Influencing factors of crude oil maritime shipping freight fluctuations: a case of Suezmax tankers in Europe–Africa routes

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Received 18 April 2021
Revised 5 October 2021
8 December 2021
16 December 2021
Accepted 20 December 2021

Abstract

Purpose – The paper aims to identify the contributors to freight rate fluctuations in the Suezmax tanker market; this study selected the refinery output, crude oil price, one-year charter rate and fleet development as the main influencing factors for the market analysis.
Design/methodology/approach – The paper used the vector error correction model to evaluate the degree of impact of each influencing factor on Suezmax tanker freight rates, as well as the interplay between these factors.
Findings – The conclusion and results were tested using the 20-year data from 1999 to 2019, and the methodology and theory of this paper were proved to be effective. Results of this study provide effective reference for scholars to find the law of fluctuations in Suezmax tanker freight rates.
Originality/value – This paper provides a decision-making support tool for tanker operators to cope with fluctuation risks in the tanker shipping market.

Keywords Crude oil, VECM, Suezmax, Impulse response, Variance decomposition

Paper type Research paper

1. Introduction

The world's petroleum product supply chains feature a large base of market players, including those engaged in production, trading, refining, distribution and petroleum transportation. Tanker shipping plays key roles of logistics and trade support in the petroleum market (Alizadeh *et al.*, 2015). Suezmax tankers, as one of the major tanker types in the world, are of significance in global oil trade and transportation. As a part of the energy cost, tanker freight rate changes significantly over time. In view of the high costs and high risks of the tanker shipping market, it is critical to study the fluctuation characteristics of tanker freight rates in order to avoid exposure to potential risks (Gavriilidis *et al.*, 2018).

In the tanker shipping market, Suezmax tankers play an important role on Europe–Africa routes, West Africa–US routes, Middle East–China routes and other routes. In addition to VLCCs and other large tankers, these routes also have a huge demand for Suezmax tankers (Wu *et al.*, 2019). Tanker freight rates are also susceptible to policies. For example, the OPEC oil production cut agreement's entry into effect, the sanctions against Iran, and other events in 2016 have caused international oil prices to continue to rise, leading to a reduced demand for Suezmax tankers. Suezmax tanker freight rates dropped as a result. Multiple complex factors contributed to the fluctuating freight rates, and tanker operators need to decide on the capacity input to the market, which makes the industry significant for studying the factors of Suezmax tanker freight rates.

Maritime Business Review
Vol. 8 No. 1, 2023
pp. 48-64
Emerald Publishing Limited
2397-3757
DOI 10.1108/MABR-04-2021-0033

Tanker freight rate is a barometer of market supply and demand. The fluctuation risks of the global Suezmax tanker shipping market have been a concern of scholars for a long time. Currently, they have conducted many studies on fluctuation trends and predictions of tanker freight rates (Tsouknidis, 2016; Abouarghoub *et al.*, 2018). To further determine the causes of tanker freight fluctuations, some scholars turned their sights on external factors, policies and events. Gavriilidis *et al.* (2018) found that oil price shocks from different sources could improve the accuracy of tanker freight fluctuation predictions. Regli and Nomikos (2019) used the AIS technology as a measure of capacity input in the new tanker market, improving the price discoverability of freight rates. Dai *et al.* (2020) used the BEKK–GARCH model to analyze Baltic Dirty Tanker Index (BDTI) and Brent crude oil prices from January 2007 to November 2015. The study showed that volatility shifted from the crude oil market to the tanker market rather than from the tanker market to the crude oil market over the long term. Lam and Wong (2018) pointed out that after the *Paris Agreement* was signed, shipping companies faced many challenges, such as increased shipping costs and mandatory carbon emission reduction targets. Fei *et al.* (2020) used the improved R/S model to study the development trends of various qualitative events on BDTI, and found that the financial crisis and international competition both suppressed BDTI, while environmental awareness and crude oil agreements could stimulate BDTI.

Similar to the studies on oil tanker freight fluctuations, the research methods for the dry bulks market are also worth learning from. Scholars have carried out much research in this area. Tsouknidis (2016) used the multivariable DCC–GARCH model to capture the impacts related to dynamic conditions in the shipping and freight market. He found that during the global financial crisis, there was a significant volatility spillover effect in the shipping and freight market, and that there existed a long-term equilibrium relationship between freight rates and corresponding freight futures. Adland *et al.* (2016) established a fixed-effect model and implemented variance decomposition for 2,863 VLCC tanker fixtures and 1,789 Capesize ship fixtures between 2011 and 2014, and found that the charterers' personal characteristics and fixed match of ship owner and charterer had large contributions to the spot freight rates of Capesize ships. Ruan *et al.* (2016) used cross-correlation statistics and multi-analysis to test BDI and crude oil price using multifractal detrended cross-correlation analysis. The empirical results showed that the relationship between BDI and crude oil prices had obvious multifractal properties.

Based on the above similar studies on tankers and dry bulks shipping, we can find that freight rates change over time, and external factors such as time charter market, fleet development, and crude oil price are correlated with tanker freight rates. However, very few of current studies look at the quantitative impacts of multiple external factors on Suezmax tanker freight rates and the composition of tanker freight rate fluctuations. To determine factors' degrees of impacts on tanker freight rates and the dynamic relationships between them, this paper will use vector error correction model (VECM) to study the tanker market, analyze the dynamic relationships between and the impacting mechanisms of various fluctuation-contributing factors of tanker freight rates, and calculate the contributions of factors to freight fluctuations, so as to fill the gap of current research on Suezmax tanker market fluctuations.

The rest of the paper is structured as follows. Section 2 briefly introduces the influencing factors and volatility mechanism of freight fluctuations in the Suezmax tanker market. Section 3 introduces the basic framework and main steps of relevant theories and application of the methodology and model used in this paper. Section 4 uses this model to conduct an empirical study on the Europe–Africa route from the port of Sidi Kerir to the port of Marseille-Fos, and describes the results and discussion of model application. Section 5 gives the conclusion of this paper.

