ORIGINAL RESEARCH (AR)

DOI: 10.4274/jems.2023.66487

Journal of ETA Maritime Science 2023;11(2):127-135

Volatility Transmission Between Container and Dry Bulk Freight Markets During the COVID-19 Pandemic

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Abstract

Shipping is a highly volatile, cyclical, and capital-intensive industry defined by extreme highs and lows. This makes information regarding volatility in this market material and relevant for decisions related to portfolio diversification, forecasting, and hedging in the maritime industry. Understanding how volatility is disseminated across the shipping market can help shipping companies to improve operational efficiency by making them more responsive to market changes. When shipping companies can anticipate market changes, they can swiftly respond and adjust their operations accordingly. In addition, volatility transmission in the shipping industry is crucial for policymakers seeking to improve the economic outlook of individuals and business entities that depend on the shipping industry. By monitoring the flow of volatility between shipping markets, they can promote effective pro-industry economic policies by more accurately estimating the effects of introducing new shocks to one freight market on another one. Therefore, understanding the volatility transmission between the container and dry bulk freight markets could provide an effective risk management mechanism that improves decision- making in shipping. This study analyzes volatility transmission between the container and dry bulk freight markets during the coronavirus disease-2019 pandemic using an asymmetric BEKK-GARCH(1,1) model that can also serve as a weak efficiency test. The results indicate that there was bidirectional volatility transmission between the container and dry bulk freight markets during the pandemic and that transmission from the container to dry bulk freight market was dominant. These findings support the price formation hypothesis of shipping, which states that dry bulk freight rates will follow container freight rates when freight rates exhibit an upward trend. Furthermore, the statistical significance of volatility transmission suggests that container and dry bulk freight rates can be used as a prediction mechanism for each other, serving as a market inefficiency indicator for both freight markets.

Keywords: Volatility transmission, Market efficiency, Freight markets, COVID-19, Lead-lag relationship

1. Introduction

Volatility transmission is defined as the transmission or spread of instability in a market, which is generated by external shocks and innovations, to another market. Transmission occurs when changes in volatility in one market have a lagged impact on changes in volatility in another market, beyond the level of fluctuation that is typical or normal. These types of interactions are especially common in financial markets [1].

When information flows are considered, volatility transmission is expected when markets are interconnected [2]. Given this interconnectedness, volatility transmission becomes material for portfolio diversification, forecasting, hedging, and asset pricing decisions [3].

Reinhart and Rogoff [4] show that during crisis time, volatility strongly increases and is transmitted to other markets. Therefore, we expect that the coronavirus disease-2019 (COVID-19) pandemic caused increased volatility and fueled volatility transmission among various markets. Before we analyze such transmission, we briefly address the nature of volatility.

The mechanisms and structures of financial asset return volatilities have been thoroughly studied since Baillie and Bollerslev [5], and Lin et al. [6] laid the foundation for

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Received: 18.01.2023
Last Revision Received: 28.04.2023
Accepted: 10.05.2023

To cite this article: R. Memişoğlu, and S. Sigalı. "Volatility Transmission Between Container and Dry Bulk Freight Markets During the COVID-19 Pandemic." *Journal of ETA Maritime Science*, vol. 11(2), pp. 127-135, 2023.

this field of research. They observed that volatilities vary across asset classes, time periods, markets, and regions, and volatility research has been pursued in various areas of finance, such as asset pricing, portfolio structuring, and risk management, over the years.

As the amount of time between financial crises has decreased since the Asian financial crisis of 1997, the question of how those crises affect volatility transmission between markets has become more urgent. Over the last two decades, the globalization of capital markets has increased the degree of inter-dependence across these markets. First, liberalization in capital markets greatly enhanced economic ties among countries and regions through policy coordination. This promoted global economic integration through international trade and foreign direct investment. The emergence of regional trade blocks, monetary unions, and free trade zones has increased cooperation and therefore interdependency among the world's economies [7]. Second, deregulation of capital markets, numerous financial innovations, and advances in information flow and mode of communication have intensified the interdependencies among capital markets across various countries [8]. The growth in international portfolio management (especially by hedge funds), cross-listings of companies on stock exchanges in different countries, and allowing foreign investment in many financial markets have elevated the linkages between national and international financial markets [9]. Given this background information on volatility and volatility transmission concepts, we now explain the objectives of this study.

