no information given on the load to the included vessels, speed observations could be partly misleading. This would have resulted probably in an upwards bias, as vessels not fully loaded can go faster with the same fuel consumption as a slower, fully loaded vessel. Additionally they would like to go faster in order to be able to fix the next full load, if possible at respective market conditions. But it is rather hard to set up a specific assumption on this, because partly loaded vessels only occur if the market is down and therefore the assumption that they would go faster in order to get the next full load has to be treated with caution. Generally it is hard to say if partly loaded vessels would really cause an upwards bias, as shipowners could also decide to go as slow as they would do otherwise and just save fuel cost. The latter scenario might even be the more probable one.

Collective Incentives

Looking at the owner distribution of VLCC vessels reveals that some actors could have some market power.



Clarkson Shipping Intelligence Network

Figure 15: Fleet seperated by Ship Owners³⁶

The largest owner, counts 38 VLCC vessels in his fleet. Considering that the size of the whole VLCC fleet is currently at 596 vessels, some actors in the market obviously have some market power, even if not extraordinarily large. If several large owners would cooperate on going slow however, they would reduce the capacity available and hence push up freight rates. As a consequence speeds could be distorted through invisible cooperation initiatives, leading to speeds which look like a train schedule.

Bunker Hedging

Dealing with volatile bunker prices as a main determinant of the cost of a shipowner, brings up the question of whether shipowners hedge their exposure to volatile bunker prices?

If they would successfully do so, they would not be as extremely exposed to the risk from rising bunker prices as they seem to be and could sail with more constant speeds. But according to Mr. Seijling, head of Maersk Tanker,

[..]Hedging bunkers is not the answer to the problem. The fact that bunkers have more than doubled in five years means that owners are unlikely to benefit from a forward hedge. Also, owners only hedge a small part of their bunker requirements because hedging is speculative[...](Lloyds List, 19.03.2012) Another article of The Centre for Global Energy Studies claims furthermore that there exist no standardized, exchange-traded futures contract for fuel oil. Hence it is not possible for a shipping company engaged in spot trading to offset the price risk associated with bunker fuel completely(Global Oil Insight - Industry Watch, 2009). Instead shipowners can hedge their bunker positions with the help of crude oil futures since bunker prices move well along with crude oil prices. However, as also shown before in this work, there is still some difference between bunker prices and crude oil prices which leaves room for risk exposure.

One popular measure seen as hedging risk in the shipping industry, is to put a share of your fleet on time charter. This insures a fixed income over time and shipowners do not have to worry about bunker prices. However, since this analysis focuses on the speed decision, this option is no remedy to the speed decision taker. If a vessel is on time charter, the charter decides on the speed since he has to pay the fuel. As a consequence the problem is just shifted to the charterer. The argument that constant shipping speeds are a result of ship operators successful hedging strategies seems logical at first sight. But according to some industry experts and opinions it is not generally applied. According to Bunkerworld.com, Duncan Jeffcock of V. Ships Marine Fuels blamed shipowners to be reluctant to hedge against bunker risk:

"[..]the risk-taking nature of shipowners means they are reluctant to hedge their exposure to bunker prices despite the benefits (Lloyds List, 19.03.2012).

. However, it is not certain to which extent effective bunker hedging is used by ship owners and charters, but it is an argument which justifies that the observed speeds do not follow changes in bunker prices to some extent.

The above notes provide some explanations to justify the outcomes of this specific analysis of VLCC vessel speeds. It is revealed that one the one hand some measurement errors and omitted variables can have distorted the outcome, even if the extent should not be too large. On the other hand there are some- if not many- explantions which favor the consistency (with optimizing behaviour) of the observed outcomes. In addition to hedging and weather conditions, modern motors with a narrower technical speed ranges and limiting charter party clauses make it more probable, that the observed speeds are a result of speed optimizing behaviour(Adland and Strandenes, 2007). Nevertheless, none of the explanations, including the consideration of the cargo value, can account completly for the resulting unexpected outcomes. Even if there are many uncertain and random variables determining vessel speed, it is still astonishing that VLCC vessel speeds could not be observed to respond to the relative movement of bunker prices and freight rates.

