Exploring the link between oil prices and tanker rates

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Given the secular and sharp rise in oil prices over the past decade, this study analyses the impact that the spike in oil prices has on tanker rates. We investigate a dynamic model explaining spot tanker rates. The magnitude of the impact of oil prices on the shipping industry, in terms of the level and volatility of spot (voyage) under bull and bear market conditions. The West African–US Gulf Tanker Rates, West Texas Intermediate spot and 3-month futures contract, and US Weekly Petroleum Inventories are analysed using cointegration and Granger causality analysis, from 1997 through 2007, in order to examine the lead–lag relationship between oil prices and tanker freight rates. Our findings show a relationship between spot and future crude oil prices, crude oil inventories and tanker rates. The significant increase of freight rates, and the simultaneous increase in oil prices, during the recent years, provides an intriguing economic environment to identify relationships between shipping market rates and oil prices. These relationships have significant implications for the markets. At the practical level, the better understanding of the relationship between freight rates and crude oil prices can improve operational management and budget planning decisions.

1. Introduction

Oil is the paramount energy source in the global economy and its pricing has profound macroeconomic, political and social effects. An important element of the world oil market is the tanker industry, which moves oil from producer areas to consumer markets. Spot tanker prices are strongly influenced by the crude oil market, specifically spot prices, future contract prices, and petroleum inventories.

Crude oil is commodity traded on global markets. It is subject to relative demand shifts from economic growth globally and by regions. Supply disruptions and shocks in oil exporting countries lead to price volatility. The pricing of crude and petroleum products reflects changing supply and demand including the impact of special entities such as OPEC and even Russia. The final end use price depends on production costs, refining, marketing, and transportation costs of crude oil and petroleum products from producing countries to consumer markets.

In the US, about one-fourth of all energy consumption is for transportation. This is almost entirely supplied by petroleum products. In fact, three-quarters of petroleum consumption is related to transportation and is expected to increase over
the next 25 years [1]. Motor gasoline is about 50%, diesel or distillate fuel about 15%, and jet fuel about 10%.

Our study focuses on the relationship between spot tanker rates, crude oil prices and inventories in the US for shipping from West Africa to the US Gulf between 1998 and 2005. We use the Baltic dirty tanker index for very large crude carriers (VLCCs), the spot West Texas Intermediate Crude Oil Price, the NYMEX future contract 3, and crude oil stocks in the analysis. The frequency of observations is the closing price for each week on the Baltic index.

West Africa contributed about 14% of the US total petroleum products imported in 2004. This was about 1.6 million barrels per day and 8% of total consumption. Over 95% came from three countries: Nigeria, Angola and Gabon. West Africa is expected to become an even more important source of imports in the future increasing deep water off-shore oil production in the region. Also, rising demand for oil by southern and eastern Asia is likely to come from the Middle East.

Our results suggest that the spot tanker market is related to the intertemporal relationship between current and future crude oil prices, such that relatively higher expected prices put upward pressure on spot tanker rates. In addition, higher inventories and movements in inventories put downward pressure on spot tanker rates.

This paper is structured into five further sections. We begin with a brief description of the literature on the tanker market and its relationship with the oil market in Section 2. Next, the data series used in the analysis is presented. The fourth section describes the economic model and econometric methodology. In the fifth section, we present the empirical results from the analysis. This is followed by a discussion of the results and the conclusion.

2. A review of the relationship between the tanker and oil markets
There is a long history of research examining the determinants of tanker prices and their relationship oil prices [2–11]. Kavussanos and Alizadeh-M [12] and Kumar [13] provide a good discussion of the tanker market supply and demand determinants.

The quest for understanding tanker price movements has become more significant because, of the substantial rise in oil tanker prices. Poten & Partners (2004a), a leading ship broker in New York, have noted that VLCC rates are at the highest they have been in over 10 years. Tanker rates, which averaged less than 40 Worldscale (WS) in July 2002 and WS 50 in July 2003, jumped up to a far higher average in the mid-100 WS range in July 2004. According to Poten & Partners, the factors which have put upward pressure on the VLCC, Aframax and Suezmax market have been increased oil demand by the developing economies, especially India and China.

Since transportation costs are a component added cost to the oil, their prediction is important to forecasting the all-in cost of oil at the port of debarkation. The current study demonstrates that the variation of tanker rates is due to the price of oil carried, and 40% is due to other factors, thus it can be observed that excluding seasonal periods of low tanker demand due to refinery maintenance there has been a general increase in tanker rates consistent with the price of oil.

Other factors which have impacted the pricing of the oil and tank ships over the past few years include the strength of the US economy, increasingly turbulent weather including the disruption of Gulf Port facilities by a series of hurricanes such as Hurricanes Katrina, Charles, Frances and Ivan, the reduction of Iraqi oil production due to disruptions in Niger and legal problems of Yemen. On the oil side, we just the first and second in 14 years, at 82.2 data, with demand

A complete picture would include refer to October of 2004, VIX, fixture activity was at the change in expected. More specifically, the exports generated a key role.

Kavussanos [16] conditional means is high during and just before the 1973–1974 Iraq. He finds a positive freight rates for the oil market, indicate that there is a positive relationship between the two markets.

These findings are consistent with the idea that demand for oil and oil tankers is elastic and that the demand for oil is pro-cyclical. This study looks at the demand for oil and oil tankers and finds that an upward shift in the demand for oil is due to an upward shift in the demand for oil tankers.

3. The data
We focus on the spot market for oil in the US. The sample period is from January 2005 to January 2006. We define the spot market as the market in which oil is bought and sold on a short-term basis. The West Africa–Mexico route is an important one for both oil and tankers.
Exploring the link between oil prices and tanker rates

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3. The data
We focus on the spot oil tanker market between West African and the US Gulf of Mexico. The sample period for our analysis is from 16 January 1998 through 2 January 2006. We use the last trading closing in each week on the Baltic exchange which yields a total of 409 observations. Table 1 provides a list of the data series with acronyms, descriptions, units and sources.