One of the objectives is to verify results in previous studies regarding the weak form of the efficient market hypothesis (EMH), using an alternative validation tool. Therefore, we briefly review the EMH and its role in freight markets. The EMH focuses on the availability of information. Under the EMH, a market can be considered efficient only if prices fully reflect information that is available to the public [10]. The "weak" form of the theory states that it is impossible to predict prices in a market using historical price information. Thus, if a market displays weak form efficiency, using technical analysis to outperform the market is ineffective. Market efficiency has deep roots in the literature; almost all markets have been analyzed using this concept, and shipping is no exception. A number of studies suggest that various segments of the shipping market are indeed inefficient such as Evans [11], Kavusannos and Alizadeh [12], Hale and Vanags [13], Veenstra [14], Adland and Cullinane [15], and Adland and Strandenes [16]. According to the EMH, this situation suggests that participants in the shipping market can profit from information asymmetries in that market.

This study contributes to the literature by providing insights about how volatility is disseminated in shipping freight markets. This can help shipping companies to improve operational efficiency by making them more aware of the effects of market changes. When a shipping company can accurately anticipate market changes, it can respond swiftly and adjust its operations accordingly. In addition, volatility transmission in the shipping freight markets can help policymakers who seek to improve economic conditions for individuals and organizations that depend on the shipping industry. Keeping the transmission of volatility between these shipping markets in mind can help to promote targeted economic policies more accurately, as they would more accurately estimate the ripple effects of introducing new shocks to a shipping freight market.

This study also differs from previous studies in the literature in two ways. First, current studies attempted to explain the volatility transmission mechanism among freight markets using variance causality and diagonal autoregressive methods (which are discussed in the next section). However, transmission effects mostly reside in off-diagonal matrices. Therefore, this study employs asymmetric full BEKK-GARCH parameterization to capture bivariate volatility transmission effects to the highest extent. Also, because a bivariate BEKK-GARCH model directly specifies the conditional variance-covariance matrix of freight returns, hedge ratios for container and dry bulk freight rates can be generated as a byproduct of our estimation as fresh observations become available [17]. Investors in the maritime industry could benefit from having such a tool at their disposal.

Second, to the author's knowledge, no study examining volatility transmission between freight markets based on financial contagion has focused on the COVID-19 pandemic period. Financial contagion refers to the spread of financial disturbances or shocks from one market or institution to another, leading to a wider systemic crisis. Understanding financial contagion is important as it can have significant adverse effects on the global financial system, economies, businesses, investors, and consumers. Thus, this study examines the systemic effects of the COVID-19 pandemic on container and dry bulk freight markets.

The remainder of this study is organized as follows. In section 2, the shipping volatility literature is discussed and prevailing hypotheses of the lead-lag relationship between container and dry bulk markets are laid out. In section 3, the modeling process and methodology of the study are explained and the data is introduced. The last section discusses the estimation results and offers conclusions.

2. Shipping Volatility

During the last decade, emerging market economies that have experienced substantial growth and increased trade volumes have increased volatility in all subsectors of shipping freight markets. As emerging economies, most notably China, became heavily involved in global trade in a globalizing world, shipping markets that arose from international trade became one of the first markets to be affected by changes in the global economic climate. The first group of studies on this topic focuses on the dynamics of shipping market volatility. Kavussanos and Visvikis [18] discuss global freight rates and point out that enormous freight volatility and a high risk-high reward structure characterize the shipping market. As a result, high short-run volatility in freight rates has caused frequent bubbles and crashes over the years [15]. As freight revenues comprise the majority of a shipping company's revenues, freight rate volatility is a critical factor affecting maritime business profitability. Thus, during times of turmoil, volatility could threaten business survival.