2. Key influencing factors and mechanism of freight fluctuations in the Suezmax tanker market

The tanker shipping market has a strong fluctuation caused by the interweaving of subjective factors such as world economy and international trade, international finance and exchange rate, war and international politics and support policies. In order to further determine the fluctuation mechanism of Suezmax tanker freight rates, the factors influencing the tanker freight rate should be analyzed first. During the period from 1999 to 2019, under the background of financial crisis, oil production reduction by OPEC countries and Iranian sanctions, this paper analyzes the volatility mechanism of Suezmax freight rates from the crude oil market, time charter market, fleet supply market and refined oil product market. There are two main mechanisms for the link between crude oil prices and tanker rates. On the one hand, tankers are mainly used to transport crude oil, which can be understood as synergistic effects. On the other hand, the fluctuation of tanker freight rates is largely due to the impact of crude oil prices on fuel costs (Chen *et al.*, 2017; Zheng and Lan, 2016). The time charter market allows the avoidance and hedging of spot freight rate risks, and determining the relationship between the time charter contract and spot freight will help reveal the fluctuation mechanism of spot freight market (Gavriilidis *et al.*, 2018; Tsouknidis, 2016; Chen *et al.*, 2019; Kavussanos and Visvikis, 2004; Zhang and Zeng, 2015). The size of the tanker fleet reflects the supply relationship in the tanker shipping market. Any change will lead to changes in the world fleet capacity and world seaborne trade, thus promoting the fluctuations in the market (Stopford, 2008; Lun and Quaddus, 2009). Refined oil products production reflects the transportation demand of crude oil transportation market (Gary *et al.*, 2007; Bai and Lam, 2021; Xu *et al.*, 2011; Lauenstein, 2017). Therefore, based on previous research results, this paper summarizes four factors that affect Suezmax tanker freight fluctuations, and uses the monthly data from 1999 to 2019 to list the correlation coefficient (Table 1), and present a graph depicting the relationship between freight rates and factors (Figure 1). There is a relatively strong positive correlation between refinery

Table 1. The correlation coefficient between four factors and Suezmax tanker freight rates

	Fleet development	Refinery output	Time charter rate	Crude oil price
Pearson	−0.4542	0.5508	0.6825	−0.1481
Spearman	−0.4073	0.5558	0.6987	−0.1963

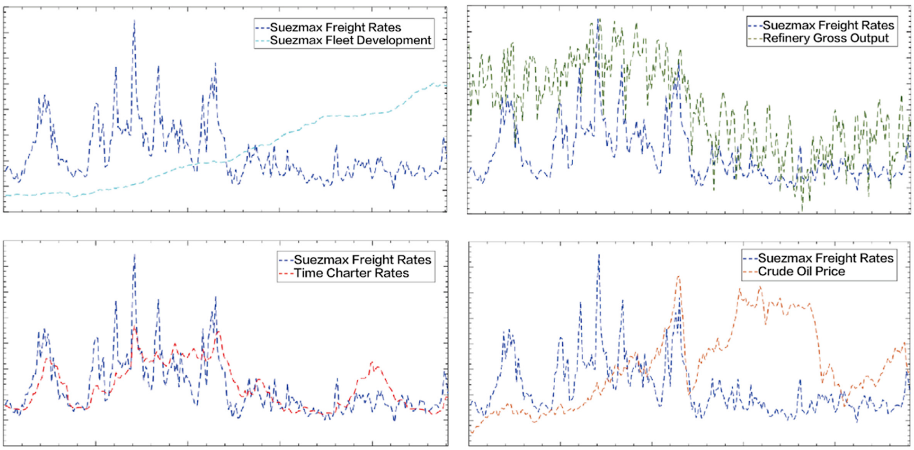

Figure 1. Relationship between Suezmax tanker freight rates and four factors

production and freight rates as well as one-year charter rate and freight rates, which shows similar fluctuation trend in the short and long term. It is worth studying that the crude oil price has a weak negative correlation with the tanker freight price, while the crude oil price has a significant impact on the tanker fuel cost, and has a similar trend in the short and long term shown. Fleet development has a relatively strong negative correlation to the freight rate. The fleet development has been on a rise from 1999 to 2019, while the freight rate since 2008, in the wake of the financial crisis, has been in a low level. The long-term trend of fluctuations is in consistent with the correlation. The fleet development grew faster when the freight rate was lower, reflecting the supply-demand changes in the market. Before the financial crisis in 2008 freight is high, which stimulated the shipbuilding industry, but the lag after tankers put into use made the fleet development still go up after the financial crisis. In addition, the shipbuilding cost reduction prompted the decision of the owner for new production of ship and so on. These cause the different trends with the other three factors.

Based on the above qualitative analysis, this paper attempts to explain the volatility mechanism of Suezmax tanker shipping market and quantitatively study the relationship between freight rates and fluctuation-contributing factors. Table 2 briefly describes the four factors.

The Suezmax tanker shipping market features strong volatility. Such fluctuation will affect the development of shipping policies, transactions and contracts. Therefore, it is of great practical significance to study its volatility mechanism. As shown in Table 2, the new market information spreads faster in the time charter market than in the spot market. The time charter rate can improve the predictive ability on spot price fluctuations, and reflect the whole market trends to some extent. The refinery output in European OECD countries reflects the refined oil product demand in the European market, which further affects the oil shipping volume, and then the freight rates on the Europe–Africa routes. The change in the global Suezmax fleet development reflects to some extent the prosperity of the Suezmax tanker shipping market. As an important source of fuel, crude oil price directly affects the shipping costs and profitability of tankers, which further catalyzes freight fluctuations.

