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The Effect of Bunker Prices on the Volatility and Return Structure of Time Charter Market in Maritime Transport

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Abstract— The fluctuation in the prices in the maritime market concerns many people and institutions such as shipowners, chartering companies, financial companies and investors. In this study, it is aimed to examine the effect of bunker prices on time charter volatility structures in three different dimensions of the bulker, containership and tanker markets for the period between July 2001 and June 2021. For this purpose, GARCH-X and GJR-GARCH-X models are used. According to our findings, the consideration of bunker prices has a reducing effect on the volatility of small and mid segments of tanker markets; mid and big size segments of bulker markets; small and mid size segments of container markets. As a result, it would be beneficial for maritime transport companies to have a strategic policy and risk management understanding regarding the special impact of bunker prices on their businesses.

Index Terms— asset pricing, bunker prices, time charter rates, volatility structure.
JEL Codes: G12, G32, C22, R40

I. INTRODUCTION

The fluctuation in the prices in the maritime market concerns many people and institutions such as shipowners, chartering companies, financial companies and investors. It is important for them to understand the price dynamics and market trend so that they can make appropriate strategic decisions that minimize their losses against these fluctuations.

There are a number of markets in maritime transport where bunker cost is reflected in prices. It is one of the largest operating expenses and so having a major impact on operating profits in the industry. Operating costs include fuel, general expenses, insurance, repairs and maintenance, crew and capital expenditures. The weight of the cost elements varies with different ship types, sizes and speeds at sea. Bunker fuel management strategy varies according to the selection of bunker ports, determination of fuel quantities, determination of the route, adjustment of ship speed (important for the cargo to be transported), and ship type and size. It is important to establish an appropriate consumption model in the bunker fuel management strategy. Due to the effects of fuel prices and environmental policies on operating costs, carriers have developed measures to save fuel through some operational adjustments. Energy efficiency is expected to be an important feature for a ship operating company as it affects their overall costs and revenues. In time charter contracts, shipowners take care of the technological energy efficiency level, while charterers bear the costs associated with the energy efficiency level chosen by the agency, i.e. fuel bill in the case of the maritime market [1]. Changes in fuel prices due to speed adjustments, transition to lighhter and cleaner fuel, environmental policies, energy efficiency, etc. directly affect the operating cost and the fuel share in the expense. Therefore, bunker fuel prices also affect time charter rates [2]. Erdogan (1996) state that although the main indicator for earnings in maritime transport is freight rate, time charter is more widely used in terms of the earnings of the relevant shipowner and the costs of the carrier company. Such that the Baltic Dry index (BDI), which is often incorrectly referenced as a freight market indicator, is actually an index calculated based on different time charter rates. International market risk can be measured by freight rates, time charter rate, bunker prices. Although the stock exchanges are thought to be efficient, changes in the international maritime markets may not be reflected in the stock prices in a timely manner. Institutional investors stay away from the maritime sector due to the specialization required and various risks. Finally, the sector, beyond its economic characteristics, can be subject to state policies and also subject to international common standards. While maritime companies traded in financial markets are largely compatible with the asset pricing model, their sensitivity to international parameters such as freight values, chartering costs and bunker changes necessitates an improved pricing model [2].

Bunker prices by different regions reflect the supply and demand obtained from the current conditions in the oil market. It is observed that bunker prices differ significantly from the crude oil price and petroleum products. Increasing transportation activities with international standardization and liberalization in trade contribute greatly to the demand for oil. Due to the high trade volume and high volatility in the global and regional bunker markets, which directly affect the profit margins of shipowners and shipping companies, derivative contracts are used to minimize the exposure of shipowners and businesses to the fluctuations in bunker prices.

Time charter rates include the expectations of both parties and are used as a risk management tool. The time-varying features of freight rates and ship prices have made it difficult for carriers and shipowners to make operational decisions. Since ships are often bought and sold as assets, the freight rates and ship prices are the key determinant of the ship price. In addition to the fact that the main concept for the maritime market is freight rate, there are also subsector prices, an extension of the maritime industry with time charter rate at the beginning of the systematic prices. The most decisive decision in the maritime market is whether the ship is bought for the cargo to be transported or whether the ship is chartered and operated. From this point of view, time charter rates can be used as the most systematic data.

To understand the connection of bunker prices with the time charter rate, it is necessary to understand the return and volatility structure for different time charter markets. First of all, time charter rates have different volatility structures in different segments (bulker, container and tanker) in different size and maturity structures [3],[4],[5],[6]. For this reason, shipowners, charterers, investors, researchers, specialists in the maritime market need to pay attention to the ship which is interested in size, term structure and segment for volatility and return structure. Thus, risk management in the maritime time charter market attracts attention by market participants, investors and researchers. For instance, Kavussanos (1996a) uses the GARCH model for comparing volatile models in different sizes in spot freight rate and time charter rate in the bulker market. In general, it is seen that volatility in the time charter market is higher than in the spot freight market and there are more severe fluctuations in volatility [3]. Therefore, a risk-averse shipowner who has the option to operate his/her ship between the spot and time charter markets will prefer the spot market with lower risk over time charter. Furthermore, Kavussanos (1996b) makes volatility comparison for different size in the secondhand ships in the tanker market. Small vessels are to be less volatile than big ones. He also states that oil price is negatively related to the change in tanker prices, while there is a positive relationship with volatility [4]. Kavussanos (1997) applies a SARIMA-X/GARCH-X model by using secondhand ship prices, time charter rates and interest rates for different sizes (handysize, panamax, capesize) in dry bulk segment [5]. In addition, he examines the importance of macroeconomic factors of Beenstock and Vergottis (1989) in conditional variance [7]. They argue that the introduction of such macro factors into conditional variance reduces the degree of permanence in the GARCH model. Phylaktis, Kavussanos and Manalis. (1996) explore the dynamics of price changes (return) and information flow to the market. It is seen that the information flow (trading volume) is effective in explaining the variance of stock returns and significantly reducing the GARCH effects [8]. Gavriilidis, Kambouroudis, Tsakou and Tsouknidis (2018) examine volatility estimates for spot and time charter rates for tanker by including oil price shocks of different origin as exogenous variables in the set of GARCH-X models. The results reveal that the inclusion of aggregate oil demand and oil-specific demand shocks significantly improves the accuracy of volatility forecasts [9].

