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A Quantitative Model of the Oil Tanker Market in the Arabian Gulf*

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Abstract

Using a novel dataset, we develop a structural model of the Very Large Crude Carrier (VLCC) market between the Arabian Gulf and the Far East. We study how fluctuations in oil tanker rates, oil exports, shipowner profits, and bunker fuel prices are determined by shocks to the supply and demand for oil tankers, to the utilization of tankers, and to bunker fuel costs. Our analysis shows that time charter rates respond only slightly to fuel cost shocks. In response to higher fuel costs, voyage profits decline, as cost shocks are only partially passed on to round-trip voyage rates. Oil exports from the Arabian Gulf also decline, reflecting lower demand for VLCCs. Positive utilization shocks are associated with higher profits, a slight increase in time charter rates and slightly lower fuel prices and oil export volumes. Tanker supply and tanker demand shocks have persistent effects on time charter rates, round-trip voyage rates, the volume of oil exports, fuel prices, and profits with the expected sign.

JEL code: Q43, R41.

Keywords: Shipping, VLCC, crude oil, bunker fuel, tanker, voyage, time charter, profits, exports, passthrough.

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*The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Federal Reserve Bank of Dallas or the Federal Reserve System. The authors have no conflict of interest to disclose.

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1. Introduction

There has been increasing interest in recent years in understanding the market for the shipping vessels used in transporting bulk industrial commodities.[1] Much of this literature has focused on dry-bulk cargo trade, while some studies have specifically focused on modeling the market for oil tankers. It is widely understood that the demand for vessels responds to shifts in the demand and supply of the industrial commodities awaiting transportation. There is also a growing recognition of the importance of accounting for shocks to the cost of shipping (including, most importantly, the cost of the bunker fuel used to operate vessels), shocks to the utilization of the fleet of vessels, and shocks to the fleet size, with new cargo vessels being added in response to higher demand and older cargo vessels being scrapped, as demand subsides.

Most studies in this literature have examined the theoretical foundations of the shipbuilding and scrapping cycle, the determination of ship charter rates, and the determinants of shipowners' profits. The remainder of this literature has documented lead-lag patterns and correlations of key variables in shipping markets.[2] None of these studies, however, addresses the question of how key variables in this market such as tanker rates, oil exports, bunker fuel prices, and the cyclical component of shipowner profits are determined by shocks to the supply of and demand for oil tankers, fuel cost shocks and shocks to the utilization of the fleet of tankers.

Our paper develops a structural model of the Very Large Crude Carrier (VLCC) tanker market between the Arabian Gulf and the Far East. About one third of the global trade in crude oil takes place in this region and 70% of this oil is shipped on VLCCs. We use two

[1] Examples include Glen and Martin (2005), Stopford (2009), Kalouptsidi (2014), Parker (2014), Greenwood and Hanson (2015), Kilian and Zhou (2018), Brancaccio, Kalouptsidi and Papageorgiou (2020), and Brancaccio, Kalouptsidi, Papageorgiou and Rosaia (2020). For a recent review of this literature see Alexandridis, Kavussanos, Kim, Tsouknidis and Visvikis (2018).

[2] For example, Nomikos and Regli (2019) document the predictive correlations between oil tanker rates, bunker fuel prices, and the availability of oil tankers in the Arabian Gulf measured by high-frequency satellite data.

alternative specifications of the structural model to quantify the causal effects of fuel cost, utilization, tanker supply and tanker demand shocks on the volume of oil exports from the Arabian Gulf, bunker fuel prices, one-year VLCC time charter rates, round-trip VLCC voyage rates from the Arabian Gulf to East Asia, and the voyage profits of the owners of VLCCs chartered for round-trip voyages on this route.

Impulse response analysis suggests that a positive fuel cost shock causes the time-charter rate to fall slightly with a delay, reflecting the lower demand for time charters, as charterers face higher operating costs. The overall volume of oil exports from the Arabian Gulf declines, reflecting lower demand for VLCCs in response to higher costs. The magnitude of this response is small, consistent with the view that the demand for shipping is fairly inelastic with respect to changes in freight costs (see Stopford 2009). Moreover, real voyage profits decline in response to positive cost shocks, suggesting that cost shocks are only partially passed on to round-trip voyage rates. Positive utilization shocks are associated with higher profits, a slight increase in time charter rates and slightly lower fuel prices and oil export volumes. Tanker supply and tanker demand shocks have persistent effects on time charter rates as well as on the volume of oil exports and the bunker fuel price with the expected sign. Lower tanker supply and higher tanker demand are reflected in persistently higher voyage profits for vessel owners as well as higher round-trip voyage rates.

Whereas the variability of the real voyage profits of ship owners and round-trip voyage rates depends mainly on utilization shocks and tanker demand shocks, that of time-charter rates depends first and foremost on tanker demand and supply shocks. The variability of bunker fuel prices mainly depends on tanker demand and supply shocks, followed by fuel cost shocks, with utilization shocks playing only a negligible role. The determinants of the variability of the volume of oil exports from the Arabian Gulf cannot be precisely pinned down in the data.

Our analysis also allows us to quantify the extent to which the historical evolution of oil exports, bunker fuel prices, time charter rates, round-trip voyage rates and shipowner profits has been caused by each of the structural shocks. The results are reasonably robust across model specifications. We find that, until 2008, the volume of oil exports from the Arabian Gulf was largely determined by tanker demand shocks, consistent with conventional wisdom. Interestingly, there is robust evidence of a tanker-demand driven spike in oil export volumes (as well as in both tanker rates) associated with the temporary détente in U.S. trade policy in 2018/19, confirming that trade disputes have real effects on industrial commodity markets.

Cost shocks have only minor effects on the evolution of real time charter rates. The demand-driven cycle in time charter rates largely mirrors that found in oil export volumes and voyage profits. Between 2009 and 2015 (and again between 2016 and 2019), there is evidence of a trough in real time charter rates caused by the cumulative effects of tanker supply shocks, consistent with the delivery of many newly built vessels during this period. Qualitatively similar results hold for the real round-trip voyage rate from the Arabian Gulf to East Asia and for the real vessel owners' profits from these round-trip voyages. Another noteworthy finding is that the historical evolution of round-trip voyage rates and profits is more sensitive to utilization shocks than tanker supply or cost shocks.

The remainder of the paper is organized as follows. In section 2, we review the institutional details of the tanker market and the construction of the data. Section 3 describes the structural model and the econometric methodology. Section 4 discusses the impulse responses and variance decompositions for real time charter rates, oil export volumes and real profits in the baseline model. Section 5 presents an alternative model specification that allows us to assess the determination of real round-trip voyage rates and discusses the corresponding empirical results. In section 6, we draw on both models to examine the historical evolution of the model variables. The concluding remarks are in section 7.

2. Institutional Background

Our analysis focuses on the market for Very Large Crude Carriers (VLCCs) which refers to oil tankers with a capacity of between 200,000 and 325,000 dwt. These vessels are the backbone of long-distance oil shipping from the Arabian Gulf to East Asia.[3] This industry is competitive with the largest company owning only 6.3% of the VLCC fleet. By construction, oil tankers can only be used to transport crude oil, so the market for oil tankers can be viewed in isolation from the market for other vessels.

VLCCs may be chartered for transporting crude oil by entering into a voyage charter contract or a time charter contract. A voyage charter involves a payment to the ship owner for a voyage from one port to another port. The shipowner is responsible for all voyage costs, including fuel costs, cargo loading and discharge costs, port charges, as well as the costs associated with the up-keep and maintenance of the vessel such as maintenance fees, insurance premia and crew wages. Voyage charter spot rates are available for the most commonly used routes. These quotes serve as a reference price for transactions.

A time charter, in contrast, involves leasing the vessel for a specific period, which may range from a few months to several years. A typical lease would be for one year. The lessee pays the shipowner a daily fee during this year. The lessee is responsible for paying all voyage costs associated with the operation of the vessel. Although time charters only account for about 5% of the VLCC market, the inclusion of time charter rates in the structural model facilitates the identification of cost shocks. Our analysis exploits the fact that time charter rates by definition are not directly affected by fluctuations in bunker fuel prices and related voyage costs because the shipowner is not responsible for these costs (see Stopford 2009;

[3] As of April 2020, there are 815 VLCCs in operation, accounting for 40% of the total cargo carrying capacity of the global oil tanker fleet. They are exceeded in size only by ULCCs (Ultra Large Crude Carriers). There are currently only two ULCCs in service, however, allowing us to focus on the VLCC market.