The West Africa–US Gulf Tanker spot price on the World Scale index (BDT14) was obtained from the Baltic Exchange. The Baltic Exchange reports the
### Table 1.

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Description</th>
<th>Units</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBDT14</td>
<td>Log Baltic Dirty Tanker Index TD4: 260,000mt, West Africa to US Gulf</td>
<td>Index</td>
<td>Baltic Exchange</td>
</tr>
<tr>
<td>LRCLC3</td>
<td>Log Cushing, Ok Crude Oil Future Contract 3</td>
<td>$/Barrel</td>
<td>NYMEX</td>
</tr>
<tr>
<td>LRWTC</td>
<td>Log West Texas Intermediate Spot Price</td>
<td>$/Barrel</td>
<td>Futures prices</td>
</tr>
<tr>
<td>LWCESTUS1</td>
<td>Log US Weekly Crude Oil Ending Stocks Excluding SPR</td>
<td>1000s of Barrels</td>
<td>EIA</td>
</tr>
<tr>
<td>SP_WTI3</td>
<td>Spread between WTI Spot Price and 3-mo Future Contract</td>
<td>$/Barrel</td>
<td>NYMEX</td>
</tr>
<tr>
<td>WCESTUS1</td>
<td>U.S. Weekly Crude Oil Ending Stocks Excluding SPR</td>
<td>1000s of Barrels</td>
<td>EIA</td>
</tr>
</tbody>
</table>

Note: A capital "D" in the beginning of a variable means that it has been transformed into natural logarithms.

transactions from a number of different indices for the tanker market. The base year for this index is 1998. The West Texas intermediate crude spot price (RWTC) and 3-month futures contract rates (RCLC3) in dollars per barrel were obtained from Bloomberg, the New York Mercantile Exchange, and the Energy Information Agency. The US weekly petroleum inventories in 1000s of barrels (WCESTUS1) are provided by the Energy Information Agency. Unless otherwise indicated, we have transformed all series into natural logarithms for the analysis.

Figure 1 charts the three price series. The first chart is the Baltic Dirty Tanker Index. Spot prices were stagnant and falling in 1989 and 1999. They tripled in 2000 before falling to their previous level; There is a 9/11 effect, which lasts until about the fourth quarter of 2002. Then spot prices begin a roller-coaster ride with cycles of near tripling and falling in prices. Prices peaked in November 2004. These peaks coincided with periods when OECD commercial inventories were below their 5-year average band. Forward cover, days' supply dropped below 50 days in these periods. The volatility of prices appears to have increased in this period. It appears that at the end of the 1990s, oil demand was depressed by recessionary economic conditions in Western Europe and Japan, compounded by the increasing calls for using alternative energy sources (nuclear power, hydroelectric power, coal). Subsequently, oil prices increased on the basis of a large shift in demand for oil imports by industrializing China and India and heightened demand by the US. The increased demand effect was compounded by oil supply disruptions and shortfalls in Venezuela, Nigeria and later the invasion and occupation of Iraq.

The second and third charts show the WTI spot price and the 3-month contract price. We observe similar patterns in the movements in oil prices and tanker price. The collapse of oil prices is seen in 1998 followed by a gradual rise through 2000. Who can recall oil prices at $11-$12/barrel in January through March of 1999? Prices had recovered to the $25 to $30 range by the end of 2000. There is a collapse in prices following 9/11 to about $20 through early 2002. Then they rise to above $30 and have peak in the winter of 2003 when inventories were critical. Prices then began the climb to above $30 in October 2004.

Since the American invasion in the Middle East. Uncertainty a hallmark of the oil
market. The base year at price (RWTC) and I were obtained from Energy Information (WCESTUS1) are se indicated, we have:

Baltic Dirty Tanker. They tripled in 2000 h lasts until about the er ride with cycles of er 2004. These peaks are below their 5-year days in these periods. It appears that at the wonomic conditions in s for using alternative bsequently, oil prices ors by industrializing seased demand effect enezuela, Nigeria and the 3-month contract ces and tanker price. al rise through 2000. ugh March of 1999? There is a collapse in hey rise to above $30 cal. Prices then began

Since the American invasion and occupation of Iraq in 2002, there has been a steady increase in oil prices because of shortfalls in Iraqi oil (destabilization of the Middle East). Uncertainty about the stability and security of supply has been a hallmark of the oil market since 2000. Exacerbating the impact of Iraq has been

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**Figure 1.**
a series of exceptionally destructive hurricanes, especially in the US Gulf Region, an unprecedented tsunami which especially impacted the oil country of Indonesia, and production cutbacks occasioned by the arrest of the CEO of Russia's largest oil company, Yukos. The equilibrium price of oil also reflects the interaction of supply and demand. Supply is the result of production from existing wells plus intensified extraction from those wells plus production of new wells.

Figure 2 contains the US Weekly Inventory measure. Through mid 1999 inventories were above 330MB. They decline dramatically and remain about 290 MB through 2000. The recession in 2001–2002 may have lead to the expansion of inventories back up to about 310 MB. Economic growth domestically and internationally and higher prices may have lead to the decline in inventories back under 300 MB in 2003 and 2004. Speculators and the convenience yield led to the increase in inventories through 2005. Prices had risen from $45 to over $65 per barrel and the futures market was geared toward higher prices.

In Figure 3, a comparison is given of the trend and dynamics for West Africa–US Gulf Tanker Rates and the West Texas Intermediate Spot Price, which are graphically displayed. The former is on the left-hand scale and the later is on the right-hand scale. The two prices appear to move together cyclically and in relative levels following the discussion above. There appears to be far greater volatility in the Baltic Dirty Tanker Index than oil prices. This might be driven by other demand and supply factors. One example might demand side effects from actual inventory levels and (future) desired inventory levels. Second, on the supply side there is tanker capacity. This depends on current capacity plus added new tankers minus older tankers scrapped. We were unable to obtain a measure or proxy of capacity, so our results are conditioned upon this fact.