Source	Factor	Description	References
Time Charter Market	One-year time charter rate (TCR) of Suezmax tankers	Charter rates are more responsive to market dynamics than the spot freight rates are, and feature price discoverability, which is conducive to predicting the spot freight rates	Gavriilidis *et al.* (2018), Chen *et al.* (2019), Kavussanos and Visvikis (2004), Tsouknidis (2016), Zhang and Zeng (2015)
Refined Oil Product Market	Refinery gross output (RGO) of European OECD countries	Refinery products refer to the products obtained through separating crude oil, such as liquefied petroleum gas, gasoline and kerosene. The output of these products, the most important strategic materials, reflects the shipping demand in the crude oil shipping market	Gary *et al.* (2007), Bai and Lam (2021), Xu *et al.* (2011), Lauenstein (2017)
Fleet Supply Market	World Suezmax fleet development (FD)	To some extent, the expansion of tanker fleet development reflects the prosperity of the tanker shipping market	Xu *et al.* (2011), Regli and Nomikos (2019), Stopford (2008), Lun and Quaddus (2009)
Crude Oil Market	Crude oil price (COP)	Crude oil price directly affects the shipping cost and profitability of tankers	Li *et al.* (2018), Alizadeh and Nomikos (2004), Chen *et al.* (2017), Zheng and Lan (2016), Dai *et al.* (2020)

Table 2.
Influencing factors of Suezmax tanker freight fluctuations

The volatility mechanism of the Suezmax tanker shipping market is the root cause of market changes, and the influencing factors of these market changes have cross-correlation with freight fluctuations. This feature directly results in the complex internal relations between tanker freight rates and various factors, and leads to violent fluctuations in the shipping market. Figure 2 shows the influencing mechanism between each variable and the Suezmax tanker freight rate. When the refinery augments production which exceeds the demand in the market, the oil tanker supply in the market fails to respond promptly, and the shipping demand decreases. Ship owners offer lower prices to seize market shares, which can lead to a reduction in oil tanker freight rates. To reduce losses, ship owners begin to cut capacity input. After a period of time, the crude oil supply for the refinery becomes insufficient, and the output falls to a level that fails to meet the market demand for oil products. Then the refinery begins to augment the output to meet market demand, and the freight rates start to go up. As the oil shipping market shows signs of improvement, ship owners start to input more capacity to the market to bag more profits. The refinery output increases as well. When the oil tanker fleet development grows, ship owners will try to win over shipping contracts by lowering freight rates. The market begins to slump as the freight rate drops. Ship owners then sell or dismantle oil tankers to control the capacity. The capacity of the tanker shipping market becomes insufficient to meet the oil shipping demand after a period of time, and then freight rates begin to rise again. The crude oil price determines the shipping cost, and the freight rate follows the same trend as the oil price. The time charter rate and spot rates have the same fluctuating direction, which indicates when it comes to a favorable prospect of the market, the market capacity will be in short supply, so freight rates will rise.

3. Methodology

3.1 Model framework

This paper uses VECM to study the factors of Suezmax tanker freight rates in the world, so as to determine the quantitative relationships between each factor and the freight rate. Traditional time series model only reflects the short-term fluctuation relationship among variables, failing to present the long-term equilibrium relationship between them. Engle and Granger combined co-integration and error correction model to establish VECM, which imposes more restrictions on the parameters of the traditional error correction model, overcomes the pseudo regression problem and captures the linear correlation among multiple sequences. It reflects the dynamic process of adjustment from short-term fluctuation to long-term equilibrium among variables (Engle and Granger, 1987; Kavussanos and Visvikis, 2004). Built on previous research results,

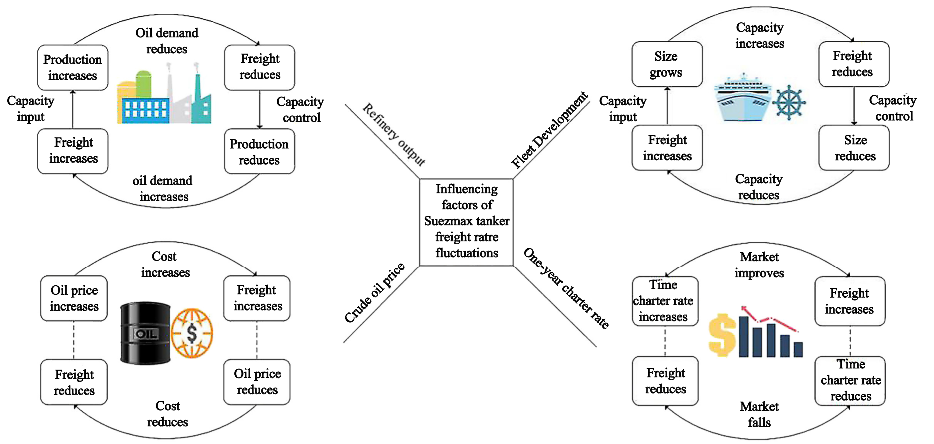

Figure 2.
Influencing factors of Suezmax tanker freight rate fluctuations

this paper builds VECM and uses Granger causality analysis, impulse response function and variance decomposition to evaluate the causal relationships between factors and Suezmax tanker freight rates, determine the impact on freight rates. The specific research framework is shown in Figure 3.

3.2 Steps of model construction

Main steps to establish the Suezmax tanker freight fluctuation model are as follows:

(1) For the high order autoregressive model of multivariate series in this paper, the stationarity of the time series needs to be validated using the Augmented Dickey–Fuller (ADF) test on the Suezmax tanker raw data (Dickey and Fuller, 1981), as shown in Formula 1.

$$\Delta y_t = \alpha y_{t-1} + \sum_{i=1}^{p} \theta_i \Delta y_{t-i} + \varepsilon_t \tag{1}$$

(2) According to the Akaike Information Criterion (AIC), Schwarz Criterion (SC) and Likelihood Ratio (LR) criteria, determine the lag value p of freight fluctuation model (Dickey and Fuller, 1981; Schwarz, 1978; Shibata, 1976). Obtain the lag value that corresponds to the minimum value calculated following the AIC and SC criteria, respectively. If they are different, the lag value of the LR criterion is regarded as the optimal lag value, as shown in Formulas 2, 3, and 4:

$$AIC = 2(\mathrm{n}/\mathrm{T}) - 2(l/T) \tag{2}$$

$$SC = \mathrm{n}\ln T/T - 2l/T \tag{3}$$

$$LR = (T-m)\{\ln|\Sigma_{j-1}| - \ln|\Sigma_j|\} \sim \chi^2(k^2) \tag{4}$$

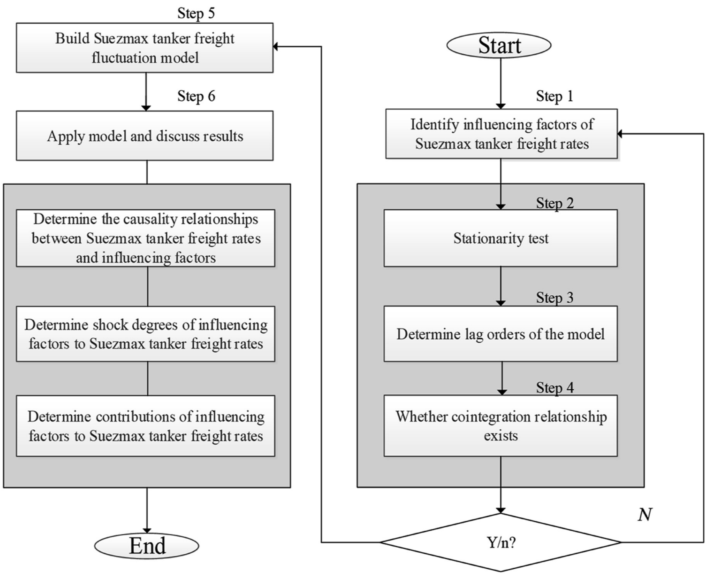

Figure 3. Research framework of factors affecting global Suezmax tanker freight fluctuations

Where $m = d + k_j$. d is the number of exogenous variables, k is the number of endogenous variables, T is the sample length and l is the log-likelihood value.

(3) Perform the cointegration test on the time series of factors of Suezmax tanker freight rates. The cointegration relationship indicates a long-term equilibrium relationship between economic variables (Granger, 1986). Johansen (1988) proposed a multiple cointegrating relationship test based on the VAR model:

$$Y_t = \Phi_1 Y_{t-1} + \ldots + \Phi_p y_{t-p} + HX_t + \varepsilon_t \quad t = 1, 2, \ldots, T \tag{5}$$

Where Y_t is a k-dimension endogenous variable, X_t is a d-dimension exogenous variable, p is the lag order, T is the number of samples, $k \times k$-dimension matrix $\Phi_1 \ldots \Phi_\mathrm{p}$ and $k \times d$-dimension matrix B are the coefficient matrixes to be estimated. ε_t is a k-dimension disturbance vector.

Transform the difference of Formula (5):

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_\mathrm{i} \Delta Y_{t-i} + HX_t + \varepsilon_t \tag{6}$$

Where

$$\Pi = \sum_{i=1}^{p} \Phi_i - I, \quad \Gamma_i = -\sum_{j=i+1}^{p} \Phi_j \tag{7}$$

Whether co-integration relationships exist between $Y_{1\mathrm{t}-1}, Y_{2t-1}, \ldots, Y_{kt-1}$ is dependent on the matrix Π rank.

Figure out the rank (r) of matrix Π to identify the number of cointegration relationships between variables in the Y_t series. Use the trace statistic test and the maximum eigenvalue statistic test to calculate the number of cointegration relationships. Formulas (8) and (9) introduce the trace statistic test and the maximum eigenvalue statistic test (Ong and Sek, 2013):

$$\text{trace statistic} : LR(\lambda_{trace}) = -T\sum\nolimits_{i=r+1}^{\mathrm{m}} \ln\left(1 - \hat{\lambda}_i\right) \tag{8}$$

$$\text{maximum eigenvalue statistic} : LR(\lambda_{\max}) = -T \log\left(1 - \hat{\lambda}_{r+1}\right) \tag{9}$$

Where $\hat{\lambda}_i$ is the i-th greatest eigenvalue, T is the total number of observation periods, the null hypothesis and the alternate hypothesis of the trace test and the maximum eigenvalue tests are:

H0. Matrix π has r co-integration relationships at most

H1. Matrix π is of a full rank, and has m co-integration relationships

H2. .Matrix π has r co-integration relationships

H3. .Matrix π has r+1 co-integration relationships at most

(4) Construct VECM of Suezmax tanker freight fluctuations. Formula (10) can explain when the freight rate ΔY_t acts as the explained variable, the impact degrees of the lag variable ΔY_{t-i} of each period of fluctuation-contributing factors on tanker freight rate based on their coefficients Γ_i, and the error correction term ECM_{t-1} that corrects the short-term fluctuations of freight rates to an equilibrium state when the model meets the long-term stationary relationship. α represents the correction margin.

$$\Delta Y_t = A_0 + \alpha ECM_{t-1} + \sum_{i=1}^{p} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \tag{10}$$

(5) Perform a Granger causality test on the factors of Suezmax tanker freight fluctuations to determine the directions of influences between the factors. In the test to determine whether a causality relationship exists between x_t and y_t, y_t can act as the explained variable, and all the lag variables of x_t on the right side of the formula can be deleted without affecting the establishment of the formula, as shown in Formula (11).

$$y_t = \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{i=1}^{p} \beta_i x_{t-i} + u_{1,t} \tag{11}$$

(6) Impulse response analysis calculates the dynamic impact of disturbance items on VECM. Consider how the impacts of disturbance items propagate to freight and other factors of freight fluctuations, and examine the transmission of the impact in itself and other variables to reflect the changes caused by positive shocks.

- Take the VAR (2) model as an example.

$$\left\langle \begin{array}{l} x_t = a_1 x_{t-1} + a_2 x_{t-2} + b_1 z_{t-1} + b_2 z_{t-2} + \varepsilon_{1t} \\ z_t = c_1 x_{t-1} + c_2 x_{t-2} + d_1 z_{t-1} + d_2 z_{t-2} + \varepsilon_{2t} \end{array} \right. \quad t = 1, 2, \ldots, T \tag{12}$$

- Send an impulse to x in Period 0. Set $x_{-1} = x_{-2} = z_{-1} = z_{-2} = 0$

$$\varepsilon_{10} = 1,\ \varepsilon_{20} = 0 \tag{13}$$

$$\varepsilon_{1t} = 0,\ \varepsilon_{2t} = 0 \tag{14}$$

- Calculate the responses resulting from the impulses of x_t to work out the x response function $x_0, x_1, x_2 \ldots$. and the z response function $z_0, z_1, z_2 \ldots$

When $t = 0$: $x_0 = 1, z_0 = 0$

Substitute the result into Formula (12). When $t = 1$: $x_1 = a_1, z_1 = c_1$

Substitute the result into Formula (12) again. When $t = 2$: $x_2 = a_1^2 + a_2 + b_1 c_1, z_2 = c_1 a_1 + c_2 + d_1 c_1$