Kilian and Zhou 2018; Nomikos and Regli 2019).

One advantage of focusing on oil exported from the Arabian Gulf to East Asia is that this route is representative for the VLCC market. About one third of the global trade in crude oil originates in this region and more than 70% of this oil is shipped on VLCCs, the majority of which is destined for East Asia. Another advantage is that virtually all trade on this route relies on VLCCs. This allows us to abstract from the existence of smaller tankers. A third advantage is that the focus on one regional market helps address the concern that equilibrium outcomes depend on the demand for oil cargoes in each load area market and the availability of ships within proximity to the market (see Parker 2014).

Our data set is monthly. The estimation period is 1991.1 through 2019.10. There are no data available prior to January 1991. Our analysis utilizes a novel data set consisting of the volume of seaborne crude oil exports from the Arabian Gulf (in mb/d); the price of bunker fuel in Fujairah (in U.S. $/ton); the one-year time-charter rate for VLCCs (in U.S. $/day); the round-trip voyage rate on the benchmark Ras Tanura-Chiba route (in U.S. $/mt); and the corresponding profits earned by owners of VLCC tankers on this route (in U.S. $/day), defined as earnings net of bunker fuel and other cargo-related costs. Details of the construction of the data can be found in the appendix. The nominal data have been deflated by the U.S. CPI for all urban consumers to control for dollar inflation.

3. The Baseline Structural Model of the VLCC Oil Tanker Market in the Arabian Gulf

In this section we introduce a structural VAR model of the VLCC oil tanker market in the Arabian Gulf that serves as the baseline for our analysis. An alternative model specification is discussed in section 5. The challenge is how to identify economically meaningful exogenous variation in the data with the few variables available. Using a comparatively short estimation period rules out the construction of more elaborate models. Although not all estimates of the structural relationship between these variables are precise, we show that there is nevertheless useful information in these data. The baseline structural model includes the log of the real time-charter (TC) rate for VLCCs, the log-linearly-detrended volume of oil exports from the Arabian Gulf, the real profits of owners of VLCCs from the Ras Tanura-Chiba trade route, and the real price of bunker fuel in Fujairah (see Figure 1).[4]

Our objective is to explain variation in these four variables in terms of four mutually uncorrelated structural shocks: (1) A tanker utilization shock that captures changes in the intensity with which VLCCs are being used. (2) A cost shock that captures unexpected changes in the cost of the bunker fuel used to run tankers, which accounts for as much as 70% of overall voyage costs and much of their variability. (3) A tanker supply shock that reflects unexpected additions to the VLCC tanker fleet as well as the scrapping of older tankers over time due to wear and tear, new regulations and technological or economic obsolescence.[5] (4) A tanker demand shock that reflects unexpected shifts in the demand for tanker transportation services. Such shifts are typically triggered by changes in the demand for crude oil from oil-importing countries. They may also reflect an unexpected increase in oil supplies. A good example is the increase in tanker rates in early 2020 (which occurred outside of our sample), when Saudi Arabia expanded its oil exports in an effort to gain market share.

3.1. Identifying Restrictions

Let $y_t = (\text{TC rate, exports, profits,fuel price})'$ be generated by the covariance stationary structural VAR(12) process of the form $B_0 y_t = B_1 y_{t-1} + ... + B_{12} y_{t-12} + w_t$, where the stochastic

[4] Linear detrending preserves the long-cycles in measures of the volume of oil exports and hence is widely used in modeling commodity markets (e.g., Kilian and Zhou 2018). It can be shown that the results are not overly sensitive to expressing the volume of oil exports in log-differences.
[5] An example of a tanker supply shock induced by regulatory changes is the gradual decommissioning of the single-hull tanker fleet in the 1990s, following the passage of the 1990 Oil Pollution Act by Congress. Another interesting example of a tanker supply shock is the lockdown of all major recycling destinations in the Indian subcontinent in March 2020, following the Covid-19 outbreak. This stalled all ship scrapping activity globally, since scrapyards in the subcontinent account for more than 90% of the global demolition capacity.

error w_t is mutually uncorrelated white noise and the deterministic terms have been suppressed for expository purposes. We follow Kilian and Lütkepohl (2017) in setting a conservative lag order of 12, which avoids the pitfalls of data-based lag order selection. The reduced-form errors may be written as $u_t = B_0^{-1} w_t$, where B_0^{-1} denotes the structural impact multiplier matrix, $u_t = y_t - A_1 y_{t-1} - ... - A_{12} y_{t-12}$, and $A_l = B_0^{-1} B_l$, $l = 1,...,12$. The $\{ij\}th$ element of B_0^{-1}, denoted b_{ij}^0, represents the impact response of variable i to structural shock j, where $i \in \{1,...,4\}$ and $j \in \{1,...,4\}$. Given the reduced-form estimates, knowledge of B_0^{-1} suffices to recover estimates of the structural impulse responses, variance decompositions and historical decompositions from the reduced-form estimates, as discussed in Kilian and Lütkepohl (2017).

3.1.1. Static and dynamic identifying restrictions on the structural impulse responses

Let $w_t = \left(w_t^{utilization}, w_t^{\text{cost}}, w_t^{\text{supply}}, w_t^{\text{demand}}\right)'$ and $u_t = \left(u_t^{\text{TC rate}}, u_t^{\text{exports}}, u_t^{\text{profits}}, u_t^{fuel\ price}\right)'$. We postulate that

$$\begin{pmatrix} u_t^{TC\,rate} \\ u_t^{\text{exp}orts} \\ u_t^{profits} \\ u_t^{fuel\ price} \end{pmatrix} = \begin{bmatrix} + & 0 & + & + \\ - & - & - & + \\ + & - & + & + \\ 0 & + & - & + \end{bmatrix} \begin{pmatrix} w_t^{utilization} \\ w_t^{\text{cost}} \\ w_t^{\text{supply}} \\ w_t^{\text{demand}} \end{pmatrix}. \quad (1)$$

The model distinguishes between tanker supply shocks on the extensive margin and the intensive margin. The extensive margin is defined as changes to the aggregate number of VLCCs in the fleet, as vessels are launched and take into service or retired (w_t^{supply}). The intensive margin measures how hard these vessels are being worked ($w_t^{utilization}$). Higher utilization of vessels may occur, for example, as trading routes are affected by the risk of storms, piracy or military attack, forcing vessel owners to take detours, to sit idle until the risk has passed, or to wait to travel in convoys. It may also occur, as VLCCs are chartered for storing crude oil at sea and become unavailable for transportation (see Adland and Regli 2019).[6] Higher utilization may also reflect congestion at ports or the temporary closure of shipping channels after accidents, and it may reflect refinery outages or storage constraints in the receiving country. In addition, it may reflect sanctions on owners of tankers.[7] In all these cases, fewer vessels are available for loading cargoes of oil in the Arabian Gulf, causing tanker rates to increase. As tanker rates increase, fewer cargoes are being moved and the volume of oil exports falls. The impact on profits is positive because tanker rates increase, and the elasticity of seaborne trade to freight costs is known to be low (see Stopford 2009). Fuel prices are unaffected on impact, because a typical roundtrip voyage from the Arabian Gulf to East Asia takes 50 days and VLCCs facing utilization shocks tend to be at sea.

A positive cost shock associated with higher bunker fuel prices leaves unaffected the real TC rate on impact, but lowers the volume of oil exports and the real profits from round-trip voyages. The restriction that the TC rate does not respond within one month to a cost shock follows directly from the fact that such costs are borne by the lessee rather than the lessor of the vessel (for related discussion of this point see Stopford 2009; Kilian and Zhou 2018; Nomikos and Regli 2019). Following a positive cost shock, operating costs for time charterers increase, so there is less demand for shipping oil and the volume of oil exports must fall. Likewise, the real profits of the owners of VLCCs must also drop, given prior evidence of imperfect cost passthrough (see Agnolucci et al. 2014).[8]

A negative tanker supply shock raises both the TC rate and the round-trip voyage rate.