In the earlier part of the period, the two rates fluctuate reflecting the impact of higher oil prices on tanker prices which makes sense from the viewpoint that higher oil prices would generally reflect to some degree a shortage of tanker capacity for the demand level. However, after 2002, the relationship diminishes as oil prices increase steadily while tanker rates are highly volatile. It may be that by 2002 the tanker industry had adjusted much higher plateaus including some major market having entailed heightened Middle East production levels in the Arabian Gulf area, where

Figure 4 contains the US Weekly Petri index to 2005. There is a significant and US Gulf tanker market where inventories are the tanker spot rate current and future which translates pairs process based on which can raise their rates supply and also the because of the will between the tanker between tanker price mean higher prices for the oil price. That conversely, high oil import prices.
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Industry had adjusted more slowly than the oil market. Oil prices had moved to a much higher plateau, and the tanker market entered a period of high volatility including some major price cuts. Additional upward pressure on tanker rates was the market having entered a period of higher level of political/military risks due to heightened Middle Eastern instability, pushing up the rates was a significant increase in maritime insurance rates due to the perception of heightened risk, especially in the Persian Gulf area, where tankers would naturally congregate.

Figure 4 contains a chart of the West African–US Gulf of Mexico tanker rates and US Weekly Petroleum inventories are shown on a log basis for the period 1998 to 2005. There is a strong and consistent inverse relationship between West Africa and US Gulf tanker rates and US weekly petroleum inventories. We observe that when inventories are high, tanker spot rates are low, and, when inventory is down, the tanker spot rate goes up. Lower inventories, would suggest upward pressure on current and future oil prices. Low inventories can indicate a strong demand for oil which translates partially into higher tanker rates. Tanker rates reflect an auction process based on changing supply and demand. When oil prices are high the tankers can raise their rates because the higher oil price in part reflects a scarcity of tanker supply and also the tanker price is essentially inelastic in time of high demand because of the willingness of shippers to pay the higher rates. The relationship between the tanker rates and inventories is more apparent than the relationship between tanker prices and WTI spot prices. This could be because lower inventories mean higher prices for tankers because the inventory level is an inverse surrogate for the oil price. That is, low inventories are synonymous with high oil prices and conversely, high oil inventories are synonymous with low oil prices. Since most oil is imported using tankers, a high oil price implies low inventories and high tanker prices.
Figure 5 shows the spread between the natural logarithms of the WTI spot price and the 3-month contract price. Alizadeh and Nomikos [20] have used this variable as a cost of carry or convenience yield measure. It captures the interest rate costs, storage costs and transportation costs to the delivery point. We interpret this more as a convenience yield measure in that US refiners are willing to hold inventory. Increases in the spread might suggest higher prices are expected or inventory build-ups are desired over the next few months. This leads to an increase in oil demand pushing up Tanker rates. Figure 6 demonstrates this relationship.

4. Econometric model
We employ the general-to-specific econometrics. It aims to uncover a parametric relationship in the findings of previous sense. Rather than which alternative the approach be to variables and dynamic hypothesis testing.

The first step in examining the first series. We look at the order of integration for each series. This step includes residual diagnostic and examining the system integrated of the series which are integrated relations and test for correction model of performed and econometric model of"
4. Econometric modelling issues
We employ the general-to-specific modeling approach advocated by Hendry [21–23]. The general-to-specific modelling approach is a relatively recent strategy used in econometrics. It attempts to characterize the properties of the sample data in simple parametric relationships which remain reasonably constant over time, account for the findings of previous models, and are interpretable in an economic and financial sense. Rather than using econometrics to illustrate theory, the goal is to ‘discover’ which alternative theoretical views are tenable and test them scientifically.

The approach begins with a general hypothesis about the relevant explanatory variables and dynamic process (i.e. the lag structure of the model). The general hypothesis is considered acceptable to all adversaries. Then the model is narrowed down by testing for simplifications or restrictions on the general model.

The first step involves examining the time series properties of the individual data series. We look at patterns and trends in the data and test for stationarity and the order of integration. Second, we form a vector autoregressive regression (VAR) system. This step involves testing for the appropriate lag length of the system, including residual diagnostic tests and tests for model/system stability. Third, we examine the system for potential cointegration relationship(s). Data series which are integrated of the same order may be combined to form economically meaningful series which are integrated of lower order. Fourth, we interpret the cointegrating relations and test for weak exogeneity. Based on these results, a conditional error correction model of the endogenous variables is specified, further reduction tests are performed and economic hypotheses tested.

5. Empirical results
5.1. Time series properties of the individual series
Campbell and Perron [24] provide rules (of thumb) for investigating whether time series contain unit roots. To begin, we estimate the following three forms of the
augmented Dickey–Fuller (ADF) test where each form differs in the assumed deterministic component(s) in the series:

\[
\Delta y_t = \alpha_1 y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \epsilon_t; \quad \text{no constant and trend}
\]

\[
\Delta y_t = \alpha_0 + \alpha_1 y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \epsilon_t; \quad \text{constant only}
\]

\[
\Delta y_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 t + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \epsilon_t; \quad \text{constant and trend}
\]

The \( \epsilon_t \) is assumed to be a Gaussian white noise random error; and \( t = 1, \ldots, T \) (the number of observations in the sample) is a term for trend. The number of lagged differences, \( p \), is chosen to ensure that the estimated errors are not serially correlated based on the AIC statistic.