8 Conclusion

In this thesis it was tried to conduct an empirical analysis of vessel speeds in response to bunker prices and freight rate movements. In order to set up an empirical model to test the relationship, first theoretical optimal speed was deduced from a profit maximization model for a vessel under voyage charter. Using a standard OLS regression analysis, the estimation of the resulting relationship implied by theory, could not confirm the significance of the relative movement of bunker prices and freight rates as speed determinants. After an analysis of the data generating processes of the single variables, it was furthermore revealed that the underlying properties challenge an empirical regression analysis, and lead to rather weak results. Following this analysis it can be inferred that an empirical analysis of the form of a regression analysis is not reliably applicable to evaluate the influence of bunker prices and freight rates on vessel speeds.

However, the data analysis indicated that speeds do not respond to market conditions in the way it was implied by the standard theory. Specifically, it could be observed that on the one hand speeds of 14-to 15 knots were regularly observed in periods of high bunker prices and low freight rates. And on the other hand, speeds around 10 knots occurred even if bunker prices were relatively low and freight rates higher. On average, VLCC speeds on the route under review, were observed to be lower than design speed, indicating that Slow Steaming was generally applied, but seemingly without notice of changes in market conditions.

This results gave rise to several suspicions, of which one was that ship owners and charters do not optimize speeds very effectively- and that their behavior rather appears to be a "black box". Yet, the consideration of hedging strategies, restrictive charter party clauses, narrow technical speed ranges of modern motors and the impact of weather conditions qualified this suspicion. Opposed to this, the suspicion that the value of the transported crude oil could force vessels to sail faster than expected, emerged. A theoretic modification considering inventory costs as a an additional speed determinant could show that speeds are pulled in two directions by oil and bunker prices, although they are closely related. This outcome supports an optimizing behavior of speed decision takers in the VLCC tanker market, even if it could not be confirmed by the modifications in the empirical analysis.

Besides, it was dealt with the omission of potentially important variables such as port congestion, storage situation and actual carried weights, which also could have distorted the results. However, the relativizing explanations and all caution of omitted variables and measurement errors could not annihilate the finding that speed is less elastic to bunker price, freight rates and crude oil prices than it was expected from theory, literature and specialized press.

8 Conclusion

As a consequence further research could focus on other possible determinants and analyze the institutional framework and different actors in the shipping industry more closely. Moreover an analysis with information of actual reported speed data from navigation instruments, actual loaded weights and charter modes could give further insights. Above all, an analysis of a longer time horizon covering also situations with very high freight rates and low bunker prices could improve the outcome in the sense of the theory.

If relying on the outcomes of this work, the implication for speed regulation is, that marked based regulations have to be treated with care if the desired outcome - that vessel should use less fuel and hence emissions - should be achieved. When looking at the outcome here, the win-win market conditions do not seem to be so much "win-win" as quite some vessels sail faster no matter how high the bunker price is.

References

- ADLAND, R. AND S. P. STRANDENES (2007): "A Discrete-Time Stochastic Partial Equilibrium Model of the Spot Freight Market," *Journal of Transport Economics and Policy*, 41, 189–218.
- ALIZADEH, A. H. AND N. K. NOMIKOS (2004): "Cost of carry, causality and arbitrage between oil futures and tanker freight markets," *Transportation Research Part E: Logistics and Transportation Review*, 40, 297–316.

(2009): Shipping derivatives and risk management, Basingstoke: Palgrave Macmillan.

- BEENSTOCK, M. AND A. VERGOTTIS (1993): *Econometric modelling of world shipping*, International studies in economic modelling, London: Chapman & Hall.
- BENJAMIN PJEDSTED PEDERSEN AND JAN LARSEN (15.09.2008): "Modeling of Ship Propulsion Performance," .
- BHAR, R., S. HAMMOUDEH, AND M. A. THOMPSON (2008): "Component structure for nonstationary time series: Application to benchmark oil prices," *International Review of Financial Analysis*, 17, 971–983.

BUNKERWORLD (01.02.2012): "2011 Tanker Market Shows 'Virtue' of Slow Steaming," .