[6] An example is the steep contango in the crude oil futures markets caused by Covid-19 in early 2020 that led to a surge in the chartering of VLCC for floating storage. As of April 17, 2020, 54 VLCCs were used as floating storage, according to Lloyd's List Intelligence. This is 7% of the entire fleet.

[7] An example is the decision of the Trump administration in September 2019 to prohibit several Chinese firms including a unit of COSCO Shipping Corp from carrying crude in retaliation for violations of Iran sanctions. This decision effectively reduced the available VLCC fleet in the tanker market.

[8] If cost shocks are fully passed on to round-trip voyage rates, the impact response of profits would be zero. However, if cost shocks are only partially passed on to round-trip voyage rates in the impact period, profits will fall on impact. This effect will be reinforced by a decline in the shipping volume. We therefore impose a negative sign on impact.

The increase in tanker rates causes a reduction in the demand for oil tankers and hence in oil exports. Likewise, the demand for bunker fuel and hence the price of fuel decline. Profits must increase, in contrast, given the low elasticity of seaborne trade to changes in freight costs. Finally, a positive shock to the demand for tankers raises both time charter rates and round-trip voyage tanker rates and hence is associated with higher oil exports, higher real profits, and higher fuel prices.

In addition, we impose the dynamic sign restriction that the response of the volume of oil exports from the Arabian Gulf, the response of the real time charter rate, and the response of real profits to a positive tanker demand shock remains positive for at least 6 months. This restriction makes sense given that the effects of such a shock are expected to be persistent.

3.2. Estimation and Inference

The model is estimated using the state-of-the-art Bayesian methods of Arias, Rubio-Ramirez and Waggoner (2018) and Antolin-Diaz and Rubio-Ramirez (2018), which in turn build on Rubio-Ramirez, Waggoner and Zha (2010). As is standard in the literature, we postulate a diffuse Gaussian-inverse Wishart prior for the reduced-form VAR parameters and a uniform prior for the rotation matrix Q. Let $A=\left[A_1,...,A_{12}\right]$ denote the autoregressive slope parameters and Σ_u the residual variance-covariance matrix. For a given realization of A and of the lower triangular matrix $P=chol(\Sigma_u)$ with positive diagonal elements, we draw realizations of the matrix Q as described in Arias et al. (2018).[9] We use each of these candidate solutions in conjunction with A to construct the candidate structural models and their structural impulse responses.

Given the diffuse Gaussian-inverse Wishart prior distribution for the reduced-form

[9] It should be noted that the presence of an exclusion restriction in B_0^{-1} invalidates the standard approach to generating draws from the posterior distribution of the structural impulse responses, as discussed in Rubio-Ramirez et al. (2010).

parameters, this procedure may be repeated for a large number of reduced-form posterior draws for (A, Σ_u) to account for parameter estimation uncertainty. We retain the set of models that satisfy the static and dynamic restrictions on the impulse responses. We then reweight these candidate solutions using the importance sampler based on numerical derivatives discussed in Arias et al. (2018) to allow for the fact that zero restrictions on Q render draws from the space of all possible Q matrices non-uniform. All results are based on 5,000 draws from the distribution of reduced-form parameters combined with 200 draws each for Q.

4. Empirical Results for the Baseline Model

4.1. Impulse Responses

Figure 2 summarizes the dynamic responses of the variables of interest to each of the structural shocks. Each subplot traces the response of a given variable to a given structural shock for up to 18 months. We evaluate the impulse response functions under absolute loss, as discussed in Inoue and Kilian (2020), taking account of the dependence of the impulse responses. The response functions associated with the optimal model solution under absolute loss are shown as dark solid lines and the responses of the models in the joint 68% credible set derived under the same loss function are shown in a lighter shade. Most responses are fairly precisely estimated.

All response functions make economic sense. A positive utilization shock persistently raises the real TC rate, slightly lowers the volume of oil exports, causes a short-run surge in profits and a slight, but persistent decline in bunker fuel prices. A positive tanker cost shock causes a slight decline in the real TC rate after the impact period. Although time charter tanker rates do not respond to higher fuel costs directly, higher fuel costs are associated with a persistent decline in the demand for time charters because the charterer's profits are reduced by higher operating costs. This helps explain the negative response of the volume of oil exported from the Arabian Gulf, which also reflects an increase in the real round-trip voyage rate, as higher costs are passed on to customers. This may be inferred from the fact that real profits of VLCC owners from round-trip voyage runs decline in the short run. The fact that real profits decline by more at short horizons than at long horizons is particularly interesting. It suggests that increased costs are not being fully passed on to round-trip voyage rates right away. If they were, one would expect profits to remain unchanged in the voyage market, for a given volume of shipping, and the decline in real profits should mirror the decline in export volume.[10]

A negative tanker supply shock, as expected, causes a persistent increase in the real time charter rate and a persistent decline in the oil export volume, as there are fewer vessels available and the cost of shipping increases. Given the lack of alternative means of transportation, seaborne exports are not very responsive to changes in freight costs. The net effect on the real profits of owners of VLCCs chartered for round-trip voyages is positive and persistent. Thus, on balance, tanker shortages raise real profits in the industry, but the extent of these gains declines after one year. Bunker fuel prices respond positively to a reduction in the number of vessels. Finally, a positive shock to tanker demand also raises the real time charter rate and bunker fuel prices persistently, but is associated with a persistent increase in the volume of oil exports from the Arabian Gulf and in real voyage profits.

4.2. Variance decompositions

Variance decompositions allow us to assess to what extent the variability of the model variables is explained by each shock on average. Table 1 shows the variance decomposition for the model that is optimal under absolute loss. It also reports the minimum and maximum contribution across the models contained in the 68% joint credible set, shown in Figure 2.

[10] This finding is also consistent with evidence from the dry-bulk shipping industry that owners are only partially able to recover fuel savings from time charter rates (Agnolucci, Smith and Rehmatullah 2014; Adland, Alger, Banyte and Haiying 2017).

Table 1 indicates that variation in the real voyage profits of VLCC owners operating on the Arabian Gulf (AG)-East Asia route depends mainly on the tanker demand shock and the tanker utilization shock. Whereas short-term utilization shocks are most important in explaining the profits from short round-trip voyage of 50 days, for time-charter contracts, the impact of short-term utilization shocks is diffused over the longer duration. Thus, the variability of the real time charter rate is largely determined by a combination of tanker demand shocks and to a lesser extent tanker supply shocks. The variability of real bunker fuel prices reflects mainly tanker demand shocks, tanker supply shocks and fuel costs shocks, with the role of utilization shocks being negligible. Finally, the variability in the volume of oil exports from the Arabian Gulf is so imprecisely estimated that one would be hard pressed to interpret the estimates.

5. An Alternative Structural Model of the VLCC Oil Tanker Market in the Arabian Gulf

In this section, we propose an alternative model that differs from the baseline model in that the real round-trip (RT) voyage rate replaces the real profits variable.

5.1. Identifying Restrictions

We postulate that

$$\begin{pmatrix} u_t^{TC\,rate} \\ u_t^{exports} \\ u_t^{RT\ rate} \\ u_t^{fuel\ price} \end{pmatrix} = \begin{bmatrix} + & 0 & + & + \\ - & - & - & + \\ + & & + & + \\ 0 & + & - & + \end{bmatrix} \begin{pmatrix} w_t^{utilization} \\ w_t^{\text{cost}} \\ w_t^{\text{supply}} \\ w_t^{\text{demand}} \end{pmatrix}. \tag{2}$$

As in the baseline model, we exploit the fact that bunker fuel prices do not respond to the utilization shock and that time charter rates do not respond to cost shocks on impact. A higher utilization of VLCCs is associated with higher demand for VLCCs and hence higher TC and RT rates, which explains the negative sign of the volume of oil exports. The fuel price does not respond on impact, since the utilization shock applies to vessels already at sea. A positive cost shock is associated with higher bunker fuel prices and lower exports, as voyage profits decline. TC rates are not affected on impact. We do not impose the restriction that positive cost shocks raise the real round-trip voyage rate on impact, since VLCC owners may not be able to immediately pass on a cost shock to the RT rate. Negative tanker supply shocks raise the real round-trip voyage rate and lower the volume of oil shipped (which is proportionate to the number of available carriers), as the VLCC supply curve shifts to the left of the demand curve. They also lower the demand for fuel and hence the bunker fuel price. Finally, positive tanker demand shocks raise all model variables on impact. Otherwise, the identifying restrictions and model specification are the same.