In the finance and maritime economics literature, it is seen that markets react faster to bad news than good news. This is the leverage effect proposed by Black (1976), where risky investors respond much faster to negative returns than positive returns [10]. Chen and Wang (2004) show that the downward movement of the market is more important than the upward movement of the market on the volatility in the dry cargo market, and that small ships have more leverage effect than large ships [11]. This situation can provide investors with invaluable market information to measure leverage impact on investors, understand implied volatility, pre-arrange asset allocation and risk management, thereby improving investment performance and reducing investment risk. Erdogan and Yezegel (2009), showing the importance of the news impact on the market, show how important the way companies take in terms of transparency is in terms of pricing and investor behavior. Even a statement made in the direction of “no news” has been found to have a news value and investors may behave differently in news that does not contain positive or negative news. The results show that prices continue to go down after major negative price changes, although no news has been announced. However, in the positive sub-example, prices partially reverse after no news. In the functioning of the price mechanism, it is clear that the effective processing of news and investors' buying and selling preferences are directly related to market transparency [12]. Erdogan, Tata, Karahasan & Sengoz (2013) show the existence of economical information spillover between stock markets and maritime markets using DJIA and BDI indices, respectively. In the study, while defending stock market indexes as a good variable for better price discovery in time charter contracts, it is emphasized that time charter rate is a good variable in asset pricing. The rapid increase in international trade and capital movements, financial liberalization, digitalization and increasing globalization cause the interdependence of economies to increase. The commercial interdependence between the economies actually contributes the most to the transportation and especially to the maritime markets [13].

Drobetz, Richter and Wambach (2012) analyze through the E-GARCH and GARCH-X models that by adding the asymmetry effect and macroeconomic variables in dry-bulk and tanker freight market, so time-varying volatility can be explained more appropriately. They argue that the t-distribution is more appropriate than the normal distribution. The asymmetric effect is clearly seen by adding macroeconomic variables to the variance equation rather than the mean equation in the tanker market. They show the lack of asymmetry effects in the dry bulk market [14]. In these results, they state that there are important implications for risk management in the freight market. Jing, Marlow and Hui (2008), examining the asymmetric characters of daily return volatility in different freight markets conditions, explore the asymmetric effect between past innovations and current volatility using the E-GARCH model [15]. Tsouknidis (2016) provides evidence of large time-varying volatility spillovers within and between dry cargo and tanker subsegments, which are much larger during and after the global financial crisis [16].

Alizadeh and Nomikos (2004) state that there is no cointegration between WTI futures and tanker freight rates. The reason for this is mainly attributed to regional supply and demand imbalances and they argue that there are arbitrage opportunities between oil derivatives and tanker freight markets [17]. Shi, Yang, and Li (2013) examine the relationship between oil prices and the freight market with the SVAR model. Crude oil price shocks are classified as supply shocks and non-supply shocks, and the effects of different shocks on the tanker market are examined [18]. Although these results are partially consistent with Alizadeh and Nomikos (2004), it is seen that the crude oil supply shock has a significant effect on the tanker freight rate, but not the non-supply shock. In other words, the impact of crude oil price shocks on the tanker freight market is limited. From a practical perspective, tanker operators should have a clear understanding of the various shocks in the crude oil market as they affect crude tanker market levels in different ways. Tankers should also take different measures according to different sources of fluctuation in market levels. Few studies have been conducted on modeling and estimating volatility in tanker freight markets [19]-[20]. The relevant literature has included oil price as an exogenous variable in the GARCH-X model [4]-[12]. Alizadeh and Nomikos (2011) reveal that freight price volatility is related to the maturity structure of the freight market and this relationship is asymmetrical because volatility is higher when the freight market is in recession and lower when the freight market is in decline [20].

Alizadeh, Kavussanos, and Menachof (2004) investigate the hedging effectiveness of crude oil, kerosene and heating oil futures contracts at three major shipping ports in Rotterdam, Singapore and Houston. The results reveal that risk management through cross-market hedging in the bunker industry is limited up to 43% variance reduction when using IPE crude to hedge bunker prices in Rotterdam [21].

Zhang and Zeng (2015) analyze the time charter rate effect on spot freight rate with VECM and impulse response functions. In order to see the fluctuation of the spot freight market in time better, the relationship between time charter and freight rates should be defined [22].

Batchelor, Alizadeh and Visvikis (2007) state that spot and forward prices are co-integrated in the freight market. They show that forward rates help forecast spot rates, and ARIMA and VAR models forecast better than VECM model when estimating forward rates [23]. Koekebakker and Ådland (2004) use time charter rates to investigate the term structure dynamics of forward freight rates. They demonstrate that the correlations between the different parts of the term structure are low, and in some cases even negative [24]. Tsolakis, Cridland and Haralambides (2003) argue that the newbuilding prices and time charter rates are the most influential variables in the formation of secondhand prices [25].

Chen, Meersman, Voorde (2010) use VECM-GARCH models for cointegration, causality, volatility spillover for the relationship between volatility and return between capesize and panamax. In terms of returns and volatility, the results show that the dynamics between the two markets have changed over time on different trading routes. This shows useful information to both shipowners and charterer companies to reduce risks or to gain extra profit by switching between the two markets [26]. Dai, Hu, Zhang (2015) examine the volatility spillover in the dry bulk shipping market between newbuilding, secondhand and freight rate [27]. Li *et al.* (2018) use the GARCH model and Granger causality models to capture the dynamics and dependencies between maritime freight rates [28].