- CARIOU, P. (2011): "Is slow steaming a sustainable means of reducing CO(2) emissions from container shipping?" Transportation Research Part D-Transport and Environment, 16, 260– 264.
- CLARKSON (2012): "Clarkson Shipping Intelligence Network," .
- CLARKSON SHIPPING INTELLIGENCE NETWORK (2012): .
- CORBETT, J. J., H. F. WANG, AND J. J. WINEBRAKE (2009): "The effectiveness and costs of speed reductions on emissions from international shipping," *Transportation Research Part D-Transport and Environment*, 14, 593–598.
- COSIMO BEVERELLI AND HASSIBA BENAMARA AND REGINA ASARIOTIS (2010): "Oil Prices and Maritime Freight Rates: An Empirical Investigation,".
- CRAMER, J. S. (1969): Empirical econometrics, Amsterdam: North-Holland.
- DEVANNEY, J. (2009): "The Impact of Bunker Price on VLCC Spot Rates," .
- (2011): "The impact of the energy efficiency design index on very large crude carrier design and CO2 emissions," *Ships and Offshore Structures*, 6, 355–368.

- DICKEY, D. A. AND W. A. FULLER (1979): "Distribution of the Estimators for Autoregressive Time Series With a Unit Root," *Journal of the American Statistical Association*, 74, 427–431.
- ENDERS, W. (2010): Applied econometric time series, Wiley series in probability and statistics, Hoboken and N.J: Wiley, 3 ed.
- FORESHIP LTD. (2009): "SOME IMPORTANT NAVAL ARCHITECTURAL TERMS," .
- GLOBAL OIL INSIGHT INDUSTRY WATCH (2009): "Hedging shipping's fuel costs," .
- GRANGER, C. W. J. AND P. NEWBOLD (1974): "Spurious regressions in econometrics," *Journal* of *Econometrics*, 2, 111–120.
- GREENE, W. H. (2012): *Econometric analysis*, Upper Saddle River and N.J: Prentice Hall, 7 ed.
- GUJARATI, D. N. (1995): Basic econometrics, New York: McGraw-Hill, 3 ed.
- GÜLEN, S. G. (1998): "Efficiency in the crude oil futures market," Journal of Energy Finance & Development, 3, 13–21.
- HAMILTON, J. D. (1994): Time series analysis, Princeton and N.J: Princeton University Press.
- HARILAOS N. PSARAFTIS AND CHRISTOPH KONTOVAS (2009): "Speed Reduction as an Emission Reduction Measure for Fast Ships," .
- HAYASHI, F. (2000): Econometrics, Princeton and N.J: Princeton University Press.
- HOTELLING, H. (1931): "The Economics of Exhaustible Resources," Journal of Political Economy, 39, 137–175.
- IMO (03.06.2011): "PREVENTION OF AIR POLLUTION FROM SHIPS: Example of a Ship Energy Efficiency Management Plan: Submitted by Oil Companies International Marine Forum (OCIMF," .
- INTERNATIONAL MARITIME ORGANIZATION (2010): "IMO and The Environment," .
- JOHN VIDAL (13.02.2008): "True scale of CO2 emissions from shipping revealed,".
- KONTOVAS, C. AND H. N. PSARAFTIS (2011a): "Reduction of emissions along the maritime intermodal container chain: operational models and policies," *Maritime Policy & Management*, 38, 451–469.