This alternative model not only helps us to make statements about the determinants of the real round-trip voyage rate, but it also helps cross-validate the conclusions reached based on the baseline model.[11]

5.2. Empirical Results for the Alternative Model

5.2.1. Impulse Responses

Figure 3 shows that the responses of the volume of oil exports and of the real time charter rate are quite similar to Figure 2. One minor difference is that, unlike in Figure 2, the real time charter rate does not decline in response to a positive cost shock. Another minor difference is that the volume of oil exports does not decline in response to a positive utilization shock. Such declines would be consistent with the joint credible set, however.

Of particular interest are the additional estimates of the response of the real round-trip voyage rate. A positive tanker utilization shock raises the real round-trip voyage rate, but the response largely dies out after only three months. Real round-trip voyage rates respond

[11] It may seem that one could simply have added the real round-trip voyage rate to the baseline model instead of specifying the alternative model. This is not the case because without adding an identified shock the inclusion of real profits would render the covariance structure of this extended VAR model singular.

positively to negative tanker supply shocks in the short run. They also show a somewhat larger positive response to positive tanker demand shocks that dies out only after one year. The persistence of these responses is consistent with the baseline model.

In contrast, a positive fuel cost shock does not appear to have a large positive effect on the real round-trip voyage rate. In fact, the response to fuel cost shocks is indistinguishable from zero, although the error bands are also consistent with a small positive response. A zero response would imply that the pass-though is zero, which would be at odds with the decline in the volume of oil exports in response to the same shock. It would also be at odds with the indirect evidence from the response of real profits in the baseline model in Figure 2. Figure 2 implied that the round-trip rates must be increasing in response to cost shocks, especially at longer horizons.

5.2.2. Variance decompositions

Table 2 shows the corresponding variance decompositions. For the model variables contained in both the baseline and the alternative model, the variance decompositions are remarkably similar to those in Table 1. As in Table 1, the decomposition for the volume of oil exports is too imprecisely estimated to allow any economic interpretation. Table 2 confirms that costs shocks are not an important determinant of the real time charter rate. This finding is consistent with earlier evidence from the dry-bulk shipping industry about the imperfect cost pass through in the presence of a principal agent problem, with the vessel owner being the agent and the time charterer being the principal (see Agnolucci et al. 2014; Adland et al. 2017). Instead, much of the variation in that rate comes from a combination of tanker supply and tanker demand shocks. Moreover, the variability of round-trip is largely driven by utilization and tanker demand shocks, much like the variability of voyage profits in Table 1, and that of bunker fuel prices mainly reflects tanker supply and demand shocks.

6. Understanding the Historical Evolution of the Model Variables

The historical decompositions in Figures 4-8 provide additional information on how each shock cumulatively affected the evolution of the variables of interest, drawing on results from both the baseline and the alternative model. We focus on the decomposition of the optimal model under absolute loss. Each subplot shows the cumulative effect of a given shock on the variable of interest at each point in time, while setting to zero all other structural shocks. We deal with the transition dynamics in the construction of the historical decomposition by discarding the first ten years of data (see Kilian and Lütkepohl 2017). Since the results are quite similar across model specifications, we mainly focus on the baseline model.

6.1. Volume of oil exports from the Arabian Gulf

Figure 4 indicates that until 2008, the volume of oil exports from the Arabian Gulf was largely determined by tanker demand shocks, consistent with the view that oil tanker demand is ultimately derived from demand for oil. For example, tanker demand shocks accounted for a 26% cumulative increase in export volumes during the Great Surge in oil markets. Neither utilization shocks nor fuel cost shocks or tanker supply shocks cumulatively had much of an effect over this period. The sustained demand-driven boom from 2003 until mid-2008, is followed by a contraction during the financial crisis and an incomplete recovery from 2009 to 2011. From 2011 to 2016, the demand-driven component of the volume of oil exports from the Arabian Gulf remains relatively stable. Only in 2017, it weakens again.

A particularly interesting additional finding that holds regardless of the specification, is a spike in oil export volumes (and, as we will see later, in both tanker rates) associated with the temporary détente in U.S. trade policy in 2018/19. This evidence shows that trade disputes may have real effects on industrial commodity markets, consistent with the empirical findings of Ademuyiwa and Siklos (2019). Even granting that some aspects of the structural models are only imprecisely estimated, the baseline and the alternative structural model paint a coherent picture of the role of tanker demand shocks.

Tanker supply shocks contributed to slight increases in the volume of oil exports at times, but only in 2011/12 and in 2016-18, these contributions are noticeable. Fuel cost shocks contributed to the rise in the volume of oil exports in 2015/16 in particular, whereas utilization shocks had not much impact overall.

6.2. Real VLCC Time Charter Rates

Figure 5 shows that in the baseline model real time charter rates were relatively unaffected by fuel cost shocks, which is not surprising since such costs are not borne by the owner of the tanker. Much of the evolution of real time charter rates is driven by tanker demand shocks. It is useful to characterize this point numerically. During the Great Surge from 2002 to mid-2008, tanker demand shocks accounted for a 123% cumulative increase in real time charter rates, with no other shock even remotely as important. During the financial crisis, they caused a sharp cumulative decline in time charter rates of 121%, followed by a 44% cumulative increase during the recovery. There is also a slight slump in the tanker demand-driven component from 2011 to 2014, but interestingly not in 2014/15, suggesting that demand for crude oil from East Asia remained stable during the 2014/15 oil price decline. Likewise, time charter rates fell in 2017/18, as tanker demand fell, before the trade policy induced blip in 2018/19 that we already mentioned.

There is no evidence that tanker supply shocks help explain the rise in tanker rates in the first half of the estimation period. Tanker supply shocks did help lower real time charter rates during part of the second half of the estimation period, however. There is a sustained trough in tanker rates in 2011-14 and another trough in 2016-19 driven by positive tanker supply shocks.[12] This result is consistent with anecdotal evidence of a vessel glut in oil tanker markets. Demand for raw materials, including crude oil, surged in the 2000s, following rapid

[12] It should be noted that all results in Figure 5 are based on the baseline model, but the corresponding historical decomposition based on the alternative model is similar enough, that there is no point in showing it.

growth in many emerging economies and China's admission to the WTO in 2001. This caused a surge in the demand for seaborne transportation which, after a prolonged period of underinvestment in the shipping industry in the 1990s, caused a sustained increase in shipping rates. The strong freight market, from 2003 to mid-2008, coincided with an increase in the orderbook for new vessels. Significant construction lags meant that these vessels were delivered, just as the financial crisis was unfolding and the shipping market contracted.[13] The pattern of overinvestment at the peak of the market cycle is a key feature of the shipping industry (e.g., Kalouptsidi, 2004; Greenwood and Hanson, 2015; Moutzouris and Nomikos, 2020). Finally, the gradual decline in time charter rates from 2009 to 2014 is seen to be the result of a combination of lower tanker demand, lower utilization, and higher tanker supplies.

6.3. Real Bunker Fuel Prices

Figure 6 reveals that fuel cost shocks were not an important determinant of bunker fuel prices before late 2014, when the global price of crude oil declined sharply and persistently. Some of this decline was offset by higher cumulative fuel demand after 2015 caused by positive tanker supply shocks. Utilization shocks helped lower fuel prices slightly from 2009 to 2011, but generally were inconsequential for fuel prices. As is the case for other variables, the main driver of the increase in bunker fuel prices until mid-2008, their decline in late 2008, and their recovery in 2009 was tanker demand shocks. Since 2010, the demand-driven component of fuel prices has gradually declined with the exception of the 2018/19 blip associated with trade policy shifts. Some of the recovery in fuel prices in 2010-12 must be attributed to the cumulative effects of positive tanker supply shocks.