At this stage, we briefly determine that, although there are enough studies on time charter rate; there is a lack of studies on the importance and/or the impact of reducing the effect of the bunker returns on time charter volatility. While risk management on bunker prices is possible in practice, it would be meaningful to consider it in terms of its impact on time charter rate volatility as well. Hence, it is necessary to examine the effect of bunker rates on time charter volatility.

In this study, we examine (1) cointegration and causality relationship between bunker and crude/brent oils, (2) cointegration and causality relationships between bunker and time charters for three different selected dimensions of three different ship types as bulker, container and tanker (3) bunker return volatility (4) time charter rates volatility (5) crude and brent oil effect on bunker's return volatility with GARCH-X model, (6) bunker effect on time charter's return volatility with GARCH-X model, (7) GJR-GARCH models with asymmetric model allowing separate response to negative and positive shocks in both time charter and bunker prices (8) GJR-GARCH-X model, which consists of combining the model that allows both the external variable in variance equation and the asymmetric model. The important point is to compare individual time charter volatility structures with volatility structures including the bunker and asymmetric effect. While the reducing effect of brent/crude oil on bunker's return volatility, the reducing effect of bunker return on time charter volatility are expected.

The structure of this paper is as follows: section 2 describes data and introduces research methodology, section 3 reports empirical results and section 4 concludes.

II. DATA AND METHODOLOGY

In the study, monthly data covering the period of July 2001-June 2021 are used. Data are obtained from Clarksons Intelligence and Reuters Database. The data consist of bunker price, brent oil spot, brent oil futures, crude oil spot, crude oil futures and time charters.

Time charter rates are selected from three ship types' three different sizes. Handysize TC, panamax TC, capesize TC from bulker time charter; 350 TEU TC, 2000 TEU TC, 3500 TEU TC from containership; handysize, panamax, suezmax from tanker market are selected. different sizes. All price series are converted to percentage change (P_t/P_{t-1}-1)*100% for return.

In Table 1, the correlation matrix consist of monthly time charter and bunker price changes (return) covering the period of 2001 July-2021 June. According to correlation matrix, bunker-bulker time charter and bunker-containership time charter price change correlations are positive, while the bunker-tanker price change correlations are negative.

Table 1: The correlation matrix between bunker and time charter rates

	Bulker Handysize	Bulker Panamax	Bulker Capesize	Container 350TEU TC	Container 2000TEU TC	Container 3500TEU TC	Tanker Handysize	Tanker Panamax	Tanker Suezmax	Bunker
Bulker Handysize	1									
Bulker Panamax	0.7660	1								
Bulker Capesize	0.5845	0.7882	1							
Container 350TEU	0.2816	0.2117	0.0820	1						
Container 2000TEU	0.3407	0.2157	0.1178	0.4997	1					
Container 3500TEU	0.3043	0.2022	0.0712	0.4851	0.7286	1				
Tanker Handysize	0.1294	0.1635	0.1297	0.1370	0.1234	0.1149	1			
Tanker Panamax	0.0063	0.0485	0.0105	0.0911	0.1200	0.1077	0.6532	1		
Tanker Suezmax	0.0968	0.1083	0.0582	0.1005	0.0579	0.0513	0.4591	0.5507	1	
Bunker	0.2617	0.2893	0.2481	0.2118	0.2102	0.1817	-0.0504	-0.2051	-0.0883	1

Note: The correlation matrix consists of three tonnage of bulker, containership and tanker and bunker price changes. The price change is calculated as return r_t= (p_t/p_{t-1})*100.

As ship sizes increase, bunker's correlations with bulker take an inverted U shape, while with containership tends to downward. In addition the correlations between bunker and tanker markets with all vessel sizes are negative, the correlation power increases in medium-size tanker and approaches zero in small and large tankers. In other words, on average in the tanker market, there is an inverse relationship between the change in time charters and bunker price.

Table 2 shows the descriptive statistics of all series except for time charters:

Table 2: Descriptive statistics

	Bunker	Brent oil (spot)	Brent oil (fut.)	Crude oil (spot)	Crude oil (fut.)
Mean	0.77	1.31	0.99	1.07	1.06
Std.Dev.	8.49	12.4	9.89	11.52	11.38
Skew.	-0.3	0.61	-0.63	1.17	1.3
Kurtosis	4.23	16.9	7.79	15.97	18.52
Obs.	239	239	239	239	239

Looking at the descriptive statistics of bunker, brent oil and crude oil in the spot and futures markets, it is seen that the mean of the spot market are larger than the mean of the futures market.

Table 3: Descriptive statistics of time charter rates

	Bulker Handysize TC	Bulker Panamax TC	Bulker Capesize TC	Container 350TEU TC	Container 2000TEU TC	Container 3500TEU TC	Tanker Handysize TC	Tanker Panamax TC	Tanker Suezmax TC
Mean	0.9	1.2	1.57	0.29	0.76	0.88	-0.07	-0.04	0.07
Std. Dev.	8.96	11.94	15.28	3.39	8.31	10.85	4.62	5.51	8.31
Skew.	-0.76	-0.08	0.2	-0.02	0.2	0.86	0.78	0.2	1.4
Kur.	11.56	6.61	6.81	9.09	7.32	8.08	8.43	8.48	10.86
Obs.	239	239	239	239	239	239	239	239	239

When the descriptive statistics of time charters are examined, it is seen that the mean values increase as the size of each ship type increases. The order of means among ship types is bulker, containership and tanker. The means of the bulker and containership are positive, while the mean of the tanker is negative for small and medium sizes. As can be seen from kurtosis, it is seen that all of the price change (return) series are leptokurtic. The skewness changes from left to right as the ship size increases in bulker and container, while the tanker market is right skew in all dimensions. The unit root test results of the return series are presenteded Table 4. Since we interested in return series, price changes series are calculated as $(P_t/P_{t-1}-1)100\%$. According to the ADF and PP unit root test results, all series are stationary at the 1% significance level. Namely, it is seen that all series are stationary in the first order.