It is crucial for all stakeholders in the maritime industry to understand the structure and transmission of volatility between shipping markets. Adland and Cullinane [19] point out that short-term variations in freight rates could easily result in bubbles and crashes. It would help shipping carriers and other businesses to better understand the lead–lag interaction between dry bulk transportation and container shipping freight markets, and the volatility transmission between these two markets, for hedging and managing freight rate risks. Kavussanos [20] shows the benefits of Autoregressive Conditional Heteroscedasticity (ARCH) modeling in assessing risks in spot and time charter dry bulk markets, as their variances are not constant over time. Another study examines the structure of secondhand tanker market price volatility using ARCH modeling [21]. Prices for larger tankers, such as Very/Ultra Large Crude Carriers, fluctuate more than prices in smaller market segments. Another pioneering study uses ARCH-type modeling to analyze the volatility properties of the secondhand market for different-sized dry bulk vessels [22] and reveals volatility clustering for all segments and higher volatility for prices of larger ships.

The second group of studies focuses on the drivers of shipping market volatility. Lim et al. [23] analyze the drivers of freight market volatility using several macroeconomic and shipping-related factors known to affect supply and demand for shipping, and examine their impact on the term structure of freight options' implied volatilities. They state that volatility is mainly driven by global economic policy uncertainty, although shipping-specific factors such as fleet size growth, new building orders, and scrapping activity also play a role. Homan [24] examines how the Maritime Transportation Security Act affected the stability of marine firms using a market model. His findings suggest the Act might reduce financial risks these firms face and help maritime businesses to raise financing. Chi and Cheng [25] examine how maritime trade between Australia and some of its most significant trading partners, notably China, is impacted by real income and exchange rate volatility. They conclude that the volatility of exchange rates has a considerable and long-term impact on the volume of maritime exports.

Following these studies of the volatility characteristics of shipping markets, other studies examined interactions across these markets. Studies of the interaction between container and dry bulk markets mainly focused on the lead-lag relationship among them. The three prevailing hypotheses regarding this relationship are as follows.

The Transport of Goods Hypothesis suggests that when the market it trending upward, the container market will follow the dry bulk market. The reasoning behind this hypothesis is that the demand for raw materials will react first in an upward-trending economy, and will indicate changes in demand for finished and semifinished products. In contrast, in a downward trending economy demand for finished and semifinished products will react first, leading to changes in demand for raw materials [26]. The Shipping Contract Hypothesis states that dry bulk contracts are typically short-term by nature. Therefore, dry bulk freight rates are more flexible in adapting to market trends [12]. The price formation hypothesis assumes that the market for dry bulk shipping approaches perfect competition in the absence of large participants that would have enough influence and market share to corner the market by setting the price of a homogeneous product. As the market structure of liner shipping exhibits an oligopolistic structure, it is heavily influenced by large shipping alliances that dominate the market [27] (Table 1).

Table 1. *The Lead-Lag relationships of three hypotheses*

Hypothesis	Downwards Trend	Upwards Trend
Transport of Goods	Container Leads Dry Bulk	Dry Bulk Lead Container
Shipping Contract	Dry Bulk Lead Container	Dry Bulk Lead Container
Price Formation	Dry Bulk Lead Container	Container Leads Dry Bulk
Source: Hsiao et al. [26]		

If we summarize the main characteristics of the maritime industry as capital intensity with a high risk-high reward structure, the volatility of freight rates stands out as one of the most important threats to monitor. Therefore, understanding volatility transmission between the container and dry bulk freight markets could improve risk management and aid the decision-making process in shipping [28].