- KONTOVAS, C. A. AND H. N. PSARAFTIS (2011b): "The link between economy and environment in the post-crisis era: lessons learned from slow steaming," *International Journal of Decision Sciences, Risk and Management*, 3, 311–326.
- KUMAR NARAYAN, P. AND R. SMYTH (2007): "Are shocks to energy consumption permanent or temporary? Evidence from 182 countries," *Energy Policy*, 35, 333–341.
- LLOYDS LIST (19.03.2012): "Cost-Cutting Shipowners Compromise Tanker Safety," .
- MAERSK (21.12.2011): "Slow steaming: The Full Story," .
- MAERSK TANKERS (2012): "Slowing down speeds up cost-savings," .
- MAN (2009): "Propulsion Trends in Tankers,".
- MASLYUK, S. AND R. SMYTH (2008): "Unit root properties of crude oil spot and futures prices," Energy Policy, 36, 2591–2600.
- MCQUILLING SERVICES (2011): "No. 11 Flat Rate Forecast," .
- NORMAN, V. AND WERGELANDTOR (1979): "Oil Prices and World Shipping,".
- NORSTAD, I., K. FAGERHOLT, AND G. LAPORTE (2011): "Tramp ship routing and scheduling with speed optimization," *Transportation Research Part C-Emerging Technologies*, 19, 853– 865.
- NOTTEBOOM, T. E. AND B. VERNIMMEN (2009): "The effect of high fuel costs on liner service configuration in container shipping," *Journal of Transport Geography*, 17, 325–337.
- PINDYCK, R. S. (1999): "The long-run evolution of energy prices," Energy Journal, 20, 1–27.
- POSTALI, F. A. S. AND P. PICCHETTI (2006): "Geometric Brownian Motion and structural breaks in oil prices: A quantitative analysis," *Energy Economics*, 28, 506–522.
- PSARAFTIS, H. N. AND C. A. KONTOVAS (2011): "Balancing the economic and environmental performance of maritime transportation (vol 15, pg 458, 2010)," *Transportation Research Part D-Transport and Environment*, 16, 270–271.
- RONEN, D. (1982): "THE EFFECT OF OIL PRICE ON THE OPTIMAL SPEED OF SHIPS," Journal of the Operational Research Society, 33, 1035–1040.
- (2011): "The effect of oil price on containership speed and fleet size," Journal of the Operational Research Society, 62, 211–216.

- STEEN, K., A. ROAR, AND S. SIGBJØRN (2006): "Are Spot Freight Rates Stationary?" Journal of Transport Economics and Policy, 40, 449–472.
- STOPFORD, M. (2009): Maritime economics, London: Routledge, 3 ed.
- STUDENMUND, A. H. (2011): Using econometrics: A practical guide, Boston: Pearson, 6 ed.
- SVENNING, S. B. (2007): "Slow Speeds Ahead!" .
- UNITED NATIONS CONFERENCE OF TRADE AND DEVELOPMENT (2011): "Unctad Review of Maritime Transport 2011," Unctad Review of Maritime Transport.
- WHITE, R. (2010): "Ocean shipping lines cut speed to save fuel costs: 'Slow steaming' upsets some customers, who worry about delays in delivery. But it also keeps more ships in service and lowers emissions.".
- WORLDSCALE.CO.UK (????): "Introduction to Worldscale Freight Rate Schedules," .

APPENDIX

A Further Regression Results

A.1 OLS on logs of weekly Data without Intercept

A.1.1 REG1: Distance Included

	Estimate	Std. Error	t value	$\Pr(> t)$	
lfr	0.0031	0.0142	0.22	0.8297	
lfujbunk	0.0119	0.0176	0.68	0.4994	
ldist	0.2770	0.0119	23.31	0.0000 ***	
Residual standard error: 0.09584 on 309 degrees of freedom					
Multiple R-squared: 0.9986,					
Adjusted R-squared: 0.9985					

F-statistic: 7.13e+04 on 3 and 309 DF, p-value: < 2.2e-16

Signif. codes: $0 * * * 0.001 * 0.01 *$	0.05 .
---	--------

Table 9: OLS on Logs of Weekly Data Without Intercept



Figure 16: ACF of Residuals REG1

A.1.2 REG2:	Distance	Excluded
-------------	----------	----------

	Estimate	Std. Error	t value	$\Pr(>\! t)$
lfr	0.0338	0.0235	1.44	0.1511
lfujbunk	0.3991	0.0102	39.19	0.0000
Residual stand	ard error:0.15	693 on 310 degr	ees of freed	om
Multiple R-squ	ared: 0.996			
Adjusted R-sq	uared: 0.996			
F-statistic: 3.866e+04 on 2 and 310 DF, p-value: $<$ 2.2e-16				
Signif. codes:	0 ***	0.001 **	0.01 *	0.05 .

Residuals of Regression without Intersept & Distance



Figure 17: ACF of Residuals REG2

As obvious from the two regression results above, the R^2 is extremely high. In the first regression the distance accounts for a large share of explanatory power, but still the logs of bunker prices and freight rates exhibit no significance. If the logs of the distance are excluded, the picture changes and logs of bunker prices seem to be significant, but a look at the acf of the residuals shows that the results are spurious.