Table 4: The Results of Unit Root Tests

	ADF t-stat.	PP t-stat.
Bulker Handysize	-9.277*	-9.008*
Bulker Panamax	-9.601*	-9.343*
Bulker Capesize	-11.386*	-11.037*
Tanker Handysize	-10.783*	-10.822*
Tanker Panamax	-11.086*	-11.042*
Tanker Suezmax	-12.065*	-12.065*
Container 350 TEU	-5.094*	-9.957*
Container 2,000 TEU	-5.902*	-7.928*
Container 3,500 TEU	-8.369*	-8.395*
Bunker	-11.194*	-10.956*
Brent Oil Spot	-11.691*	-12.781*
Brent Oil Futures	-12.26*	-11.948*
Crude Oil Spot	-13.365*	-13.351*
Crude Oil Futures	-13.078*	-12.999*

Note: *,** and *** indicate significance levels at %1, %5 and %10, respectively.

This study focuses on time charters and bunker volatility models. In addition to the individual volatility models, an variance regressor has been added to the variance equation. For this variable selection, return structures are examined by cointegration and causality tests[1]. Thus, this section includes the ARMA, GARCH, GJR-GARCH, GARCH-X and GJR-GARCH-X models.

Traditional time series and econometric models operate under the assumption of constant variance. The ARCH (Autoregressive Conditional Heteroskedastic) model, which allows time-varying conditional variance as a function of past error terms, is introduced to the literature by Engle (1982) [29]. A short time later, Bollerslev (1986) develop the model the GARCH (Generalized Autoregressive Conditional Heteroskedasticity) model to the literature [30]. For p=0, the process is reduced to the ARCH(q). ε_t is reduced to the process with white noise for $p = q = 0$. While the conditional variance is specified only as a linear function of the past sample variances in the ARCH(q), the GARCH(p,q) process also allows lagged conditional variances to be entered. p and q degrees are determined by applying traditional Box and Jenkins (1976) time series techniques to autocorrelations and partial autocorrelations for the ε_t^2.

In its simplest form, the GARCH(p,q) model is as follows:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \quad (1)$$

[1] Since the study focuses on volatility models, only application results are reported without cointegration and causality methodology.

Here, the condition $\varepsilon_t \sim N(0, \sigma_t^2)$ is provided on the information set ψ_{t-1} at t-1 time. The coefficients of ε_{t-i}^2, σ_{t-j}^2 are called the reaction parameter (ARCH) and persistence parameter (GARCH), respectively. For nonnegativity, the parameters should be p>0, q≥0, α_0>0, α_i>0. For the unconditional or stationary variance to be finite, the following condition must be satisfied: $\sum_{i,j=1}^{\max\{p,q\}}(\alpha_i + \beta_j) < 1$. The GARCH(1,1) model for bunker and time charter models are as follows:

$$h_{bunker,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} \tag{2}$$

$$h_{TC,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1} \tag{3}$$

The expression of the asymmetrical GJR-GARCH (1993) model, which allows different responses to positive and negative shocks, in its simplest form for time charter is as follows [31]:

$$h_{bunker,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} + \gamma D\varepsilon_{t-1}^2 \tag{4}$$

$$h_{bunker,t} = \begin{Bmatrix} \alpha_0 + (\alpha+\gamma)\varepsilon_{t-1}^2 + \beta h_{bunker,t-1}, & if\ \varepsilon_{t-1} < 0 \\ \alpha_0 + \varepsilon_{t-1}^2 + \beta h_{bunker,t-1}\ , & if\ \ \varepsilon_{t-1} \geq 0 \end{Bmatrix}$$

$$h_{TC,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1} + \gamma D\varepsilon_{t-1}^2 \tag{5}$$

$$h_{TC,t} = \begin{Bmatrix} \alpha_0 + (\alpha+\gamma)\varepsilon_{t-1}^2 + \beta h_{TC,t-1}, & if\ \varepsilon_{t-1} < 0 \\ \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1}\ , & if\ \varepsilon_{t-1} \geq 0 \end{Bmatrix}$$

Here, D is the dummy variable that takes the value 0 for positive news and 1 for negative shocks. For the unconditional or stationary variance to be finite, the following condition must be satisfied: $(\alpha + \frac{\gamma}{2} + \beta) < 1$ For the model to be accepted, leverage effect must be greater than zero, $\gamma > 0$ or if γ is less than 0, the inequality $\alpha_1 + \gamma \geq 0$ must be satisfied.

We used the GARCH model to examine heteroscedasticity in the time charter rate and bunker returns. In the study, the effect of bunker returns on time charter volatility and the effect of crude/brent oils on bunker volatility are examined. Therefore, the GARCH-X equations are formed by adding the bunker and crude/brent oils return to the GARCH equations.

In the GARCH-X model, using the simultaneous bunker, crude/brent oils return at time t to explain volatility, since it raises the issue of simultaneity bias, this problem is attempted to be overcome by using lagged bunker, crude/brent oils return in the GARCH equations:

$$h_{bunker,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} + \delta oil_{t-1} \tag{6}$$

$$h_{TC,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1} + \delta bunker_{t-1} \tag{7}$$

Finally, GJR-GARCH-X model is presented, which allows both variance regressor and asymmetric effects (differently reacting to good and bad news) in time charter volatility models:

$$h_{bunker,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} + \gamma D\varepsilon_{t-1}^2 + \delta oil_{t-1} \tag{8}$$

$$h_{bunker,t} = \begin{cases} \alpha_0 + (\alpha+\gamma)\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} + \delta oil_{t-1}, & if\ \varepsilon_{t-1} < 0 \\ \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{bunker,t-1} + \delta oil_{t-1}, & if\ \varepsilon_{t-1} \geq 0 \end{cases}$$

$$h_{TC,t} = \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1} + \gamma D\varepsilon_{t-1}^2 + \delta bunker_{t-1} \quad (9)$$

$$h_{TC,t} = \begin{cases} \alpha_0 + (\alpha+\gamma)\varepsilon_{t-1}^2 + \beta h_{TC,t-1} + \delta bunker_{t-1}, & if\ \varepsilon_{t-1} < 0 \\ \alpha_0 + \alpha\varepsilon_{t-1}^2 + \beta h_{TC,t-1} + \delta bunker_{t-1}, & if\ \varepsilon_{t-1} \geq 0 \end{cases}$$

III. FINDINGS

In this section, the results of the volatility structures mentioned in the methodology section are given. In addition, cointegration, causality tests between the variance regressor and dependent variable in the GARCH-X and GJR-GARCH-X model are presented.