(7) Variance decomposition on VECM works out the contribution of each influencing factor when each random disturbance causes a fluctuation in the tanker freight rate, as shown in Formula (15).

$$RVC = \frac{\sum_{q=0}^{\infty} \left(a_{ij}^{(q)}\right)^2 \sigma_{ij}}{\mathrm{var}(y_i)} = \frac{\sum_{q=0}^{\infty} \left(a_{ij}^{(q)}\right)^2 \sigma_{ij}}{\sum_{j=1}^{k} \sum_{q=0}^{\infty} \left(a_{ij}^{(q)}\right)^2 \sigma_{ij}} \quad (i, j = 1, 2, \ldots, k) \tag{15}$$

4. Model applications and result analysis

4.1 Data description

This paper studies the route from the port of Sidi Kerir to the port of Marseille-Fos. As one of the main Suezmax tanker routes in the Mediterranean area, this route plays an important role in the oil trade between Europe and Africa and can represent the fluctuations of the global Suezmax tanker market. The data dates range from January 1999 to January 2019, with a total of 241 sets of data. In this paper, Suezmax tanker freight rates are based on the Worldscale data, the crude oil prices are based on Brent crude oil prices. Suezmax tanker freight rates, one-year charter rates, fleet development, crude oil prices are all from the Clarkson SIN database, while refined oil refinery output data is from the IEA monthly reports. The Suezmax tanker freight rates on this route fluctuated violently, reaching the highest point of WS375 in November 2004 for the period between January 1999 and January 2019. From the financial crisis in 2008 to January 2019, the freight rate plummeted, then kept fluctuating violently at low levels and reached the lowest point of WS45.63 in August 2016 (Figure 4).

All variables are logarithmized, which eliminates the possible non-linear trends in the time series, so that data is more stationary. As a result, the variables become more sensitive to the differences in small values than to those in large values, which is conducive to analyzing the volatility mechanism of tanker freight rates. After the logarithmic transformation, Suezmax tanker freight rates are expressed in Logarithmized Worldscale Rates (LWS), fleet development in Logarithmized Fleet Development (LFD), refinery output in Logarithmized Refinery Gross Output (LRGO), one-year charter rates in Logarithmized Time Charter Rates (LTCR) and crude oil prices in Logarithmized Crude Oil Price (LCOP).

4.2 Empirical results and discussion

4.2.1 ADF testing. To figure out the relationships between influencing factors of Suezmax tanker freight fluctuations and construct VECM, this paper considers the ADF unit root test to determine the stationarity of each time series. Table 3 lists the test results of the ADF test hypothesis. The p values of the original series are all greater than 0.05, meaning that the series are not stationary. After the first-order difference processing, the p values are all 0, meaning that each series is stationary. So the next step can be continued.

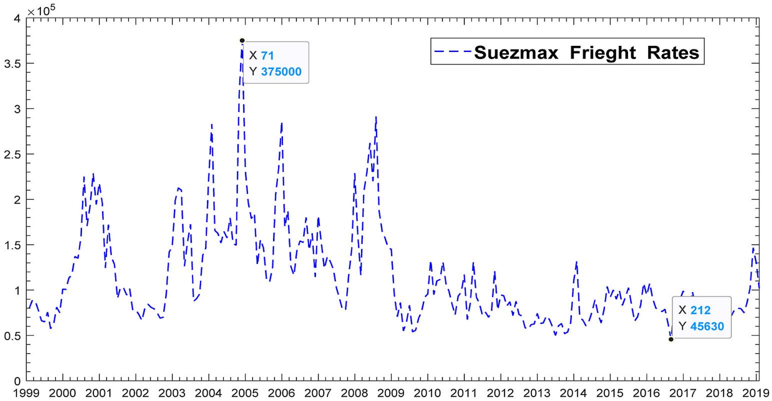

Figure 4.
Suezmax tanker freight rate (WS index)

Table 3.
Unit root test results

	ADF value of original series	p value of original series	Conclusion	ADF value after first-order difference processing	p value after first-order difference processing	Conclusion
LWS	−0.0238	0.6739	Not stationary	−7.4117	0.0000	Stationary
LFD	2.4476	0.9967	Not stationary	−2.216	0.0000	Stationary
LRGO	−0.8299	0.3555	Not stationary	−4.6521	0.0000	Stationary
LTCR	0.0535	0.6989	Not stationary	−10.4946	0.0000	Stationary
LCOP	0.5751	0.8399	Not stationary	−12.2993	0.0000	Stationary

4.2.2 Determine the optimal number of lag periods. To construct VECM, we need to determine the number of lag periods of the model, which sets the number of lag variables in the model. With Formulas 2, 3, and 4, we can work out the optimal lag periods for the AIC and SC criteria to be 7 and 1, respectively, and that for the LR criterion is 7, as shown in Table 4.

4.2.3 Cointegration test. The premise of constructing VECM is to determine whether cointegration relationships exist between the factors, which reflect the long-term equilibrium between these factors. Perform cointegration tests on each influencing factor using Formulas 8 and 9. As shown in Table 5, the p value of the trace statistical test in the null hypothesis of "no cointegration relationship exists" is 0.0037, rejecting the null hypothesis, meaning that there exists at least one co-integration relationship; the p value of the null hypothesis of "at most one cointegration relationship exists" is 0.1990, which is insufficient to reject the null hypothesis. For this reason, we say the trace statistical test shows that there exists a co-integration relationship between Suezmax tanker freight rate and the four factors. Perform maximum eigenvalue tests on each influencing factor. In the null hypothesis of "no co-integration relationship exists", the p value in the maximum eigenvalue test is 0.0050, rejecting the null hypothesis and in the null hypothesis of "at most one co-integration relationship exists", the p value is 0.2282, insufficient to reject the null hypothesis.