As Stopford [29] indicates, the dry bulk freight market is considered a primary indicator of international trade and demand for raw material, whereas price levels in the container freight market directly reflect international trade and demand for semifinished and finished products. Due to the direct link between freight rates and the economy activity, they are considered leading indicators of the global economic climate [30]. Thus, it is evident that freight rates are situated at the inner circle of the global money stream [31], making it crucial for decision-makers in the maritime industry, financial markets, and businesses that rely on shipping to get their products to markets and their materials from suppliers to understand volatility transmission between the container and dry bulk freight markets.

3. Methodology

As discussed in the previous sections, the existing literature analyzes volatility transmission in shipping using variance causality and diagonal autoregressive methods. However, transmission effects are mostly found in off-diagonal matrices [32]. Kroner and Ng [33], and Abdelradi and Serra [34] argue that the BEKK-GARCH (p,q) model is superior to alternative, more restrictive specifications used in previous studies and is capable of capturing asymmetric volatility patterns. Also, since a bivariate BEKK-GARCH model directly specifies the conditional variance-covariance matrix of freight returns, hedge ratios can be generated as a byproduct of updated estimations as new observations become available [17]. Therefore, this study employs an asymmetric full BEKK-GARCH parameterization to best capture bivariate volatility transmission effects.

To do so, we employ an asymmetric BEKK-GARCH(1,1) model, optimized for measuring volatility transmission effects between two markets, to model volatility transmission between the container and dry bulk freight markets during March 2020 through May 2022. The data analysis was conducted using WinRATS 9.2 Pro software, which was shown to be effective in the software benchmarking analysis for BEKK-type models conducted by Brooks et al. [35]. Figures were produced using the Eviews 12 software package due to the authors' visual preferences.

Our mean function is constructed as follows:

$$R_{i,t} = \mu_i + \Gamma_i R_{i,t-1} + \varepsilon_{i,t} \text{ where } i = BDI, SCFI \quad (1)$$

Where $R_{i,t}$ and $R_{i,t-1}$ are the freight index return variables at times t and $t-1$, μ_i is the constant coefficient, Γ_i is the correlation coefficient, and $\varepsilon_{i,t}$ is the conditional variance coefficient. And the variance function is

$$\varepsilon_{i,t} | \Omega_{t-1} \backsim N(0, H_{i,t}) \quad (2)$$

$$H_{i,t} = C_i' C_i + A_i' \varepsilon_{i,t-1} \varepsilon_{i,t-1}' A_i + B_i' H_{i,t-1} B_i + D_i' \xi_{i,t-1}' \xi_{i,t-1} D_i' \quad (3)$$

where

$$C_i = \begin{pmatrix} c_{i,11} & c_{i,12} \\ 0 & c_{i,22} \end{pmatrix}, A_i = \begin{pmatrix} a_{i,11} & a_{i,12} \\ a_{i,21} & a_{i,22} \end{pmatrix}, B_i = \begin{pmatrix} b_{i,11} & b_{i,12} \\ b_{i,21} & b_{i,22} \end{pmatrix}, D_i = \begin{pmatrix} d_{i,11} & d_{i,12} \\ d_{i,21} & d_{i,22} \end{pmatrix} \quad (4)$$

Here, $\xi_{i,t-1}$ is represented as $\varepsilon_{i,t-1}$ if $\varepsilon_{i,t-1}$ is negative, and 0 if positive, which reflects the impacts of asymmetric shocks. $H_{i,t}$ is a conditional variance matrix and C_i is a lower triangular matrix with its inverse co-efficient matrix C_i'. A_i, B_i and D_i ($a_{i,mn}$ $b_{i,mn}$ *and* $d_{i,mn}$) matrices, which represent the diagonal parameters, measure the impacts of historical shocks, volatility, and negative shocks seen in market m on the current conditional variance of market n, while A_i', B_i', and B_i' are their inversed forms. Meanwhile, Ω_{t-1} is the information set containing all information available up to time $t-1$.