A. *Relationships Between Crude/Brent, Bunker and Time Charter Rates*

The long-term cointegration results of bunker with crude oil and brent oil in spot and futures markets are given in Table 5.

Table 5: The Results of Engle-Granger Cointegration Test

Dependent variable	tau-statistic	z-statistic
Bunker	-5.992*	-74.685*
Brent Oil (Spot)	-8.187*	-106.775
Bunker	-6.132*	-77.754*
Brent Oil (Futures)	-6.199*	-79.585*
Bunker	-5.069*	-53.291*
Crude Oil (Spot)	-5.280*	-57.836*
Bunker	-4.922*	-50.244*
Crude Oil (Futures)	-5.124*	-54.506*

Note: *,** and *** indicate 1%, 5% and 10% significance levels.

Table 6: The Results of Granger Causality Test

Null Hypothesis:	Prob.
Brent oil (futures) does not Granger Cause Bunker.	0.0000*
Bunker does not Granger Cause Brent oil (futures).	0.3737
Brent oil (spot) does not Granger Cause Bunker.	0.0000*

Bunker does not Granger Cause Brent oil (spot).	0.4511
Crude oil (spot) does not Granger Cause Bunker.	0.0000*
Bunker does not Granger Cause Crude oil (spot).	0.1039
Crude oil (futures) does not Granger Cause Bunker.	0.0000*
Bunker does not Granger Cause Crude oil (futures).	0.147

Note: *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

According to the test results, the bunker return is cointegrated with crude oil and brent oil in both markets in the long term. The causality direction of bunker, crude and brent oils is examined with the Granger causality test. The causality is on one side in crude oil and brent oil (Table 6). That is, while brent oil and crude oil in both the spot and futures markets are the Granger cause of the bunker, the reverse is not true.

Table 7: The Results of Engle-Granger Cointegration Test

Dependent	tau-statistic	z-statistic
Bunker	-2.118	-8.206
Bulker Handysize TC	-2.568	-14.320
Bunker	-2.207	-8.778
Bulker Capesize TC	-2.938	-26.324**
Bunker	-2.233	-9.052
Bulker Panamax TC	-2.501	-13.117
Bunker	-2.577	-12.067
Containership 350 TEU TC	-1.834	-11.770
Bunker	-2.653	-12.951
Containership 2000 TEU TC	-1.829	-13.186
Bunker	-2.684	-13.316
Containership 3500 TEU TC	-1.802	-12.310
Bunker	-2.551	-11.815
Tanker Handysize	-1.993	-8.164
Bunker	-2.534	-11.697
Tanker Panamax	-1.977	-8.297
Bunker	-2.560	-11.919
Tanker Suezmax	-2.289	-11.206

Note: *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

The focus of the study is the bunker effect on time charters' return and volatility structures. Cointegration and causality tests are investigated between bunker return and containership and tanker time charter rates. Cointegration results between bunker and time charter are given in Table 7.

According to the Engle-Granger cointegration results (Table 7), it has not been found to be cointegrated bulker (except for bulker capesize), containership and tanker markets with bunker in the long run. There is at least one causality between two cointegrating series, but the statement that there is no causality in non-cointegrated series is incorrect ($p \Rightarrow q \neq p' \Rightarrow q'$). For this reason, causality relationships between bunker and time charter can be examined. Granger-causality test results between bulker and time charter are given in Table 8. According to the results, while the bunker is the Granger cause for all three ship sizes in the bulker time charter market, the opposite is not true. In the container market, while the bunker is the Granger cause for all three sizes of time charters, the opposite is not true (except for 2000TEU). In the tanker market, the bunker is the Granger cause for all three ship sizes, while in the opposite case, the tanker market (except for handysize tanker TC) is also the granger cause of the bunker at 10% significance level, albeit weakly.

Table 8: The Results of Granger Causality Test

Null Hypothesis	Prob.
Bulker Handysize TC does not Granger Cause Bunker.	0.1459
Bunker does not Granger Cause Bulker Handysize TC.	0.0041**
Bulker Panamax TC does not Granger Cause Bunker.	0.2482
Bunker does not Granger Cause Bulker Panamax TC.	0.0494**
Bulker Capesize TC does not Granger Cause Bunker.	0.2311
Bunker does not Granger Cause Bulker Capesize TC.	0.0779***
Container 350TEU TC does not Granger Cause Bunker.	0.3589
Bunker does not Granger Cause Container350TEU TC.	0.0337**
Container 2000TEU TC does not Granger Cause Bunker.	0.0368**
Bunker does not Granger Cause Container 2000TEU TC.	0.0349**
Container 3500 TEU TC does not Granger Cause Bunker.	0.3021

Bunker does not Granger Cause Container 3500TEU TC.	0.003*
Tanker Handysize TC does not Granger Cause Bunker.	0.3197
Bunker does not Granger Cause Tanker Handysize TC.	0.0017*
Tanker Panamax TC does not Granger Cause Bunker.	0.0870***
Bunker does not Granger Cause Tanker Panamax TC.	0.0257**
Bunker does not Granger Cause Tanker Suezmax TC.	0.097***
Tanker Suezmax TC does not Granger Cause Bunker.	0.0046*

Note: *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

B. GARCH Results

The study focuses the effect of bunker rates on time charter rates of different size of the different ships, and also the asymmetric characters of time charter return volatility. In addition to time charter volatility structures, oil price effect on bunker return volatility and leverage effect of bunker return volatility are examined. In the analysis, the monthly return time series of dry-bulk, container, tanker time charter, bunker, crude oil (spot, futures), brent oil (spot,futures) are used, with sample periods in ARIMA, GARCH, GJR-GARCH, GARCH-X and GJR-GARCH-X models.