According to above tests, Suezmax tanker freight rate and the four factors have one and only one cointegration relationship, which proves the existence of a statistically long-term equilibrium relationship, rendering it feasible to construct a VECM for Suezmax tanker freight fluctuations. The long-term relationships between the Suezmax tanker freight rate and the four factors can be expressed by the cointegration Formula (16).

$$\begin{aligned} ECM_{t-1} = {} & LWS_{t-1} - 0.1871LTCR_{t-1} - 4.2324LRGO_{t-1} - 0.0644LFD_{t-1} \\ & -0.0339LCOP_{t-1} + 44.0528 \end{aligned} \tag{16}$$

4.2.4 VECM. Through the above steps, we can use Formula 10 to build VECM for Suezmax tanker freight fluctuations, as shown in Formula 17. The correction factor α is

Lag	LR	AIC	SC
0	NA	−0.997959	−0.923903
1	3421.892	−15.85778	*−15.41344
2	120.6296	−16.18657	−15.37194
3	25.32090	−16.08866	−14.90375
4	32.78537	−16.02872	−14.47353
5	69.83065	−16.15147	−14.22600
6	55.73563	−16.21280	−13.91704
7	*55.25511	*−16.27869	−13.61265
8	28.48686	−16.21246	−13.17614

Note(s): *The optimal lag periods decided by each criteria

Table 4. Determination of the number of lag periods

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	Critical value 0.05	Prob.	Max-Eigen statistic	Critical value 0.05	Prob.
At most 1	0.089514	40.68149	47.85613	0.1990	21.85005	27.58434	0.2282
At most 2	0.047397	18.83144	29.79707	0.5051	11.31389	21.13162	0.6160
At most 3	0.031742	7.517550	15.49471	0.5183	7.515691	14.26460	0.4301
At most 4	7.98E−06	0.001859	3.841466	0.9626	0.001859	3.841466	0.9626

Table 5. Trace statistic tests and maximum eigenvalue test

-0.3258, which means that, in the event that the model satisfies the long-term equilibrium and stationarity, when the error correction term $ECM_{t-1} > 0$ and $\alpha ECM_{t-1} < 0$, it indicates that the error correction term will exert a negative effect of 0.3258 to bring the freight rate back to equilibrium if the freight rate shows a positive deviation; when $ECM_{t-1} < 0$ and $\alpha ECM_{t-1} > 0$, that is, a negative deviation, the error correction term will exert a positive effect of 0.3258 to bring the freight rate back to equilibrium.

$$
\begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_t = \begin{bmatrix} -0.0002 \\ 0.0076 \\ -0.0021 \\ 0.0017 \\ -0.0046 \end{bmatrix} + \begin{bmatrix} * -0.3258 \\ 0.0025 \\ 0.0470 \\ 0.0008 \\ -0.1286 \end{bmatrix} ECM_{t-1}
$$

$$
+ \begin{bmatrix} -0.0173 & 0.3538 & -2.3426 & 4.4390 & 0.2935 \\ 0.0806 & 0.2392 & -0.0262 & 0.2103 & 0.1458 \\ -0.0157 & 0.0120 & -0.5068 & 0.2324 & -0.0532 \\ -0.0023 & 0.0110 & -0.0068 & 0.1653 & 0.0034 \\ 0.1006 & -0.1900 & -0.0652 & 1.6510 & 0.1393 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-1}
$$

$$
+ \begin{bmatrix} -0.0399 & -0.1698 & -0.9562 & 0.0509 & 0.1226 \\ 0.0320 & -0.0356 & 0.1194 & 0.3072 & 0.0206 \\ -0.0408 & 0.0840 & -0.2900 & 0.2749 & 0.0295 \\ 0.0006 & -0.0014 & -0.0079 & 0.0894 & 0.0014 \\ 0.1104 & -0.0825 & -0.1851 & 0.9556 & -0.0112 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-2}
$$

$$
+ \begin{bmatrix} -0.0665 & 0.6359 & -0.4784 & -2.5769 & 0.0998 \\ -0.0040 & 0.0711 & 0.1179 & -0.2180 & 0.0086 \\ -0.0452 & 0.0133 & -0.2442 & 0.8270 & 0.0310 \\ -0.0050 & 0.0120 & -0.0072 & 0.1319 & -0.0039 \\ 0.0785 & -0.0622 & -0.3813 & -1.6154 & 0.0058 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-3}
$$

$$
+ \begin{bmatrix} -0.0042 & 0.0233 & -0.3183 & -4.4264 & 0.1471 \\ -0.0073 & 0.0612 & 0.0341 & -1.5115 & -0.0093 \\ -0.0494 & -0.0368 & -0.1471 & -0.4414 & 0.0016 \\ -0.0025 & -0.0236 & -0.0089 & 0.1116 & 0.0072 \\ 0.1179 & -0.1254 & -0.5554 & 0.5216 & -0.0891 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-4}
$$

$$
+ \begin{bmatrix} -0.0152 & 0.0958 & 0.8902 & 1.2983 & 0.1694 \\ -0.0034 & 0.0145 & 0.1198 & -0.0712 & 0.1365 \\ -0.0470 & -0.0052 & 0.0356 & 1.0553 & 0.1044 \\ 0.0012 & -0.0047 & -0.0257 & -0.0128 & -0.0025 \\ 0.0909 & 0.0978 & -0.5262 & -0.1725 & 0.0276 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-5}
$$

$$
+ \begin{bmatrix} -0.0276 & 0.3031 & 0.6437 & 0.3357 & 0.0893 \\ 0.0061 & 0.0629 & 0.0379 & -0.7258 & -0.0797 \\ -0.0153 & 0.0240 & -0.3635 & -0.5156 & -0.0259 \\ 0.0027 & -0.0012 & 0.0024 & 0.0622 & 0.0008 \\ 0.0170 & 0.1153 & -0.3507 & 0.6660 & -0.1582 \end{bmatrix} \begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-6}
$$

$$+\begin{bmatrix} 0.1751 & -0.4305 & 0.3611 & -0.6482 & 0.1520 \\ 0.0470 & 0.0026 & 0.0244 & -0.2453 & 0.0464 \\ 0.0041 & -0.0392 & -0.1584 & -1.1899 & -0.0431 \\ -0.0001 & -0.0048 & 0.0188 & -0.0230 & -0.0010 \\ 0.0105 & 0.0590 & -0.0053 & 0.5678 & 0.0191 \end{bmatrix}\begin{bmatrix} \Delta LWS \\ \Delta LTCR \\ \Delta LRGO \\ \Delta LFD \\ \Delta LCOP \end{bmatrix}_{t-7} + \varepsilon_t \quad (17)$$