6.4. Real Profits of VLCC Owners on the AG-East Asia Route

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[13] Between 1991 and 2000 the cumulative growth in the VLCC fleet was only 2.9%. In contrast, the average annual growth in the VLCC fleet from 2010 to 2019 was 5%.

Figure 7 presents the historical decomposition of real profits from round-trip voyages from the Arabian Gulf to East Asia in the baseline model. The main difference is that the cumulative effect of the utilization and cost shocks on real profits is much noisier than for the real time charter rates. Profits are driven by the profitability of a round-trip voyage with a duration of 50 days and, hence, are more volatile compared to time-charter rates that measure earnings over the calendar year. Abstracting from this noise, the qualitative pattern is quite similar to that we documented for the real time charter rate.

6.5. Real VLCC Round-Trip Voyage Rates from AG to Asia

A broadly similar pattern is also found in Figure 8, which shows the historical decomposition of the real round-trip voyage rate in the alternative model. The cumulative effect of tanker demand and supply shocks follows a pattern reminiscent of that in oil exports, real profits and the real time charter rate. The cumulative effects of the utilization shock and the tanker supply shock are more muted than for real profits, however.

7. Conclusion

The market for oil tankers is an important component of the supply chain for crude oil, yet this market has remained poorly understood, owing to the paucity of time series data and the absence of an empirical framework for studying its determinants. Our work advanced this literature in several ways. First, we constructed a new data set of key economic indicators for the VLCC market from the Arabian Gulf to East Asia for the covering January 1991 through October 2019. We noted that focusing on oil exported from the Arabian Gulf to East Asia by VLCCs facilitates the identification of shocks to tanker supply, tanker utilization, tanker demand and the costs of oil shipping. Second, we developed a structural vector autoregressive framework for this market that allowed us to quantify the determinants of these indicators. This is a major advance in that existing studies of oil markets to date have focused on documenting lead-lag relationships and reduced-form correlations without addressing the underlying identification problem. Third, using state-of-the- art econometric methods, we studied in detail the causes of fluctuations in round-trip voyage and time charter rates, oil export volumes, bunker fuel prices, and shipowner profits. Our estimates are informative, economically intuitive, and relevant for understanding today's oil market.

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Table 1: Variance Decompositions in Percent for Baseline Model

	Tanker utilization shock	Tanker cost shock	Tanker supply shock	Tanker demand shock
Volume of Oil Exports from AG	26.5 [1.0, 86.4]	31.2 [1.4, 83.6]	24.5 [0.4, 74.6]	17.8 [3.2, 84.6]
Real Time Charter Rate for VLCCs	16.7 [1.8, 65.4]	8.5 [0.2, 42.3]	24.3 [1.1, 80.1]	50.6 [5.0, 85.6]
Real Profits of VLCC Tanker Owners on AG-East Asia Route	35.9 [3.3, 70.8]	17.9 [2.2, 41.1]	11.0 [1.3, 65.7]	35.1 [6.0, 60.7]
Real Price of Bunker Fuel	7.6 [0.6, 66.6]	26.1 [0.6, 81.1]	32.5 [2.3, 78.1]	33.9 [2.0, 83.1]

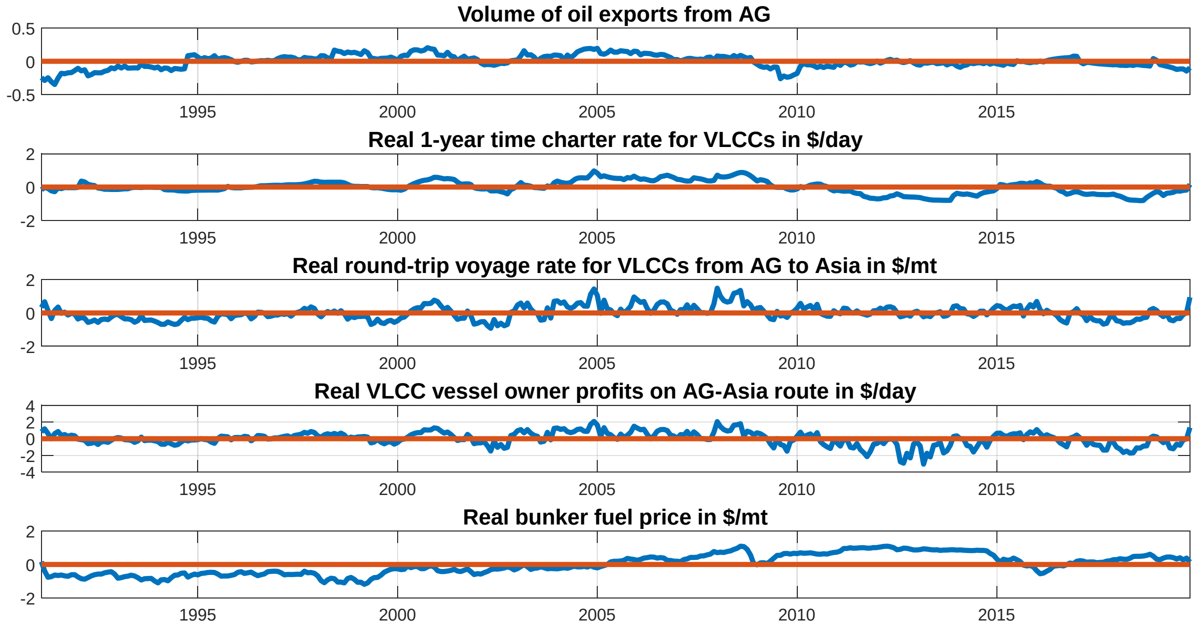
NOTES: The results shown are for the optimal model under absolute loss as shown in Figure 2 (with the minimum and maximum across the models in the 68% joint credible set shown in parentheses).

Table 2: Variance Decompositions in Percent for Alternative Model

	Tanker utilization shock	Tanker cost shock	Tanker supply shock	Tanker demand shock
Volume of Oil Exports from AG	3.0 [0.7, 80.3]	54.8 [1.5, 84.7]	26.1 [1.0, 79.9]	16.0 [2.0, 86.2]
Real Time Charter Rate for VLCCs	5.6 [0.6, 92.9]	3.6 [0.3, 42.6]	45.6 [0.6, 88.9]	45.1 [1.5, 82.4]
Real VLCC Round-Trip Voyage Rate from AG to East Asia	34.7 [3.7, 69.1]	8.2 [2.5, 38.7]	15.5 [1.3, 57.7]	41.6 [12.0, 72.3]
Real Price of Bunker Fuel	2.2 [0.2, 49.1]	21.9 [1.7, 77.8]	36.6 [4.3, 93.6]	39.2 [1.4, 75.8]