Regression Including differenced Bunker Prices

	Estimate	Std. Error	t value	$\Pr(> t)$
(Intercept)	-6.8047	2.1472	-3.17	0.0017 ***
dlfujbunk	0.2037	0.1087	1.87	0.0618^{*}
nlfr	0.0018	0.0130	0.14	0.8900
nldist	1.0618	0.2449	4.34	0.0000***

Residual standard error: 0.09015 on 307 degrees of freedom

Multiple R-squared: 0.07052

Adjusted R-squared: 0.06144

F-statistic: 7.764 on 3 and 307 DF, p-value: 5.162e-05 $\,$

Signif. codes:	0.001^{***}	0.01^{**}	0.05 *	
----------------	---------------	-------------	--------	--

Table 10: Log-Difference Regression

A.1.3 Regression on Differences of All Variables

	Estimate	Std. Error	t value	$\Pr(> t)$	
(Intercept)	-0.0007	0.0068	-0.11	0.9123	
dlfujbunk	0.1519	0.1431	1.06	0.2893	
dlfr	0.0212	0.0485	0.44	0.6623 ***	
0.1143 on 307 degrees of freedom					
Multiple R-squared: 0.08334					
Adjusted R-squared: 0.07438					
F-statistic: 9.304 on 3 and 307 DF, p-value: $6.616e-06$					
Signif. codes:	0.001***	0.01**	0.05 *		

Table 11: Regression on Differences

	Estimate	Std. Error	t value	$\Pr(> t)$	
(Intercept)	-7.1891	1.4880	-4.83	0.0000***	
ltfr	-0.0021	0.0121	-0.17	0.8642	
ltbunker	0.0073	0.0151	0.48	0.6287	
ltdistance	1.1013	0.1685	6.54	0.0000 ***	
Residual standard error: 0.1088 on 569 degrees of freedom					
Multiple R-squared: 0.0699					
Adjusted R-squared: 0.06499					
F-statistic: 14.25 on 3 and 569 DF, p-value: 5.746e-09					

0.01**

0.05 *

A.2 OLS on logs of Trip Data

A.3 OLS on NON-OII Including Dummies

Signif. codes:

	Estimate	Std. Error	t value	$\Pr(> t)$
(Intercept)	2.3316	0.1322	17.64	0.0000***
dummy	0.2852	0.3491	0.82	0.4146
lfr	0.0162	0.0180	0.90	0.3686
lfujbunk	0.0209	0.0254	0.82	0.4103
dummy:lfujbunk	-0.0448	0.0556	-0.81	0.4202

Residual standard error: 0.09506 on 307 degrees of freedom

Multiple R-squared: 0.01064

Adjusted R-squared: -0.00225

F-statistic: $0.8255 \ \mathrm{on} \ 4$ and 307 DF, p-value: 0.5097

 0.001^{***}

Signif. codes:	0.001^{***}	0.01^{**}	$0.05 \ *$	
----------------	---------------	-------------	------------	--

	Estimate	Std. Error	t value	$\Pr(> t)$
(Intercept)	-7.3566	2.2081	-3.33	0.0010 ***
lfujbunk	0.0146	0.0353	0.41	0.6801
ldist	1.1144	0.2493	4.47	0.0000 ***
lbrent	0.0013	0.0426	0.03	0.9765
Residual standard error: 0.09057 on 308 degrees of freedom				

A.4 OLS including Crude Oil Prices (BRENT) and excluding Freight Rates

Multiple R-squared: 0.06097

Adjusted R-squared: 0.05183

F-statistic: 6.667 on 3 and 308 DF, p-value: 0.0002251

Signif. codes:	0.001^{***}	0.01^{**}	0.05 *	
----------------	---------------	-------------	--------	--

A.5 OLS using only Speed data from trips to Mizushima

	Estimate	Std. Error	t value	$\Pr(> t)$	
(Intercept)	11.0460	0.4227	26.13	0.0000 ***	
m.fujbunk	0.0017	0.0011	1.54	0.1263	
m.fr	-0.0129	0.0172	-0.75	0.4563	
Residual standard error: 1.427 on 146 degrees of freedom					
Multiple R-squared: 0.01594					
Adjusted R-squared: 0.002464					
F-statistic: 1.183 on 2 and 146 DF, p-value: 0.3094					
Signif. codes: 0.001*** 0.01** 0.05 *					

B Dickey Fuller Test

B.1 Dickey Fuller Test Procedure

The condition for a autoregressive process to be stationary (and to fulfill the above requirements) is that its characteristic unit roots lie within the unit circle³⁷. That means that exogenous shocks will die out over time and the the series will convert to its long term mean again (Enders, 2010, p. 189).