The results from the unit root tests are found in Table 2 and Table 3. The first column lists the five variables under analysis. The second and third columns report the test results including a constant only and the constant and trend. A model with no constant and trend is not reported because the constant and or trend were significant. We find that all five series are I(1) processes. We cannot reject the null of I(1) against I(0) or stationarity. The spread variable appears to reject the null hypothesis at the 5% level with only a constant. However, it does not reject the null when a trend is included in the model. The trend does add explanatory power the equation, so we conclude it is I(1). Nominal price and financial series are found to be non-stationary in their first differences or they are I(2). We report the tests for these hypotheses in Table 2. In all cases, the null hypothesis of I(2) is rejected. Thus we

\[
\begin{bmatrix}
\ln BDT14 \\
\ln RCLC3 \\
\ln WTI \\
\ln WCESTUS1 \\
A(L) = A_1 L + A_2 L
\end{bmatrix}
\]

The price series logarithms to (partial are included in each e are assumed to be \( \epsilon \) and used in the VAR. The the \( i \)th lag.

The number of I methodology is to st necessary. Estimate t stability of the model assumption of white 1 over-parameterized m statistical model of th the fewest number of

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constant</th>
<th>Constant and trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBDTI4</td>
<td>-2.427 (2)</td>
<td>-3.048 (2)</td>
</tr>
<tr>
<td>LWTI</td>
<td>-0.071 (6)</td>
<td>-2.086 (6)</td>
</tr>
<tr>
<td>LWTI3</td>
<td>-0.517 (3)</td>
<td>-2.156 (3)</td>
</tr>
<tr>
<td>LWESTUS1</td>
<td>-2.570 (2)</td>
<td>-2.379 (2)</td>
</tr>
<tr>
<td>SP_WTI1</td>
<td>-3.181 (4)*</td>
<td>-2.565 (6)</td>
</tr>
</tbody>
</table>

Table 2. Augmented Dickey–Fuller test for unit root in levels t-statistics with lag selection based on AIC for sample 16 February 1998 to 2 January 2006.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Constant</th>
<th>Constant and trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLBDTI4</td>
<td>-13.26 (1)**</td>
<td>-13.25 (1)**</td>
</tr>
<tr>
<td>DLWESTUS1</td>
<td>-11.98 (1)**</td>
<td>-12.02 (1)**</td>
</tr>
<tr>
<td>SP_WTI3</td>
<td>-12.28 (5)**</td>
<td>-12.29 (5)**</td>
</tr>
</tbody>
</table>

Note: \( T = 400 \) observations;
Critical values: constant 5% = -2.87, 1% = -3.45, constant and trend 5% = -3.42, 1% = -3.98.
conclude that the tanker spot price, WTI spot price, WTI 3-month contract price, the spread between the WTI spot and future price, and the weekly crude inventory measure are I(1) or first difference stationary.

5.2. Specification of the VAR model
The choice of the variables is based on the analysis of the data in Section 2. The causal relationship between the West Africa–US Gulf Tanker spot price (BDTI4), West Texas intermediate crude spot price (RWTC), 3-month futures contract rates (RCLC3), and the days supply of US weekly petroleum inventories (WCESTUS1) is analysed using a vector autoregression model or system, VAR. We estimate the statistical model and test for dynamic relationships in both the short-run and long-run. The four variable VAR can be specified as:

\[
\begin{bmatrix}
\ln BDTI4_t \\
\ln RCLC3_t \\
\ln WTI_t \\
\ln WCESTUS1_t \\
\end{bmatrix} = A(L) \begin{bmatrix}
\ln BDTI4_t \\
\ln RCLC3_t \\
\ln WTI_t \\
\ln WCESTUS1_t \\
\end{bmatrix} + B \begin{bmatrix}
\text{constant} \\
\text{timetrend}_t \\
\end{bmatrix} + \begin{bmatrix}
\varepsilon_{t,1} \\
\varepsilon_{t,2} \\
\varepsilon_{t,3} \\
\varepsilon_{t,4} \\
\end{bmatrix}
\]

\[
A(L) = A_1 + A_2 L + A_3 L^2 + A_4 L^3 + \ldots + A_p L^p
\]

The price series and inventory measure have been transformed to natural logarithms to (partially) address heteroskedasticity issues. A constant and trend term are included in each equation; their role will be modified later. The two error terms are assumed to be white noise and can be contemporaneously correlated. The expression \(A(L)\) is a lag polynomial operator indicating that p lags of each price is used in the VAR. The individual \(A_i\) terms represent a 4 x 4 matrix of coefficients at the \(i^{th}\) lag.

The number of lags to use in model at the beginning is unknown. The methodology is to start with an initial trial of \(p\) lags assumed to be more than necessary. Estimate the VAR and test for serial correlation, heteroskedasticity and stability of the model. The idea or goal is to obtain results that appear close to the assumption of white noise residuals. A large number of lags is likely to produce an over-parameterized model. However, any econometric analysis needs to start with a statistical model of the data generating process. Parsimony is achieved by testing for the fewest number of lags that meet can explain the dynamics in the data system.

5.3. Lag length selection
The selection criteria for the appropriate lag length are used to avoid over-parameterizing the model and produce a parsimonious model. The Bayesian Schwartz Criterion (BSC), the Hannan–Quinn Criterion (HQ), and the Akaike Information Criterion (AIC) are often used as alternative criterion. They rely on information similar to the Chi-Squared tests and are derived as follows:

\[
BSC = \log(Det \hat{\Sigma}) + 2 * c * \log(T)T^{-1}
\]

\[
HC = \log(Det \hat{\Sigma}) + 2 * c * \log(\log(T)) * T^{-1}
\]

\[
AIC = \log(Det \hat{\Sigma}) + 2 * c * T^{-1}
\]

(1.1)
Table 4. VAR lag order selection criteria.