The rest of the section includes the GARCH results. For this, firstly the bunker variable is fixed to GARCH (1,1) and then the GJR-GARCH model is applied to examine the leverage effect. The Bunker's GARCH model is given in Table 9. In bunker GARCH models, reaction parameter is 0.22 and persistence parameter is 0.70. In the model, when the asymmetric effect is added for the leverage effect, the GJR- GARCH model made the ARCH effect insignificant, and the persistence parameter does not change. The reaction parameter responds to negative shocks 0.19 more than positive shocks. When the effect of oil on bunker volatility is examined, in the model as contemporaneus variables, their lagged states (t-1) are added to the model and taken into account since they will be a simultaneous problem in the model. While examining the effect of oil on bunker volatility, lagged variables (at time t-1) are added to the model since it would be a simultaneous problem to include variables as contemporaneus variables (at time t) in the model. Brent oil is included in the model significantly and it is seen that a 1% change in the return of brent oil reduces the bunker volatility by 0.47%, in the same way, crude oil is included in the GARCH-X model and has reduced the bunker volatility by 0.40%. Although the results of the GJR-GARCH-X model are not given, it is stated that they are insignificant models.

Table 9: The Results of Bunker GARCH Models

Bunker	(1) GARCH	(2) GJR-GARCH	(3) Brent oil	(4) Brent oil(-1)	(5) Crude oil	(6) Crude oil(-1)
c	6.7398***	7.8520***	4.1233	4.7957	4.7957	3.8812
	(1.8787)	(1.7494)	(1.3666)	(1.4869)	(1.4869)	(1.3830)
ε_{t-1}^2	0.2152*	0.0991	0.1705*	0.1843**	0.1843*	0.1771*
	(3.0157)	(1.1962)	(2.6142)	(2.5651)	(2.5651)	(2.8216)
σ_{t-1}^2	0.6976*	0.6969*	0.7809*	0.7619*	0.7619*	0.7808*
	(7.7315)	(6.2145)	(8.8563)	(8.1044)	(8.1044)	(9.4942)
$\varepsilon_{t-1}^2(\varepsilon_{t-1} < 0)$		0.1865**				
		(2.0125)				
brent oil			-0.5753*			
			(-2.8715)			
brent oil(-1)				-0.4717**		
				(-2.0097)		
crude oil					-0.5878*	
					(-2.6952)	
crude oil(-1)						-0.3993***
						(-1.6729)

Note: This table presents results from GARCH, GJR GARCH and GARCH-X model for bunker return. There are six models in the table. Each model is shown vertically. Models (3), (4), (5), (6) are GARCH-X models. In models (3) and (5), brent oil and crude oil have been added to the GARCH model as contemporaneus variables. In (4) and (6), there are predicting brent oil and crude oil variables in the GARCH-X model. The z-statistics are in parantheses, *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

As seen from Table 10, in bulker's time charters GARCH (1,1) structures, the reaction parameter for bulker takes a U shape going from handysize to capesize, while the persistence parameter takes an inverted U shape. That is, the reaction parameter is relatively higher in small-size (handysize) and large-size (capesize) bulker ships, while it is lower in medium size panamax). Conversely, persistence parameter is insignificant in the large-size (capesize), but relatively high in medium-size (panamax) and relatively low in small-size (handysize). These shapes in the reaction and persistence parameter do not change when the asymmetry parameter is added. In addition, as the ship size increases, the asymmetry parameter has a downward trend. While in the small-size (handysize), the reaction parameter responds to negative shocks 0.3939 more than positive shocks, in the medium-size (panamax) with the addition of the asymmetry effect, the reaction parameter is insignificant. On the other hand, the asymmetric effect is insignificant in the large-size (capesize). When we look at the GARCH-X model, while the reaction parameter is trending down, the persistence parameter is trending up, that is, as the ship size increases, the reaction parameter decreases and persistence parameter increases. In the GJR-GARCH-X model, the reaction parameter and bunker effect are insignificant in the medium-size (panamax), while the reaction parameter become insignificant in the large size (capesize). Persistence parameter tends upwards as the ship size increases, as in the GARCH-X model. On the other hand, the asymmetric effect tends downward, that is, as the ship size increases, the effect of negative shocks decreases in magnitude from positive shocks. For example, handysize has an effect on negative shocks (0.2499+0.5771), while the effect on positive shocks is 0.2499.