³⁷to see a more detailed explanation see Enders (2010)[p. 55]
Considering an autoregressive process of order (AR(1))

$$y_t = a_0 + a_1 y_{t-1} + \varepsilon_t \tag{19}$$

(where ε_t = white noise) The null hypothesis of the Dickey Fuller test is, if $H_0: a_1 = 1$. Using an equivalent presentation of the above process(Enders, 2010)[p. 206]:

$$\Delta y_t = \gamma y_{t-1} + \varepsilon_t \tag{20}$$

where

$$\gamma = a_1 - 1 \tag{21}$$

the hypothesis is H_0 : $\gamma = 0$, which means that the process has a unit root. Dickey and Fuller (1979) consider three different equations, which specify furthermore if the process includes deterministic terms such as a time trend or a drift term or both (Enders, 2010)[p. 206]:

$$\Delta y_t = \gamma y_{t-1} + \varepsilon_t \tag{22}$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t \tag{23}$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \varepsilon_t \tag{24}$$

The corresponding critical values depend on the model specification which is used to describe the process under consideration. It is decisive if the process includes any deterministic terms or not. There is no mechanical procedure which can be used to determine whether the process has a unit root or not, therefore it is important to look at the data to obtain more details about the presence of deterministic regressors. It has to be noted that the same critical values can be applied if the above process includes more lags.Dickey and Fuller (1979) also derived F values for a joint hypothesis on whether the process includes unit roots and trend or/and drift terms.

B.2 Unit Root Test Results

B.3 Dickey Fuller Test Results for Freight Rates

B.3.1 Including Trend and Drift

Model	Hypothesis	Test Statistic	Crit Value $95^{38}\%$
$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \varepsilon_t$	$\gamma = 0$	-4.69581	-3.42
	$\gamma = a_2 = 0$	7.3528	4.71
	$\mathbf{a}_0 = \gamma = a_2 = 0$	11.0287	6.30

Note: the lag length of the model in the test equation is determined by the Bayes information criteria

Table 12: Augmented Dickey Fuller Results for Freight Rates

B.3.2 Dickey Fuller Test for Freight rates 1998-2011

Model	Hypothesis	Test Statistic	Crit Value $95^{39}\%$
$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-6.4131	-2.86
	$\mathbf{a}_0 = \gamma = a_2 = 0$	20.5671	4.59

Note: the lag length of the model in the test equation is determined by the Bayes information criteria

Table 13: Augmented Dickey Fuller Results for Long Freight Rates

B.4 Dickey Fuller Test Results for Bunker Prices

B.5 Model Including Trend and Drift

Model	Hypothesis	Test Statistic	Crit Value 95%
$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \varepsilon_t$	$\gamma = 0$	-1.8507	-3.42
	$\gamma = a_2 = 0$	1.7196	5.36
	$\mathbf{a}_0 = \gamma = a_2 = 0$	1.442	4.71

Table 14: (Augmented)Dickey Fuller Test incl. Trend and Drift for Logs of Bunker Prices

B.6 Brent Unit Root Tests

Model	Hypothesis	Test Statistic	Crit Value 95%
$\Delta y_t = a_0 + \gamma y_{t-1} a_2 t + \varepsilon_t$	$\gamma = 0$	-1.9538	-3.42
	$\gamma = a_2 = 0$	1.9159	6.30
	$\mathbf{a}_0 = \gamma = a_2 = 0$	1.3426	4.71
$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-1.8123	-2.87
	$\gamma = a_0 = 0$	1.7405	4.61

Table 15: (Augmented)Dickey Fuller Test incl. Drift for Logs of Brent Crude Oil Prices