4.2.5 Granger causality test. This paper uses the Granger causality test to detect the interplay between factors, with statistical causality provided. Test from 1 lag period to the maximum number of lag orders. A causality relationship is deemed existent as long as one of the numbers rejects the null hypothesis. The fleet development is the Granger cause of the freight rate when the lag period is 1–7; the refinery output proves to be the Granger cause of freight rate when the lag period is 2–7 (Table 6). The freight rate proves to be the Granger cause of crude oil price when lag period is 1. The freight rate proves to be the Granger cause of product oil refinery output when lag period is 5–7, which validates the Granger causality relationship between freight rate and refinery output. The Granger causality tests for lag periods of 1–7 prove that the freight rate is the Granger cause of the one-year charter rate (Table 7**)**.

4.2.6 Impulse response analysis. Using Formula 16, we can perform the impulse response analysis on the factors affecting Suezmax tanker freight fluctuations. The analysis examines the impacts of random disturbances and measures the responses of Suezmax tanker freight rates to the changes in other variables. As shown in Figure 5, when the one-year charter rate increases by 1%, the impacts on the freight rate are always positive, and such positive impacts reach the highest point of 0.05% in the seventh month. These impacts gradually weaken over time and then level off. When refinery output increases by 1%, the freight rate will reduce by 0.04% in the second period and then rebounds to the highest point of 0.079 in the sixth month, and the impacts

Lags \ Factors	LCOP	LFD	LRGO	LTCR
1	0.6492	*0.0123	0.3521	0.1638
2	0.2318	*0.0084	*4.00E-08	0.5268
3	0.3132	0.2667	*6.00E-08	0.7946
4	0.3810	*0.0456	*2.00E-07	0.4204
5	0.2946	*0.0377	*8.00E-08	0.4732
6	0.2267	*0.0099	*8.00E-08	0.6179
7	0.2072	*0.0262	*2.00E-07	0.5767

Note(s): *The optimal lag periods decided by each criteria

Table 6. One-way causality tests of influencing factors on Suezmax tanker freight rates

Lags \ Factors	LCOP	LFD	LRGO	LTCR
1	*0.0409	0.4606	*0.0004	*8.00E-08
2	0.1538	0.684	*0.0171	*0.0005
3	0.3286	0.2161	0.1596	*0.0016
4	0.4793	0.3412	0.557	*0.0038
5	0.4462	0.2575	*0.0344	*0.0089
6	0.5462	0.343	*0.0344	*0.0124
7	0.684	0.4398	*0.0109	*0.0181

Note(s): *The optimal lag periods decided by each criteria

Table 7. One-way causality tests of Suezmax tanker freight rates on influencing factors

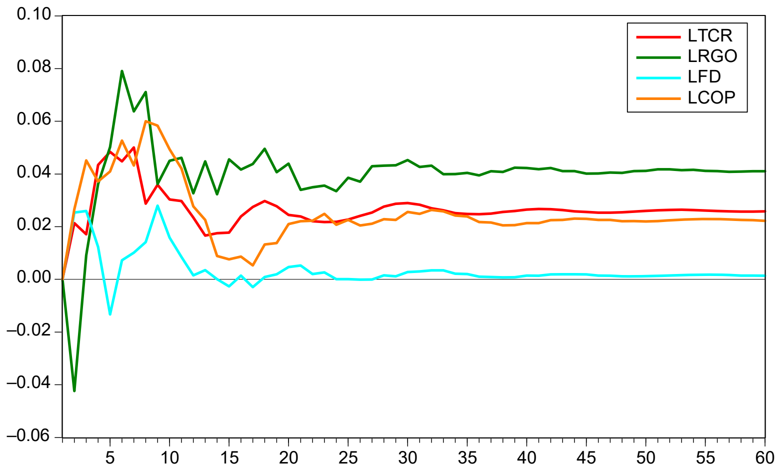

Figure 5.
Impulse responses of four factors to Suezmax tanker freight rate

are always positive. The fleet development's impacts on the freight rate see three positive and negative alternations in the first 18 months, and then level off starting from the 36th period. Crude oil prices always have positive impacts on the freight rates. When the crude oil price increases by 1%, the freight rate will increase, even by up to 0.06% in the eighth period, and then gradually levels off from the 39th period. In addition, we found that refinery output has the most significant positive impacts on the freight rate, with an impact value of 0.079, followed by crude oil price, one-year charter rate and fleet development. Refinery output also produces the largest negative impact on the freight rate, with an impact value of −0.042, followed by the fleet development. The impacts of the four factors on the freight rate reach a peak within 0.5–1 year, then gradually weaken and level off starting from the third year.

4.2.7 Variance decomposition. Through variance decomposition of the Suezmax tanker freight rate, we can get the following conclusions. First, the variance of tanker freight rates is mostly contributed by their own impacts. Second, refinery output, crude oil price, one-year charter rate and fleet development contribute 16.77%, 13.62%, 8.48% and 1.89%, respectively, to the freight fluctuation, and refinery output has been the largest contributor, followed by crude oil price, one-year charter rate and fleet development. Fleet development has a relatively smaller impact on oil tanker fright fluctuation. This finding is consistent with the impulse response analysis. The specific variance contribution of each factor is shown in Table 8 and Figure 6.