Table 10: Results of Bulker's GARCH Models

Bulker	GARCH			GJR-GARCH			GARCH-X			GJR-GARCH-X		
	1	2	3	4	5	6	7	8	9	10	11	12
	handysize	panamax	capesize	handysize	panamax	capesize	handysize	panamax	capesize	handysize	panamax	capesize
c	8.7874*	33.140**	147.490*	9.570*	45.74*	153.72*	10.79*	29.5**	37.09*	9.21*	45.21*	41.84*
	(3.725)	(2.288)	(5.987)	(3.678)	(2.882)	(5.591)	(3.560)	(2.357)	(3.410)	(3.661)	(2.630)	(2.756)
ε^2_{t-1}	0.4932*	0.1327*	0.5513*	0.3012*	-0.0234	0.5208*	0.5905*	0.1095*	0.0828**	0.2499*	-0.0167	0.0129
	(6.403)	(3.104)	(3.866)	(3.912)	(-0.533)	(2.612)	(6.302)	(2.853)	(2.566)	(3.428)	(-0.349)	(0.228)
σ^2_{t-1}	0.4577*	0.5780*	-0.1020	0.4422*	0.4732*	-0.0829	0.3642*	0.643123*	0.764513*	0.4334*	0.4849**	0.7365*
	(6.382)	(3.551)	(-1.523)	(6.568)	(2.665)	(-1.151)	(4.476)	(4.743)	10.5070	(6.450)	(2.554)	(7.213)
$\varepsilon^2_{t-1}(\varepsilon_{t-1} < 0)$				0.3939*	0.3368*	-0.1454				0.5771*	0.3131*	0.1564***
				(2.688)	(2.880)	(-0.729)				(3.208)	(2.582)	(1.904)
bunker(-1)							0.4145***	-1.497***	-4.3535*	0.515689*	-0.6934	-3.8343*
							(1.842)	(-1.949)	(-5.475)	(3.226)	(-0.651)	(-4.052)

Table 11: The Results of Container's GARCH Models

Container	GARCH			GJR-GARCH			GARCH-X			GJR-GARCH-X		
	1	2	3	4	5	6	7	8	9	10	11	12
	350TEU	2000TEU	3500TEU	350TEU	2000TEU	3500TEU	350TEU	2000TEU	3500TEU	350TEU	2000TEU	3500TEU
c	2.732*	20.797*	24.688*	2.423*	11.36*	25.756*	2.5403*	14.046*	32.577*	2.589*	13.354*	26.407*
	(7.230)	(3.675)	(5.691)	(7.224)	(3.934)	(4.419)	(6.517)	(4.272)	(5.647)	(6.441)	(4.241)	(4.343)
ε^2_{t-1}	0.4552*	0.3314*	0.3899*	0.5188*	0.3761*	0.3341*	0.5726*	0.4698*	0.5007*	0.6146*	0.4492*	0.2777*
	(5.395)	(2.679)	4.0112	(3.984)	(3.499)	(3.355)	(5.442)	(4.119)	(3.947)	(4.126)	(3.644)	(2.830)
σ^2_{t-1}	0.3571*	0.2848***	0.4016*	0.3825*	0.4414*	0.3897*	0.3512*	0.4275*	0.2718*	0.350*	0.4296*	0.3582*
	(4.781)	(1.714)	(5.078)	(5.370)	(4.103)	(3.576)	(4.695)	(4.427)	(2.568)	(4.557)	(4.445)	(3.084)
$\varepsilon^2_{t-1}(\varepsilon_{t-1} < 0)$				0.0098	0.3180	0.2417				-0.1173	0.1022*	0.4134***
				(0.064)	(1.630)	(1.277)				(-0.687)	(0.538)	(1.780)
bunker (-1)							-0.0792*	-0.8171*	0.6488*	-0.0850*	-0.7872*	0.7448*
							(-3.492)	(-5.021)	(2.754)	(-3.760)	(-4.605)	(2.620)

Table 12: The Results of Tanker GARCH Model

Tanker	GARCH			GJR-GARCH			GARCH-X			GJR-GARCH-X		
	1	2	3	4	5	6	7	8	9	10	11	12
	handysize	panamax	suezmax	handysize	panamax	suezmax	handysize	panamax	suezmax	handysize	panamax	suezmax
c	1.433*	2.735**	57.789*	0.292**	1.049***	6.491*	1.413*	3.553*	63.1578*	0.270**	0.9246*	5.470**
	(3.333)	(2.074)	(10.486)	(2.083)	(1.937)	(3.329)	(3.30)	(2.651)	(7.755)	(2.346)	(3.008)	(2.527)
ε_{t-1}^2	0.1362*	0.2014*	0.2367**	0.1333*	0.2525*	0.0873**	0.1448**	0.2179*	0.2018**	0.0869*	0.2123*	0.0453**
	(2.991)	(3.136)	(2.531)	(5.412)	(3.302)	(2.543)	(2.460)	(3.593)	(2.377)	(6.642)	4.434	(1.997)
σ_{t-1}^2	0.7991*	0.7089*	-0.0976	0.9280*	0.8658*	0.8772*	0.7932*	0.6679*	-0.1474	0.9595*	0.9072*	0.9230*
	(14.807)	(7.143)	(-1.131)	(85.828)	(16.691)	(23.307)	(12.163)	(7.623)	(-1.241)	(123.770)	(32.796)	(24.887)
$\varepsilon_{t-1}^2(\varepsilon_{t-1} < 0)$				-0.1468*	-0.2903*	-0.1722*				-0.1162*	-0.2694*	-0.1360
				(-4.281)	(-3.843)	(-3.628)				(-6.501)	-5.3572	(-3.765)
bunker(-1)							0.0282	-0.271*	-1.1327**	-0.1549*	-0.1727*	-0.3034
							(0.425)	(-2.577)	(-2.419)	(-3.388)	-2.7929	(-1.591)

Note 1: Table 10 presents results from GARCH, GJR-GARCH, GARCH-X and GJR-GARCH-X models for Bulker's time charters. The results of 4 different models are given for three different dimensions of Bulker time charter returns. In Table 10, each model is shown vertically. There are 12 models in total. The variance regressor in the GARCH-X model is the bunker(-1) return variable. The z-statistics are in parantheses, *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

Note 2: Table 11 presents results from GARCH, GJR-GARCH, GARCH-X and GJR-GARCH-X models for containership's time charters. The results of 4 different models are given for three different dimensions of Containership time charter returns. In Table 11, each model is shown vertically. There are 12 models in total. The variance regressor in the GARCH-X model is the bunker(-1) return variable. The z-statistics are in parantheses, *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

Note3: Table 12 presents results from GARCH, GJR-GARCH, GARCH-X and GJR-GARCH-X models for Tanker's time charters. The results of 4 different models are given for three different dimensions of Tanker time charter returns. In Table 12, each model is shown vertically. There are 12 models in total. The variance regressor in the GARCH-X model is the bunker(-1) return variable. The z-statistics are in parantheses, *,** and *** indicate 1%, 5% and 10% significance levels, respectively.