B.7 Unit Root Test for Differenced Brent Crude Oil Prices

Model	Hypothesis	Test Statistic	Crit Value 95%
$\Delta y_t = \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-12.2065	-3.42

Table 16: (Augmented)Dickey Fuller Test incl. Drift for Differenced Logs of Brent Crude Oil Prices

B.8 Unit Root Test for Differenced Bunker Prices

Model	Hypothesis	Test Statistic	Crit Value $95^{40}\%$
$\Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-11.3481	-2.87

Note: the lag length of the model in the test equation is determined by the Bayes information criteria

Table 17: Augmented Dickey Fuller Test for Differenced Logs of Bunker Prices

B.9 Engle Granger 2 step Cointegration Results

Using the residuals of the following regression

$$P_O = \beta_0 + \beta_1 P_B + \varepsilon \tag{25}$$

for an ADF test, gives the following results:

Model	Hypothesis	Test Statistic	Crit Value $95^{41}\%$
$\Delta y_t = \gamma y_{t-1} + \varepsilon_t$	$\gamma = 0$	-3.0622	-1.95

Note: the lag length of the model in the test equation is determined by the Bayes information criteria

Table 18: Augmented Dickey Fuller Test for Residuals of Cointegration Relationship

C Plots





Figure 18: Logs of Weekly Speeds 2006-2011

C.2 Logs of Weekly Freight Rates



Figure 19: Logs of Weekly Freight Rates 2006-2011



C.3 Logs of Weekly Fujairah Bunker Prices

Figure 20: Logs of Weekly Bunker Prices 2006-2011

D OLS Assumptions

D.0.1 OLS-Assumptions

The following list of assumptions of the Linear Regression Model is based on Greene (2012)[p.56]

A1: Linearity

The regression model is assumed to be linear of the form:

$$y = X\beta + \epsilon \tag{26}$$

where y is the vector of n dependent variable observations, X is the regressor matrix of $n \times k$ explanatory variable observations and ϵ is the column vector of n disturbances.n denotes the number of observations and k the number of regressors. This does not necessarily mean that the underlying theoretical relationship between the variables has to be linear, but the regression equation has to be linear. In the case at hand the original theoretical relationship between the variables is transformed through taking logs, which leads to a log-linear model, where coefficients can be interpreted as the elasticities of y with respect to changes in x.

A2:Full Rank

It is assumed that there is no exact linear relationship among the explanatory variables and consequently the matrix X has rank K. This assumption is supposed to hold, since neither of the combinations between bunker prices, freight rates and distances can be assumed to be perfectly collinear. Note however, that there might exist some kind of multicollinearity between the explanatory variables. Given the fact, that freight rates reflect a price for the supply of shipping, and bunker fuel costs are the variable costs determining that price to some extent (Steen et al., 2006), it seems logical that freight rates are somehow related to bunker prices. There exists furthermore some literature on the empirical relationship between freight rates and oil prices, which shows that there is a correlation between those two variables (Cosimo Beverelli and Hassiba Benamara and Regina Asariotis, 2010)[p.15]. Since it can be assumed that bunker prices in return are strongly correlated to oil prices, it makes sense to look at the correlation between weekly bunker prices and freight rates:

$$Cor(P_B, R) = 0.2462101(27)$$

It seems that this should however not lead to severe multicollinearity problems and hence this assumption should hold.

A3:Exogeneity of the independent variables

The disturbance term is assumed to have a zero conditional mean on every observation i:

$$E\left[\epsilon_i|X\right] = 0\tag{28}$$

This means that the errors are drawn from a random distribution with a zero mean and that there is no information in x on the expected value of the disturbances. The conditional zero mean implies also an unconditional zero mean of errors (Greene, 2012, p. 60). Including a constant term in the regression equation, as it is already suggested in the model proposed above, leads to a zero expected value of the disturbances. For more details see Studenmund (2011); Greene (2012)

A4: Homoscedasticity and Non Autocorrelation Under the fourth assumption the variance of the errors are constant over time, or if not applied to a time series, the variances of the errors are constant for each observation i.

$$Var[\epsilon_i|X] = \sigma^2,$$

for all i = 1, ..., n(29)

I do not see any theoretic a priori reason why the homoscedasticity assumption for the disturbances should be violated at first sight. But to get a more precise picture on that issue the residuals of the specific estimations can also be analyzed as an indicator, as the actual disturbances cannot be observed in practice. Since I am dealing with time series data, the assumption of no autocorrelation is more critical. This implies that the disturbances are not correlated with each other.

$$Cov\left[\epsilon_i, \epsilon_j | X\right] = 0,$$

for all $i \neq j(30)$

If disturbances are autocorrelated, the OLS estimator is no longer efficient, and the coefficient of determination will be biased (Studenmund, 2011). As a consequence hypotheses testing might be unreliable.