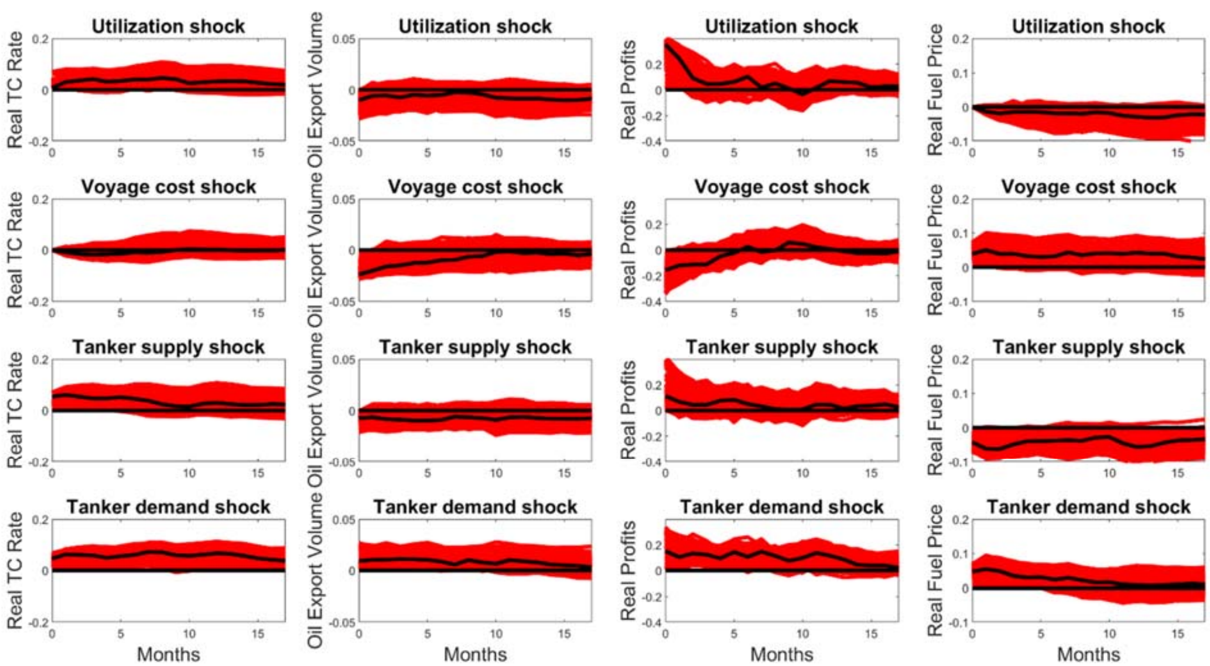
NOTES: The results shown are for the optimal model under absolute loss as shown in Figure 2 (with the minimum and maximum across the models in the 68% joint credible set shown in parentheses).

Figure 1: Key Indicators of the Arabian Gulf-East Asia Oil Tanker Market



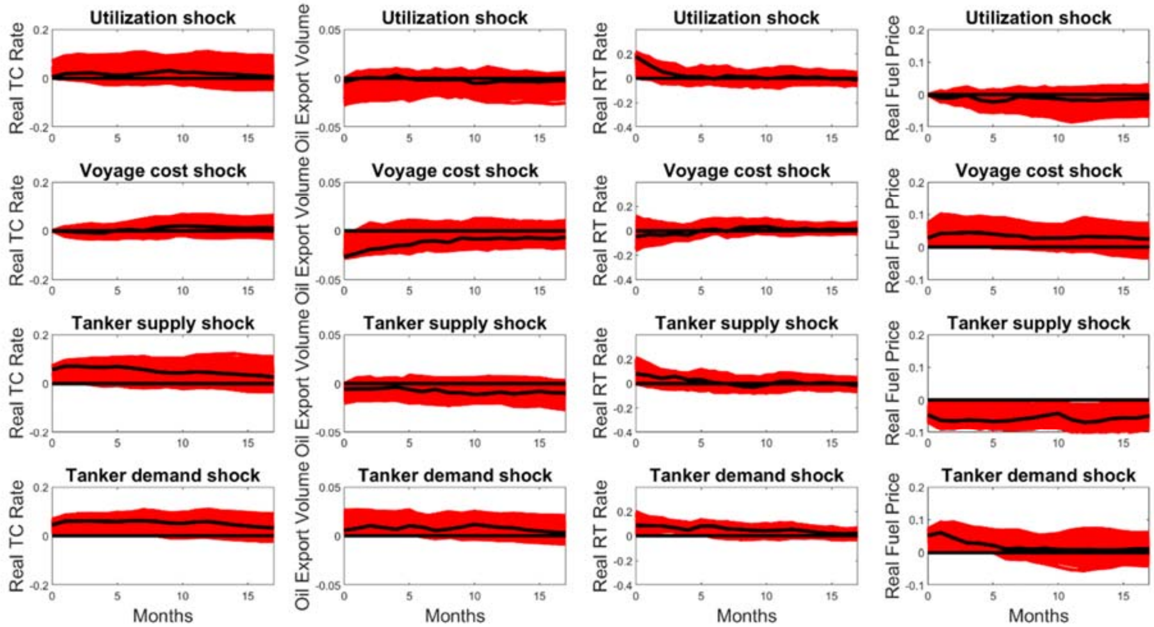
NOTES: All data are expressed in log deviations from the mean or trend.

Figure 2: Impulse Responses Estimates and 68% Joint Credible Sets in the Baseline Model under Absolute Loss



NOTES: The responses for the optimal model under absolute loss are shown as dark lines and the responses of models in the 68% joint credible set are shown in a lighter shade.

Figure 3: Impulse Responses Estimates and 68% Joint Credible Sets in the Alternative Model under Absolute Loss



NOTES: The responses for the optimal model under absolute loss are shown as dark lines and the responses of models in the 68% joint credible set are shown in a lighter shade.

Figure 4: Historical Decomposition of Tanker Demand Shocks in Baseline Model

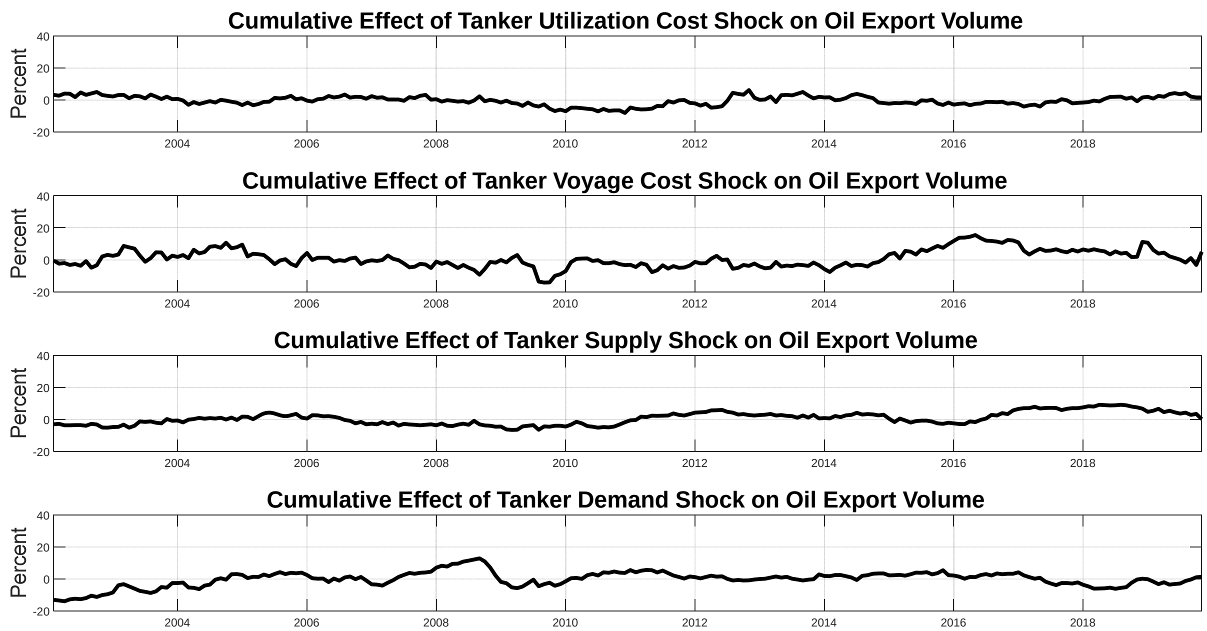


Figure 5: Historical Decomposition of the Real Time Charter Rate for VLCCs in Baseline Model