If the ARCH effect was significant in the capesize, the effect on positive shocks would be 0.0129, while the effect on negative shocks would be 0.0129+0.1564. In total, the effect on negative shocks is combined with the downward trend of the asymmetry and the U-shaped ARCH effect, and the reaction parameter to negative shocks tends to be downwards. The reason of this is the magnitude of the asymmetry is larger than the magnitude of the ARCH effect. On the other hand, the asymmetric effect tends downward, that is, as the ship size increases, the effect of negative shocks decreases in magnitude from positive shocks, for example, handysize has an effect on negative shocks (0.2499+0.5771), while the effect on positive shocks is 0.2499.

As seen from Table 11, in the containership's GARCH(1,1) time charter structure, the reaction and persistence parameters take a U shape as the ship size increases. In other words, in the containership time charter market, the reaction and persistence parameters are high in small size and large size while it is relatively less in medium size.

When the asymmetric effect was added to GARCH(1,1) model, the reaction parameter and persistence parameter change their shapes, although it is insignificant in all ship sizes. The insignificant asymmetric effect cause the reaction parameter to have a downward slope, and by reversing the persistence parameter, it takes an inverted U shape. When the bunker effect is added to the containership GARCH (1,1) volatility structure, it has a volatility-reducing effect in containerships with small and medium TEUs. The asymmetric effect become significant in the GJR-GARCH-X model, in which the bunker effect is added. While the bunker effect has a reducing effect in containerships with small and medium TEUs as in the GARCH-X model. In the model, the persistence parameter has an inverted U shape. In the GJR-GARCH-X model, the reaction parameter is in a downward trend for positive shocks, while it is in an upward trend for an asymmetrical effect.

As seen from Table 12, in GARCH(1,1) volatility structure in tanker time charter's handysize, panamax and suezmax dimensions, the reaction parameter tends to increase, while the persistence parameter tends to decrease. In the GJR-GARCH model, the reaction parameter takes an inverted U shape for positive shocks, and the persistence parameter takes a U shape as the ship size increases. In the tanker market, unlike bulker and containership, the reaction parameter responds to negative shocks 0.15, 0.29, 0.17 less than positive shocks from handysize to suezmax, respectively. The asymmetric parameter takes the absolute value inverted U shape. With the addition of the bunker effect to the GARCH(1,1) structure in the GARCH-X model, the persistence parameter of suezmax is insignificant. In the GJR-GARCH-X model, where both asymmetric and bunker effects are observed on volatility structure, the reaction parameter takes an inverted U shape and the perisistence parameter takes a U shape as the ship size increases. When the asymmetric effect is considered as an absolute value, it takes an inverted U shape. Here again, unlike the bulker and container markets, as ship size increases in the tanker, reaction parameter responds to negative shocks 0.116, 0.269, 0.136 less than positive shocks, respectively. A 1% change in the bunker return has a reducing effect 0.15% and 0.17% on the volatility of handysize and panamax time charter rate in GJR-GARCH-X model.

IV. CONCLUSION

The fluctuation in the bunker prices in the maritime market concerns many people and institutions such as shipowners, chartering companies, financial companies, investors. Since the bunker fuel is one of the largest operating expenses of any shipowner, having a major impact on operating profits in the industry, bunker prices remain an important factor in the business decisions of maritime companies in world transportation.

According to the finding, in the relevant period and frequency, the bunker price is the Granger-cause for the time charter prices of all three ship types as bulker, container and tanker, in the opposite direction, it is determined that only one size (medium) container time charter and two size (medium and large) tanker time charter is an explanatory reason for the bunker price change. In addition, it has been determined that crude oil and brent oil are an explanatory reason for the change in the bunker, while the reverse is not true.

In time charter rates GARCH(1,1) structures, the reaction parameter for bulker takes a U shape going from handysize to capesize, while the persistence parameter takes an inverted U shape. This situation does not change when the asymmetry parameter is added, but the levarege effect also takes a U shape. When bunker is added to bulker time charter volatility, reaction parameter decreases and persistence parameter increases as ship size increases. The consideration of bunker prices has a reducing effect on the volatility of mid and big size segments of bulker markets. On the other hand, in individual containership models, as the vessels grow, the reaction parameter and persistence parameter take the U shape. While the leverage effect is insignificant in all three container sizes, it becomes significant with the addition of the bunker. The consideration of bunker prices has a reducing effect on the volatility of small and mid size segments of container markets. In tanker markets, the reaction parameter increases and the persistence parameter decreases as the ship size increases. When the asymmetric effect is added, the reaction parameter and leverage effect take an inverted U shape, while the persistence parameter takes a U shape. While there is no change in the shape of the parameters with the addition of the bunker effect as the ship size increases. In summary, the consideration of bunker prices has a reducing effect on the volatility of small and mid segments of tanker markets; mid and big size segments of bulker markets; small and mid size segments of container markets.

As a result, it would be beneficial for maritime transport companies to have a strategic policy and risk management understanding regarding the special impact of bunker prices on their businesses. In addition, external shocks in the market have different magnitudes of effect on volatility in different ship types due to their different flexibility. To examine the asymmetrical effect of monthly return volatility in bulker, container and tanker time charter markets and different market conditions, the GJR-GARCH model is applied. The results show that the asymmetrical characters are different for different ship size and different market conditions. It is thought that the reasons for the difference in the causes of the results may be different flexibility to good and bad shocks on different routes and different transportation of different goods. The results to be obtained from this research will be beneficial for operators and investors in the bulker, containership, tanker transportation market to increase profitability, pre-arrange their asset portfolios and reduce investment risk.

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