A5: Data Generating process

The data generating process is assumed to be either fixed or random. If the data set used for the present analysis is assumed to be random, assumptions 3 and 4 are conditional on X.

A6: Normality Additionally it is assumed that the disturbances are normally distributed, with zero mean and constant variance:

$$\epsilon \mid N \left[0, \sigma^2 I \right] \tag{31}$$

where I denotes the identity matrix.

E Note On Programming Code

The statistical analyses were conducted in R. R is a software environment for statistical computing and graphics. For further information, please see http://www.r-project.org/. The data was filtered and prepared for the statistical analysis with Excel. The complete R code, as well as the data transformation is available upon request by mail: s106522@stud.nhh.no.

Most important Unit Root Test Commands and Regression commands are listed below.

```
################FUJAIRAH BUNKER PRICES######
```

```
##MODEL WITH TREND####
urt.lfujbunk=ur.df(lfujbunk, type="trend",selectlags="BIC")
summary(urt.lfujbunk)
```

```
##MODEL WITH DRIFT##
urd.lfujbunk=ur.df(lfujbunk, type="drift",selectlags="BIC")
summary(urd.lfujbunk)
```

```
##NO TREND NO DRIFT##
urnone.lfujbunk=ur.df(lfujbunk, type="none",selectlags="BIC")
summary(urnone.lfujbunk)
```

```
urt.dlfujbunk=ur.df(dlfujbunk,type="drift",selectlags="BIC")
summary(urt.dlfujbunk)
##--> I(1)
```

```
##MODEL WITH TREND & INTERCEPT##
urt.lfr=ur.df(lfr, type="trend",selectlags="BIC")
summary(urt.lfr)
```

```
urd.lfr=ur.df(lfr,type="drift", selectlags="BIC")
summary(urd.lfr)
```

```
urd.lbrent=ur.df(lbrent, type="drift", selectlags="BIC")
summary(urd.lbrent)
```

```
urn.lbrent=ur.df(lbrent, type="none", selectlags="BIC")
summary(urn.lbrent)
```

```
#########LONG weekly FReight RATES (1998-2012)
vlfr=read.csv2("vlfr.csv",header=T)
vlfr=interpNA(vlfr ,method="before")
vlfr
lvlfr=log(vlfr)
length(vlfr)
plot.ts(vlfr)
##Levels
urt.vlfr=ur.df(vlfr,type="trend",selectlags="BIC")
summary(urt.vlfr)
urd.vlfr=ur.df(vlfr,type="drift",selectlags="BIC")
summary(urd.vlfr)
##Logs
urt.lvlfr=ur.df(lvlfr,type="trend",selectlags="BIC")
summary(urt.lvlfr)
urd.lvlfr=ur.df(lvlfr,type="drift",selectlags="BIC")
summary(urd.lvlfr)
REGRESSIONS
#
                                  #
####DIFF Regs########
regw.diff1=lm(dlspeed~dlfujbunk+dlfr)
summary(regw.diff1)
xtable(regw.diff1)
regw.diff2=lm(dlspeed \sim dlfujbunk + dlfr + dldist) \# Including distances
summary(regw.diff2)
regw.diff3=lm(nlspeed~dlfujbunk+nlfr+nldist)
summary(regw.diff3)
xtable(regw.diff3)
regw.diff4=lm(nlspeed~dlfujbunk+nlfr)
summary(regw.diff4)
regw1=lm(lspeed~lfr+lfujbunk+ldist)
```

```
summary(regw1) #Nightmare
resw1=residuals(regw1)
plot(resw1,ylab="Residuals")
par(mfrow=c(2,1))
plot(resw1)
plot(lspeed)
```