<table>
<thead>
<tr>
<th>Lag</th>
<th>Log L</th>
<th>LR</th>
<th>FPE</th>
<th>AIC</th>
<th>SC</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1003.089</td>
<td>NA</td>
<td>7.66e-08</td>
<td>-5.033195</td>
<td>-4.993055</td>
<td>-5.017294</td>
</tr>
<tr>
<td>1</td>
<td>3210.852</td>
<td>43.59.915</td>
<td>1.23e-12</td>
<td>-16.074822</td>
<td>-15.87412*</td>
<td>-15.99532</td>
</tr>
<tr>
<td>2</td>
<td>3245.964</td>
<td>68.63132</td>
<td>1.11e-12</td>
<td>-16.171100</td>
<td>-15.80984</td>
<td>-16.02799*</td>
</tr>
<tr>
<td>3</td>
<td>3262.293</td>
<td>31.58814</td>
<td>1.11e-12*</td>
<td>-16.17276*</td>
<td>-15.65093</td>
<td>-15.96605</td>
</tr>
<tr>
<td>4</td>
<td>3270.147</td>
<td>15.36144</td>
<td>1.16e-12</td>
<td>-16.13172</td>
<td>-15.44934</td>
<td>-15.86141</td>
</tr>
<tr>
<td>5</td>
<td>3284.555</td>
<td>27.29191</td>
<td>1.17e-12</td>
<td>-16.12370</td>
<td>-15.28075</td>
<td>-15.78979</td>
</tr>
<tr>
<td>7</td>
<td>3304.917</td>
<td>28.64444</td>
<td>1.24e-12</td>
<td>-16.06507</td>
<td>-14.90100</td>
<td>-15.60395</td>
</tr>
<tr>
<td>8</td>
<td>3318.394</td>
<td>24.71382</td>
<td>1.26e-12</td>
<td>-16.05236</td>
<td>-14.72773</td>
<td>-15.52763</td>
</tr>
<tr>
<td>9</td>
<td>3330.613</td>
<td>22.16143</td>
<td>1.28e-12</td>
<td>-16.03332</td>
<td>-14.54812</td>
<td>-15.44499</td>
</tr>
<tr>
<td>10</td>
<td>3337.315</td>
<td>12.01908</td>
<td>1.34e-12</td>
<td>-15.98647</td>
<td>-14.34072</td>
<td>-15.3354</td>
</tr>
</tbody>
</table>

Notes: Sample: 26 January 1996 1/02/2006;
Included observations: 397;
The VAR system includes four variables: LBDTI4, LRCLC3, LRWTI and LWČESTUS. There is a constant and trend in the VAR as well;
*indicates lag order selected by the criterion;
LR: sequential modified LR test statistic (each test at 5% level);
FPE: Final prediction error;
AIC: Akaike information criterion;
SC: Schwarz information criterion;
HQ: Hannan–Quinn information criterion.

Intuitively, the log determinant of the estimated residual covariance matrix will decline as the number of regressors increases, just as in a single equation ordinary least squares regression. It is similar to the residual sum of squares or estimated variance. The second term on the right-hand side acts as a penalty for including additional regressors (c) which are scaled by the inverse of the number of observations (T). It increases the statistic. Once these statistics are calculated for each lag length, the lag length chosen is the model with the minimum value for the statistics respectively. The three tests do not always agree on the same number of lags. The AIC is biased towards selecting more lags than is actually needed; this is not necessarily bad.

Table 4 shows results for the three tests. The maximum possible lag length considered was ten (weeks). The first column gives the lag length for each test and the last three columns of the table provide the test statistics. In this case the choice is ambiguous, because the three tests reveal only one lag is needed by the SC, two lags with the HQ and three lags with the AIC. Further examination found serial correlation at one lag. We selected three lags for analysis to be conservative.

The residual diagnostics are examined in Figure 7 and Table 5. Figure 7 has three columns and four rows one for each equation. The columns represent the estimated residuals, a histogram with normal distribution, and the autocorrelation and partial autocorrelations respectively. There appear to be periods with very large errors or outliers in the three price series. Also, there appears to be an increase in the variance for the Tanker rates (LBDTI4, first column and first row). This leads to relatively sharp peaks in the frequency distributions and fat tails which are the norm with financial or price series. There does not appear to be any serial correlation in all four equations. Table 5 provides the residual diagnostic tests from the 4-variable system with three lags. We report both the individual equation tests and the system or
covariance matrix will enable equation ordinary least squares or estimated plus penalty for including the number of lags is calculated for minimum value for the same number of actually needed; this is a possible lag length for each test and the case the choice is led by the SC, two lags minimization found serial be conservative.

Table 5. Residual diagnostic tests normality test for residuals.

<table>
<thead>
<tr>
<th></th>
<th>LBDT14</th>
<th>LRCLC3</th>
<th>LRWTI</th>
<th>LWCESTUS1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skewness</td>
<td>0.037708</td>
<td>-0.30912</td>
<td>-0.91646</td>
<td>-0.28527</td>
</tr>
<tr>
<td>Excess kurtosis</td>
<td>6.9724</td>
<td>4.3355</td>
<td>7.7874</td>
<td>3.7658</td>
</tr>
<tr>
<td>Skewness (transformed)</td>
<td>0.31632</td>
<td>-2.5386</td>
<td>-6.6543</td>
<td>-2.3499</td>
</tr>
<tr>
<td>Excess kurtosis (transformed)</td>
<td>11.572</td>
<td>4.0823</td>
<td>6.7315</td>
<td>3.2528</td>
</tr>
<tr>
<td>J-B test</td>
<td>135.04</td>
<td>33.449</td>
<td>28.398</td>
<td>10.788</td>
</tr>
<tr>
<td>Chi²(2)=</td>
<td>[0.0000]**</td>
<td>[0.0000]**</td>
<td>[0.0000]**</td>
<td>[0.0045]**</td>
</tr>
<tr>
<td>Vector Normality test: Chi²(8) = 257.64 [0.0000]**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR 1-2 test:</td>
<td>2.1396</td>
<td>0.77893</td>
<td>0.78208</td>
<td>0.66243</td>
</tr>
<tr>
<td>F(2,392)=</td>
<td>[0.1191]</td>
<td>[0.4596]</td>
<td>[0.4582]</td>
<td>[0.5162]</td>
</tr>
</tbody>
</table>