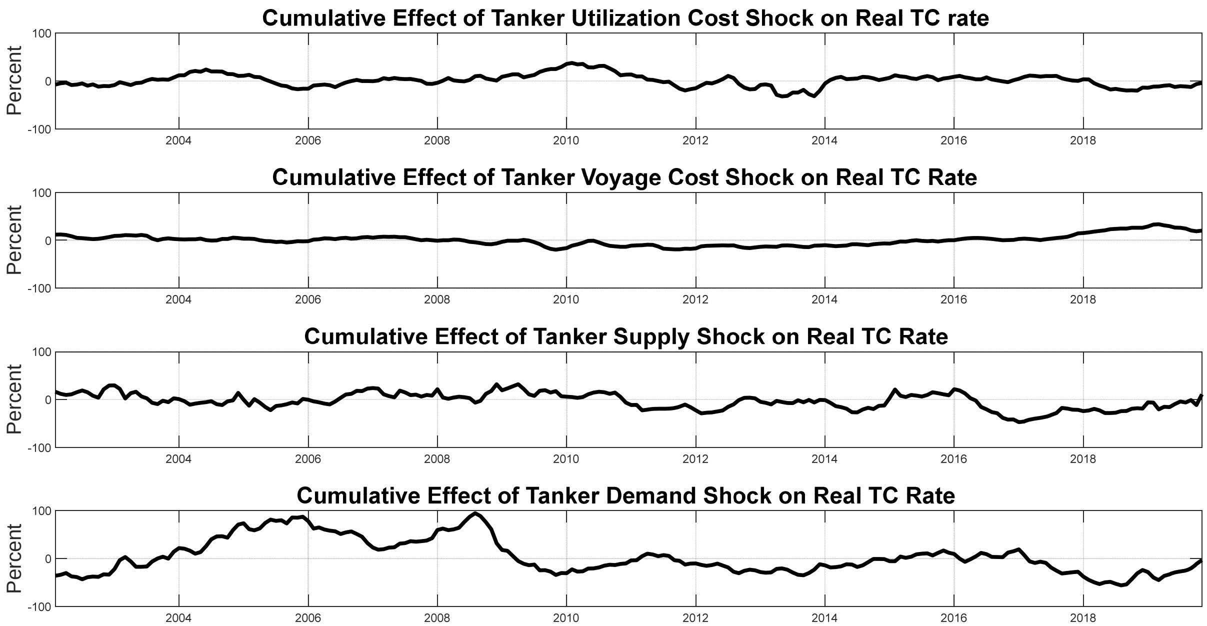


Figure 6: Historical Decomposition of Real Bunker Fuel Price in Baseline Model

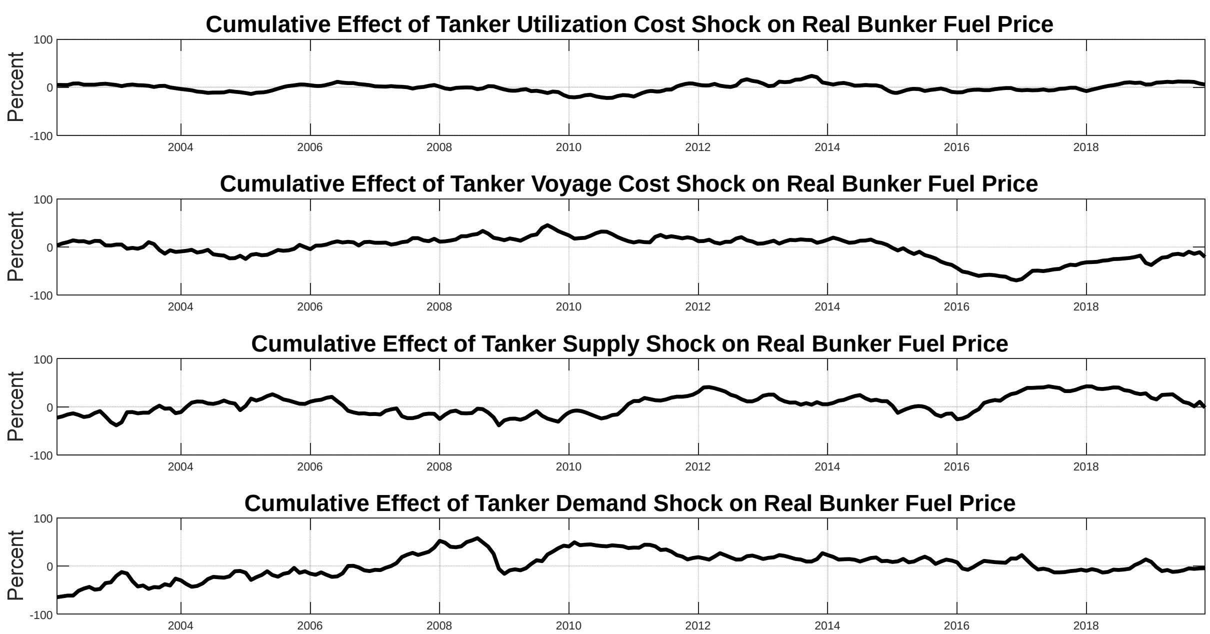


Figure 7: Historical Decomposition of Real Profits of VLCC Owners on Arabian Gulf-East Asia Route in Baseline Model

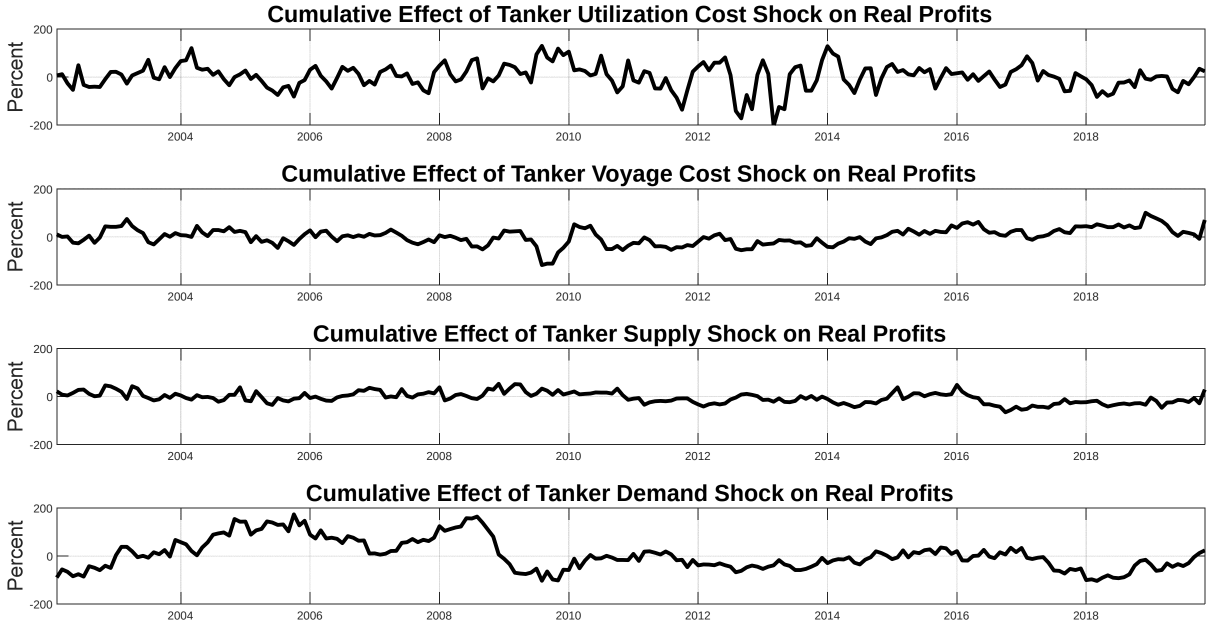
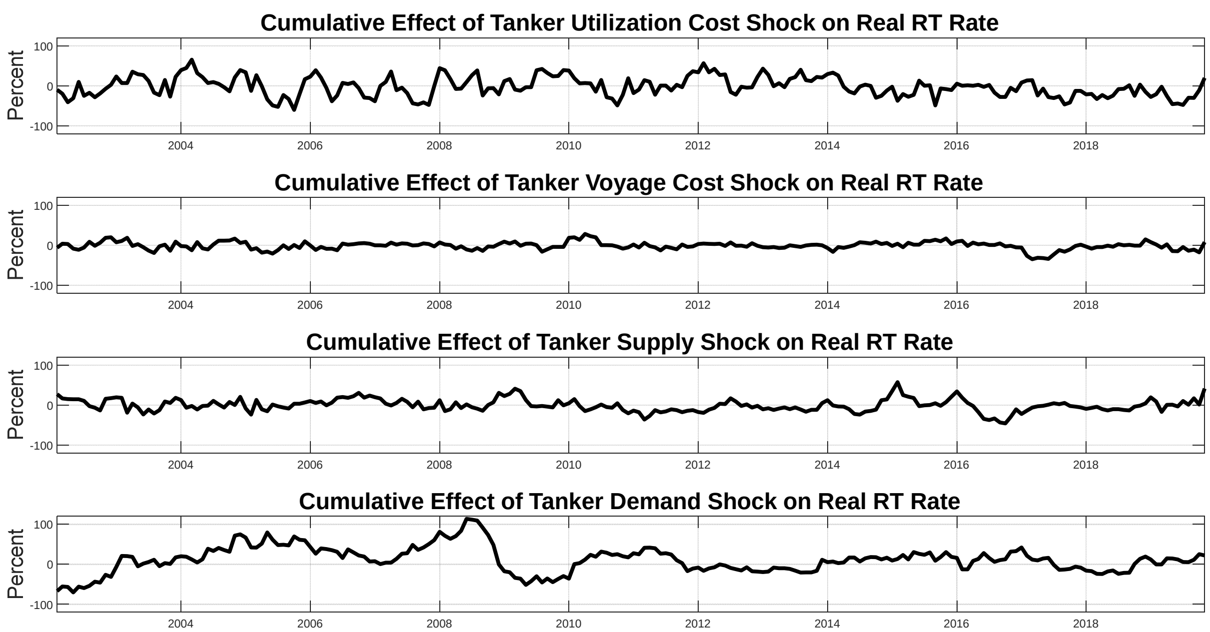