Period	Standard deviation	LWS	LTCR	LRGO	LFD	LCOP
1	0.195941	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.249482	94.20161	0.734031	2.886814	1.036247	1.141298
3	0.273920	91.07763	0.997925	2.506404	1.753671	3.664370
4	0.294258	86.81264	3.043470	3.682485	1.694376	4.767033
5	0.315826	81.81498	4.991159	5.724022	1.648484	5.821351
6	0.340294	74.77001	6.029374	10.32653	1.465014	7.409070
7	0.358042	70.54171	7.404456	12.49877	1.403725	8.151334
8	0.378758	66.92293	7.193370	14.69500	1.394102	9.794600
9	0.389116	64.17972	7.666894	14.78842	1.837764	11.52720
10	0.396414	61.90235	7.971906	15.53714	1.929824	12.65878
11	0.402575	60.06271	8.276228	16.37835	1.916036	13.36667
12	0.405804	59.24917	8.478463	16.76573	1.886997	13.61963

Table 8.
Variance decomposition analysis

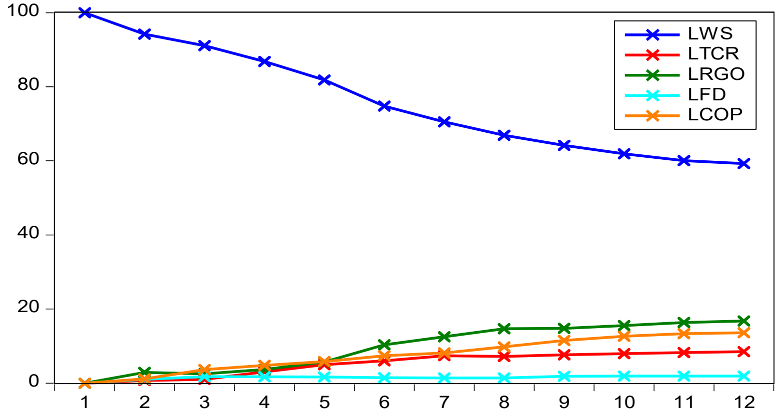

Figure 6. Variance decomposition

4.3 Result analysis

In this chapter, VECM is utilized to quantitatively analyze Suezmax tanker freight fluctuations, identify the dynamic relationships between them and work out the contribution of each influencing factor to the Suezmax tanker freight fluctuation.

The results are summarized as follows. First, the cointegration test proves that Suezmax tanker freight rate has a significant long-term equilibrium relationship with crude oil price, one-year charter rate, refinery output and fleet development, and the freight rate is corrected by a margin of 0.3258 from short-term deviation to long-term equilibrium. Second, the Granger causality test proves that there is a statistical two-way causality relationship between refinery output and tanker freight rate, the crude oil price and fleet development are one-way Granger causes of freight rate, and that the freight rate is the Granger cause of one-year charter rate. Through the impulse response analysis and variance decomposition, we find that in the short term, both the crude oil price and the one-year charter rate have a positive impact on the freight rate. The impact of the refinery output causes a drop in the freight rate in the second month. The refinery's oil shipping demand increases when the freight rate is low, and the freight rate begins to gradually pick up as a result. The fleet development has a negative impact on the Suezmax tanker freight rate in the fifth month, indicating that the fleet development growth in the first periods can still support market prosperity, and the tanker supply exceeds the market demand in the fifth month. The excess capacity causes the freight rate to fall, and the market starts to stabilize over time. Among the factors, refinery output is the biggest contributor, with an impact value of 0.079, followed by crude oil price, one-year charter rate and fleet development. In the long run, the impacts of factors on freight rates all peak within 0.5–1 year. As the time passes by, the impacts get weaker due to the cointegration relationships and they all stabilize starting from around the third year. With variance decomposition, we concluded that refinery output, crude oil price, one-year charter rate and fleet development contribute 16.77%, 13.62%, 8.48% and 1.89%, respectively, to the fluctuation, and fleet development has a smaller impact on freight rate.

5. Conclusions

Studying the impact degrees of and the impacting mechanism between factors of Suezmax tanker freight fluctuations can provide a basis for oil shipping operators to take wise measures in response to fluctuation risk. This paper summarizes and sorts out the four factors that affect freight fluctuations in the Suezmax tanker market, constructs VECM, uses the Granger causality test to determine the causality relationship between freight rates and various factors and uses impulse response analysis and variance decomposition analysis to calculate the shock degrees to freight rates and contributions to freight fluctuations. Based on the model results, we can draw the following conclusions:

First, refinery output and crude oil price are the main causes for the dramatic fluctuations in Suezmax tanker freight rates, which reflect the supply and demand relationship within the oil industry. Refinery output has a two-way Granger causality relationship with freight rate, and the impulse response test verifies the former's two-way impacts on the latter. When the refinery output growth exceeds the oil product demand in the market, the demand for the raw material of crude oil shipping will decrease. This will lead to a sharp decline of tanker freight rate, and ship owners will start to cut their capacity to minimize the loss. After a period of time, the crude oil supply of refineries will become insufficient, and the output falls to a level that fails to meet the market demand for oil products. The refineries will increase their output to meet market demand, and the demand for oil shipping will go up, driving up the freight rates and improving the oil shipping market. The refinery output will go up as well. Crude oil price is the Granger cause of freight rate. The impulse response test verifies the former's positive impacts on the latter. When crude oil price – a main part of shipping cost–increases, freight rates will also rise. Second, tanker operators should adjust ship investment strategies in a timely manner based on market conditions. The variance analysis shows that the contribution of fleet development to Suezmax tanker freight fluctuation is only 1.89%, while that of one-year charter rate is 8.48%. This demonstrates that in the current tanker shipping market, tanker operators should source ships primarily through chartering and order fewer new ships. Shipbuilding costs much. In the current situation where fleet development growth is unable to significantly drive up tanker freight rates, they should make prudent decisions on investing in new capacity. In addition, as shown in the impulse response and variance decomposition analysis, refinery output has the largest contribution to Suezmax tanker freight fluctuation, followed by crude oil price, one-year charter rate and fleet development. Specifically, fleet development has a smaller impact on freight rate. Tanker operators should pay more attention to the commissioning of refinery operations, the trend of world crude oil prices and changes in the time charter market, to better respond to the volatility risks in the Suezmax tanker shipping market. Finally, we found that the four factors impact Suezmax tanker freight rates in different directions and at different degrees in the short term, and that such impacts peak within 0.5–1 year before they gradually weaken subject to the cointegration relationship adjustment between freight rates and various factors. Their impacts level off starting from the 3rd year. This provides a reference for government administrations to formulate policies that better fit the changes in the tanker shipping market. For example, when the oil shipping market slumps, state governments can offer short-term tax exemptions to support the sustainable development of their fleets and tanker markets. In addition, oil importers and exporters should strengthen international cooperation to maintain the stability of the tanker shipping market.

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