Portmanteau test with 10 lags

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Portmanteau(10): 157.931</td>
<td></td>
</tr>
<tr>
<td>Hetero test:</td>
<td>2.9969</td>
</tr>
<tr>
<td>F(26,367)=</td>
<td>[0.0000]**</td>
</tr>
<tr>
<td>Vector hetero test: F(260 3377) = 1.5772 [0.0000]**</td>
<td></td>
</tr>
<tr>
<td>ARCH 1–1 Test:</td>
<td>6.1768</td>
</tr>
<tr>
<td>F(1,392)</td>
<td>[0.0134]*</td>
</tr>
</tbody>
</table>

Notes: Sample: 26 January 1998;
Included observations: 397;
The VAR system includes four variables: LBDT14, LRCLC3, LRWTI and LWCESTUS1. There is a constant and trend in the VAR as well;
Significant at 5% (*) and 1% (**)
vector tests. Column one explains the test in each row. The next four columns contain the statistics for LBDTI4, LRCLC3, LRWTI and LWCESTUS1 respectively. The first set of rows look at whether the estimated residuals exhibit normality. They confirm the visual observations from the figure. There does not appear to be a problem with skewness, but there is problem with kurtosis which results in the rejections of the Jarque-Bera tests. The autocorrelation tests and Portmanteau tests by equation and for the system do not reject the null of no autocorrelation. The tests for homoskedasticity are next. Again, the visual evidence is confirmed. We find that the null of homoskedasticity for the Tanker rate equation is rejected, but not for the other equations. The final test is for the null of no conditional heteroskedasticity at lag one. Tanker rate and the oil spot price appear to have an ARCH process, but this result may be due to the large outliers.

5.4. Granger causality tests
Table 6 shows the Granger causality tests for this 4-variable model. Each of the 4 variables appears to have explanatory power for one or more of the other variables in the system. The effects are direct but often complex and indirect. In the first equation, it appears that neither of the crude prices provides explanatory power for the Tanker rate and inventories only at the 10% level. However, if all these series are omitted for the equation, there is a loss of power at nearly 1%. There must be a multifaceted relationship between these series leading to an explanation of tanker rates. Futures contracts appear to be influenced by Tanker rates and inventories at 5% and 1% levels respectively. The WTI spot price is explained by past values of all three series. Inventories probably contain the information from spot prices and future prices. Financial theory would suggest that efficient markets already use the spot price. Spot prices are explained by all three other series. Inventories appear to be explained by the three price series at about the 5% level individually and jointly. The strength of this result was somewhat surprising, because we hypothesized that real supply and demand variables are important in explaining movements in inventories.

<table>
<thead>
<tr>
<th>Equations</th>
<th>LBDTI4</th>
<th>LRCLC3</th>
<th>LRWTI</th>
<th>LWCESTUS1</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBDTI4</td>
<td>3.983</td>
<td>4.496</td>
<td>7.451</td>
<td>20.902</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.263</td>
<td>0.213</td>
<td>0.059*</td>
<td>0.013**</td>
<td></td>
</tr>
<tr>
<td>LRCLC3</td>
<td>7.981</td>
<td>1.185</td>
<td>6.470</td>
<td>15.279</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.046**</td>
<td>0.757</td>
<td>0.091*</td>
<td>0.084*</td>
<td></td>
</tr>
<tr>
<td>LRWTI</td>
<td>9.553</td>
<td>16.806</td>
<td>13.146</td>
<td>34.884</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.023**</td>
<td>0.001***</td>
<td>0.004***</td>
<td>0.000***</td>
<td></td>
</tr>
<tr>
<td>LWCESTUS1</td>
<td>7.285</td>
<td>7.684</td>
<td>8.033</td>
<td>18.298</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.063*</td>
<td>0.053*</td>
<td>0.045**</td>
<td>0.032**</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Sample: 26 January 1998 1/02/2006;
Included observations: 397;
The VAR system includes four variables: LBDTI4, LRCLC3, LRWTI and LWCESTUS1. There is a constant and trend in the VAR as well;
The Chi-square tests are reported in each cell with their associated p-values. There are three restrictions in the four columns and nine restrictions in the last column;
Significant at 10% (*), 5% (**) and 1% (***)

5.5. The cointegration
In this section the cointegration. The differences.

\[
\begin{align*}
\Delta \ln BDTI & \\
\Delta \ln RCLC & \\
\Delta \ln WTI & \\
\Delta \ln WSTU & \\
\end{align*}
\]

The crux of the Johansen method which is implemented through the Engle and Granger cointegration and correction (ECMs) models with valid independent equating characteristic roots linearly independent column vectors, \( \Pi \).

The matrix \( \beta \) is elements for the \( r \)th equation. \( \beta Y_{t-1} \) is normalized and interpreted as the context, the column run’ or equilibrium particular equation can be conditioned long-run equilibrium equation. If that is the case, equation from the:

Cointegration test ships. The question testing. The number that the question o
Prices are no doubt correlated with those variables and that may explain the strong relationship.