Figure 8: Historical Decomposition of Real VLCC Round-Trip Voyage Rate from Arabian Gulf to East Asia in Alternative Model



Data Appendix

The raw data are from the Clarksons Shipping Intelligence Network (SIN) which provides freight rate and trade statistics across a number of sectors of the shipping industry. We use the following series:

Ras-Tanura to Chiba Round-Trip Voyage rates: This is the all-inclusive rate for the transportation of a VLCC cargo of near 2 million barrels of crude oil (or deadweight of about 265,000 metric tons) from Ras Tanura in the Arabian Gulf to Chiba in Japan. There are a number of shipping routes serviced by VLCC vessels, but this particular route is considered a key benchmark with consistent reporting and liquid trading activity. The rate reported by SIN covers the round-trip voyage cost (a laden leg from Ras-Tanura to Chiba and a ballast leg from Chiba to Ras-Tanura) and is expressed in Worldscale points, as is the convention in the tanker market.[14] We convert the reported round-trip tanker voyage rates from Worldscale points into the equivalent US$/mt freight rate using the appropriate Worldscale flat rates. This rate represents the all-inclusive cost for the transportation of a cargo of crude oil.

Using rates for a round-trip has a number of advantages. Combining freight rates for both the laden and the ballast leg overcomes the problem that freight costs are largely asymmetric between the front-haul (laden) and back-haul (ballast) routes and are subject to significant search costs (e.g., Behrens and Picard, 2011; Brancaccio, Kalouptsidi and Papageorgiou 2020; Brancaccio, Kalouptsidi, Papageorgiou and Rosaia 2020). In addition these rates represent the fair market assessment between a willing buyer and a willing seller

[14] The Worldscale Association calculates the cost of performing a round-trip tanker voyage between any two ports in the world. The freight cost is calculated for a standard 75,000 mt dwt “Aframax”-type tanker vessel after making certain assumptions regarding voyage costs (such as port charges, canal charges and bunker costs) that are applicable for each voyage. The resulting freight rate, quoted as U.S. $/mt, is effectively the break-even rate for the particular vessel and voyage and is known as Worldscale 100 or as the Worldscale Flat Rate. The Worldscale 100 reference rate for each voyage is usually updated once a year to reflect changes in the cost of performing a voyage. The actual negotiated rate for any trip is then quoted as a percentage of that rate. For instance, if the flat rate is U.S.$ 14.9 $/mt and the negotiated rate for a voyage is Worldscale 50, then the agreed rate is 50% of 14.9, i.e., 7.45 U.S.$/mt.

for a standard type ship and thus are not subject to differences in the quality or condition of the vessel or in the creditworthiness of the counterparties, as discussed in Tamvakis and Thanopoulou (2000).

Ras – Tanura to Chiba Profits: This is the net revenue, in US$/day, earned on the Ras-Tanura-Chiba round-trip voyage after deducting voyage costs (fuel costs and port costs) and broker's commission from the total compensation earned by the shipowner and dividing by the number of days of the voyage. These net earnings (or profits) of the vessel owner for this particular route are calculated based on the following variables:[15]

Freight Income: Voyage Rate in $/mt × cargo size.

Port Costs: Sum of loading and discharge costs for the specified route, cargo size and ship type.

Bunker fuel prices: Average of bunker fuel prices at major bunkering hubs on this route. To estimate the total fuel cost for the voyage the following speed and fuel oil consumption profile for a VLCC vessel is used: Sailing speed of 13.5 knots at 80 mt fuel oil per day (laden) and 12 knots at 55 mt fuel oil per day (ballasted).

Voyage Duration: Sea time, based on the sailing speeds above, plus 5% sea margin plus two days for cargo loading and two days for cargo discharging. For the Ras-Tanura to Chiba route the total voyage time is 50 days.

Commission: 2.5% commission is deducted from total freight revenue. This is the ship broker's commission and represents the search costs for the particular voyage.

It should be noted that our profit measure does not account for all costs borne by vessel owners. It does not adjust for fixed costs such as crew costs and maintenance costs. In

[15] For further details the reader is referred to *Sources and Methods for the Shipping Intelligence Weekly* (available from www.clarksons.net).

practice, owners will operate vessels if voyage earnings can cover voyage costs and part of the fixed costs (see Stopford 1997).

VLCC One-year Time-Charter (TC) Rate: This is the rate, in US $/day, for chartering a VLCC vessel for one year. Under a time-charter contract, the charterer (or lessee) agrees to hire the vessel from the shipowner (or lessor), for a specified period of time, which may vary from three months up to several years in general. One-year TC rates are the most commonly used form of a period contract in the shipping industry. The charterer takes commercial control of the vessel for the duration of the contract and is responsible for all voyage costs.

One key difference between earnings and voyage rates on the one hand and TC rates on the other is that earnings are for a specific route while a TC contract allows a vessel to operate globally. In addition, the duration of the contract is different. Earnings are for a voyage of 50 days, whereas TC rates are typically quoted for a period of one year. As a result, TC rates also reflect the expectations of future earnings beyond the duration of a given voyage. A third difference is TC rates do not include operating costs.

Crude Oil Exports: These are monthly seaborne crude oil exports from the Arabian Gulf (AG) measured in million barrels per day. For 2019, VLCCs transported more than 70% of total oil production out of Arabian Gulf, the majority of which was destined for East Asia. Thus, aggregate crude oil exports are representative of the overall level of VLCC trade on the AG–East Asia route.

Bunker Fuel Prices:

Bunker fuel or heavy fuel oil (HFO) is the main fuel that cargo vessels use for propulsion. It is a residual fuel from the oil distillation process. A typical VLCC consumes about 80 mt of fuel oil per day on a laden leg assuming an average speed of 13.5 knots. The total fuel consumption for the Ras-Tanura to Chiba round-trip voyage is approximately 2874 mt of HFO and cost about $939,000 at October 2019 prices. Bunker costs are the single most important part of voyage costs. Depending on the price of bunker fuel, they can account for up to 70% of the total voyage costs. In addition, they are the most volatile part of voyage costs as all other voyage costs (such as port charges) tend to increase at the rate of inflation.

We use monthly prices, in $/mt, for HFO in Fujairah which is the major bunkering hub in the Arabian Gulf. The benchmark fuel type is HFO with 380 centistokes (cst) viscosity and sulphur content of 3.5%.[16] It is worth noting that new International Maritime Association (IMO) regulations that limit ships' emissions came into effect in January 2020. As a result, ships need to use more expensive low sulphur fuel oil with a sulphur content of 0.5% or, invest in exhaust gas cleaning systems, known as scrubbers, so as to continue using high sulphur fuel oil. However, this important change came into effect only outside of our estimation period.

[16] Centistokes is the unit of measurement of fuel viscosity and also reflects its distillate content. HFO Grade 380cst has between 2 and 5% distillate content.