5.5. The cointegration analysis of the vector autoregression model

In this section the Johansen procedure is to test for the presence of cointegration. The VAR model in levels can be linearly transformed into one in first differences.

\[
\begin{bmatrix}
\Delta \ln BDTI_{t-1} \\
\Delta \ln RCLC3_{t-1} \\
\Delta \ln WTI_{t-1} \\
\Delta \ln WESTUS1_{t-1}
\end{bmatrix}
= \Pi
\begin{bmatrix}
\ln BDTI_{t-1} \\
\ln RCLC3_{t-1} \\
\ln WTI_{t-1} \\
\ln WESTUS1_{t-1}
\end{bmatrix}
+ \Gamma(L)
\begin{bmatrix}
\Delta \ln BDTI_{t-1} \\
\Delta \ln RCLC3_{t-1} \\
\Delta \ln WTI_{t-1} \\
\Delta \ln WESTUS1_{t-1}
\end{bmatrix}
+ B \begin{bmatrix}
\text{cons} \\
\tan t \\
trend_t
\end{bmatrix}
+ \begin{bmatrix}
\epsilon_{1,t} \\
\epsilon_{2,t} \\
\epsilon_{3,t} \\
\epsilon_{4,t}
\end{bmatrix}
\]

where \( \Pi = \Pi_1 + \Pi_2 - I \), \( \Gamma_1 = -\Pi_3 - \cdots - \Pi_p \), \( \Gamma_2 = -\Pi_3 - \Pi_4 - \cdots - \Pi_p, \ldots \), \( \Gamma_{p-1} = -\Pi_p \) and \( \epsilon \sim (0, \Omega) \).

The crux of the Johansen test is to examine the mathematical properties of the \( \Pi \) matrix which contains important information about the dynamic stability of the system. Intuitively, the \( \Pi \) matrix above is an expression relating the levels of the endogenous variables in the system.

Engle and Granger [25] demonstrate the one-to-one correspondence between cointegration and error correction models. Cointegrated variables imply an error correction (ECM) representation for the econometric model and, conversely, models with valid ECMs impose cointegration. Evaluating the number of linearly independent equations in \( \Pi \) is done by testing for the number of non-zero characteristic roots, or eigenvalues, of the \( \Pi \) matrix, which equals the number of linearly independent rows [26]. The matrix can be rewritten as the product of two full column vectors, \( \Pi = \alpha \beta^T \).

The matrix \( \beta \) is referred to as the cointegrating vector and \( \alpha \) as the weighting elements for the \( i^{th} \) cointegrating relation in each equation of the VAR. The vector \( \beta Y_{t-1} \) is normalized on the variable of interest in the cointegrating relation and interpreted as the deviation from the ‘long-run’ equilibrium condition. In this context, the column \( \alpha \) represents the speed of adjustment coefficients from the ‘long-run’ or equilibrium deviation in each equation. If the coefficient is zero in a particular equation, that variable is considered to weakly exogenous and the VAR can be conditioned on that variable. Weak exogeneity implies that the beta terms or long-run equilibrium relations do not provide explanatory power in a particular equation. If that is true, then valid inference can be conducted by dropping that equation from the system and estimating a conditional model.

Cointegration tests are for long-run interactions capturing fundamental relationships. The question often arises as to how many observations are necessary for testing. The number observation, per sé, is not much a concern. Juselius [27] explains that the question of how big the sample should be has, unfortunately, no obvious...
answer—whether the sample is 'small' or 'big' is a function not only of the number of observations but also of the amount of information in the data. She emphasizes that when the data are very informative about a hypothetical long-run or cointegration relation, there might be good test properties even if the sample period is relatively short, citing the case where the equilibrium error crosses the mean line several times during the period. Campos and Ericsson [28] demonstrate similar findings in the case of Venezuela. The critical issue is the information content in the data or high 'signal-to-noise' ratio. Venezuela, like many emerging markets, has experienced large shocks such as crises in banking, deregulation, volatile oil prices, fluctuating government oil revenues and inflation. While these are serious problems and can lead to tragic events for individuals and the economy, they provide valuable information to the applied econometrician. In our empirical analysis, we are using 8 years of weekly market data, almost 400 observations. We are confident that the market fundamentals or long-run relationships are testable.

The results of the Johansen cointegration test are presented in Table 7 and are partitioned into three parts. The first part provides the test results for the null hypothesis of no cointegration. The eigenvalues of the $\Pi$ matrix are sorted from largest to smallest. The tests are conducted sequentially, first examining the possibility of no cointegrating relation against the alternative that there is one cointegrating relation, and then the null of one cointegrating relation against the possibility of two cointegrating relations, e.g. essentially, these are tests of whether the eigenvalue(s) is (are) significantly different from zero. We rejected the null of no
cointegration or rate model is rejected.
Max(eigenvalue) $\alpha$

The second part
BDTI4 spot tanker rates for tankers on the

$\text{Spot Tanker Price}$

The estimates fit signs are reported. The associate three month contract future prices are ex will be upward pre crude is increasing negative trend. $E$ hypothesis is time easing the spc

We report hypo the third part of th is appropriate (and case, the estimate is the demand relation can test if the other variables are influe. Chi-square tests for significant and is $\omega$ rate. However, pa

---

**Table 7. Johansen cointegration analysis of BDTI4 tanker prices, WTI, WTI 3-mo contract and US weekly petroleum inventories.**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Eigenvalue</th>
<th>Trace</th>
<th>p-value</th>
<th>Max eigen.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11563</td>
<td>80.35</td>
<td>0.001**</td>
<td>50.26</td>
<td>0.000**</td>
</tr>
<tr>
<td>1</td>
<td>0.04902</td>
<td>30.09</td>
<td>0.503</td>
<td>20.56</td>
<td>0.220</td>
</tr>
<tr>
<td>2</td>
<td>0.01395</td>
<td>9.53</td>
<td>0.936</td>
<td>5.75</td>
<td>0.954</td>
</tr>
<tr>
<td>3</td>
<td>0.00921</td>
<td>3.78</td>
<td>0.770</td>
<td>3.78</td>
<td>0.772</td>
</tr>
</tbody>
</table>

*Standardized eigenvalues, beta values and standard errors*

<table>
<thead>
<tr>
<th>LBDTI4</th>
<th>LRCLC3</th>
<th>LRWTI</th>
<th>LWESTUS1</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>-50.492</td>
<td>48.350</td>
<td>28.143</td>
<td>0.0102</td>
</tr>
<tr>
<td>6.957</td>
<td></td>
<td>6.687</td>
<td>4.221</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*Standardized alpha coefficients and standard errors*

<table>
<thead>
<tr>
<th>LBDTI4</th>
<th>LRCLC3</th>
<th>LRWTI</th>
<th>LWESTUS1</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0088</td>
<td>0.0018</td>
<td>-0.0038</td>
<td>-0.0016</td>
</tr>
<tr>
<td>0.004</td>
<td>0.0018</td>
<td>0.0023</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Weak: 0.19  2.86  9.12
Exogeneity: (0.66) (0.09) (0.003)

Notes: Sample: 26 January 1/02/2006;
Included observations: 397;
The VAR system includes four variables: LBDTI4, LRCLC3, LRWTI and LWESTUS1. There is a constant and trend in the VAR as well;
The weak exogeneity tests are Chi-squares with 1 degree of freedom. P-values are reported in parentheses.
not only of the number of lata. She emphasizes that ongoing unemployment and cointegration mean line several times similar findings in the case of the data and high 'signal-experienced large shocks to the government oil can lead to tragic events formation to the applied years of weekly market market fundamentals or presented in Table 7 and are test results for the null matrix are sorted from lly, first examining the native that there is one strong relation against the lses are tests of whether we rejected the null of no

s, WTI, WTI 3-mo contract

<table>
<thead>
<tr>
<th>Max eigen.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.26</td>
<td>0.000**</td>
</tr>
<tr>
<td>20.56</td>
<td>0.220</td>
</tr>
<tr>
<td>5.75</td>
<td>0.954</td>
</tr>
<tr>
<td>3.78</td>
<td>0.772</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1WESTUS1</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.143</td>
<td>0.0102</td>
</tr>
<tr>
<td>4.221</td>
<td>0.003</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1WESTUS1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>−0.0016</td>
<td>0.0005</td>
</tr>
<tr>
<td>9.12</td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

and LWCESTUS1. There is a

cointegration or rank zero. The test for no cointegration (r = 0) in the spot tanker rate model is rejected at less than 0.01 with the Trace test (80.4) and the Max(eigenvalue) test (50.3).

The second part shows the first standardized eigenvector or β vector on the BDTT4 spot tanker rate. We interpret the cointegrating relation as demand relation for tankers on the spot market for the West Africa–US Gulf trade.

\[
\text{Spot Tanker Price}_t = 50(3 \text{ mo. Future Price}_t – \text{WTI Spot Price}_t) – 28 \text{ Inventories}_t
\]

The estimates for the β vector are presented in a row under each variable. The signs are reported as if the sum of the entire vector equals zero, thus the opposite signs. The associated standard errors are provided below. The β coefficients for the three month contract and WTI are roughly equal and of opposite sign. Thus, if future prices are expected to rise or the 3-month contract-spot spread is positive there will be upward pressure on tanker rates. If weekly inventories of days supply for US crude are increasing, then spot rates are falling. The cointegrating includes a small negative trend. Explaining this component is beyond the current research. One hypothesis is that it could reflect growing tanker capacity (on the spot market) over time easing the spot price. Figure 8 illustrates the error correction mechanism.

We report hypothesis tests on the α vector and the associated standard errors in the third part of the table. If the cointegrating or demand relation we have specified is appropriate (and stationary), then its own coefficient must be negative. In this case, the estimate is −0.0088 and significant. Thus, if the spot tanker rate was above the demand relation last week, the change in the spot rate this week should lower. We can test if the other α terms are significant, that is whether the equations for those variables are influenced by the cointegrating relation using the standard errors or the Chi-square tests for weak exogeneity. We find that the 3-month contract rate is not significant and is weakly exogenous with respect to the relation for the current spot rate. However, past tanker rates and inventories do help to explain the 3-month

Figure 8.
contract rate in the Granger Causal sense. The WTI is negatively, but marginally related to the spot rate demand cointegrating relation with a p-value of 0.09. Inventories may be related or partially explained by the relation; the p-value is less than 0.01.

6. Discussion and conclusions
This paper examines the relationship between weekly spot tanker prices and the oil market over the past 8 years (1998–2006). The focus is on the West African and US Gulf Coast tanker market. We find that past knowledge of spot tanker rates, 3-month future contracts, spot WTI prices and the days supply of crude inventories explain current values in a Granger causal sense. In addition we are able to uncover a demand relation for tankers in the spot market using cointegration analysis. This finding may reflect the idea that the demand for tankers is a derivative for the demand for oil. If there is a strong demand for oil, there is a strong demand for tankers, so it is possible for tanker companies to raise rates. The demand determinants suggest that when the spread or 3-month Cushing futures contract is trading above the current WTI spot price there is upward pressure on spot tanker rates. In addition, when the day’s supply of crude inventories increases the spot tanker rate declines. We find some feedback between the spot tanker market, current prices and inventories.

Future research can examine these interactions in several ways. One approach would be to see if similar relations are present in the other tanker markets. Second, the existence of cointegration implies we can continue the analysis in an error correction modelling framework. The demand relation can be used in a model of the changes in the spot tanker market from week to week. The error correction model can examine possible seasonal impacts and very short-term market effects. For example, tanker prices are weakest in the spring and summer and strongest in the winter. Specifically the fourth and the following first quarter of the year, which are the northern hemisphere winter months, are the priciest months for tanker rates.

Acknowledgements
The authors would like to thank Ilias D. Visvikis and participants at the International Association of Maritime Economists Conference in Sydney, Australia, July 2006. In addition, we benefited from comments at the Energy Economics Seminar at the University of Alberta, and the Federal Forecasters Conference in Washington, DC 2008. Also, Poten & Partners assisted in obtaining data on the spot tanker markets. The authors received valuable comments and suggestions from the editor and referees.

References
2. KOOPMANS, T. C., 1939, Tanker freight rates and tankship building (Haarlem, The Netherlands: P.S. King & Son, Ltd).
Exploring the link between oil prices and tanker rates

26. The number of linearly independent rows in a matrix is called the rank.