3.1. Data Analysis

The data used in the analysis consists of weekly Shanghai Containerized Freight Index (SCFI) data published by the Shanghai Shipping Exchange, and weekly closing values of the Baltic Dry Index (BDI) published by the Baltic Exchange for the period from March 13, 2020 through May 27, 2022. The SCFI is the most widely used index for sea freight rates for container shipping worldwide. This index has been calculated weekly since 2009 and shows the most current freight prices for container transport from China's main ports, including Shanghai. BDI, a shipping freight-cost index for the dry bulk freight market, is a composite of the Capesize, Panamax, and Supramax time charter average indices. It is used around the world as a proxy for dry bulk shipping stocks and is a general shipping market bellwether. Both series consist of 115 observations obtained from the Bloomberg Professional Terminal. The sample starting date is March 13, 2020 because that is the date the World Health Organization deemed COVID-19 to be a global pandemic.

Reviewing the descriptive statistics in Table 2, we immediately note the large difference between the maximum and minimum index values and the enormity of the standard deviations of both indices. The standard deviation/mean ratio for SCFI (0.4931) and BDI (0.5023) reflects the high variation in the series. Also, the skewness, kurtosis, and Jarque–Bera test show that the indices have excess kurtosis, are skewed, and not normally distributed [36].

Figure 1 shows overall freight rates increased exponentially when COVID-19 was declared a global pandemic. While the dry bulk freight market is clearly more volatile, the container freight market continued to increase steadily. This can be attributed to the oligopolistic market structure of the container shipping industry, where freight rates are determined by a few powerful shipping alliances that are more inclined to increase rates than decrease them [37]. This reinforces information asymmetry in the market, which is one of the main factors of inefficiency in the shipping freight markets discussed in the previous sections.

Table 2. *Descriptive statistics of SCFI and BDI*

	SCFI	BDI
Mean	3003.095	2162.617
Median	2885.000	1977.000
Maximum	5109.600	5206.000
Minimum	818.1600	393.0000
Standard deviation	1481.077	1086.487
Skewness	-0.174789	0.641206
Kurtosis	1.508344	3.041447
Jarque-Bera	11.24721	7.888523
Probability	0.003612	0.019366

Source: Bloomberg, Authors' calculations

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index, Std. Dev.: Standard deviation

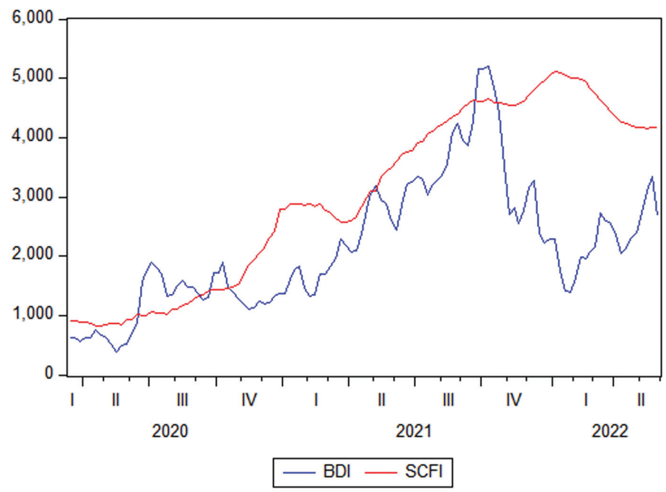

Figure 1. *Time trend of SCFI and BDI*

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index

3.2. Data Preparation

To employ GARCH-type modeling, the raw data were first converted into a percentage return time series as follows:

$$R_t = Log\left(\frac{P_t}{P_{t-1}}\right)*100 \quad (5)$$

where P_t is the freight index value and R_t is the freight index return (in percentage terms). After converting the SCFI and BDI data series to percentile return values, we computed descriptive statistics as shown in Table 3. Trend graphs are shown in Figure 2.

Table 3 shows the mean returns of both RSCFI and RBDI are positive, and the standard deviations show that price fluctuations in the dry bulk freight market are more than four times the fluctuations seen in the container freight market. The skewness, kurtosis, and Jarque-Bera test statistics show that both indices are fat-tailed, positively skewed, and do not follow a normal distribution [36].

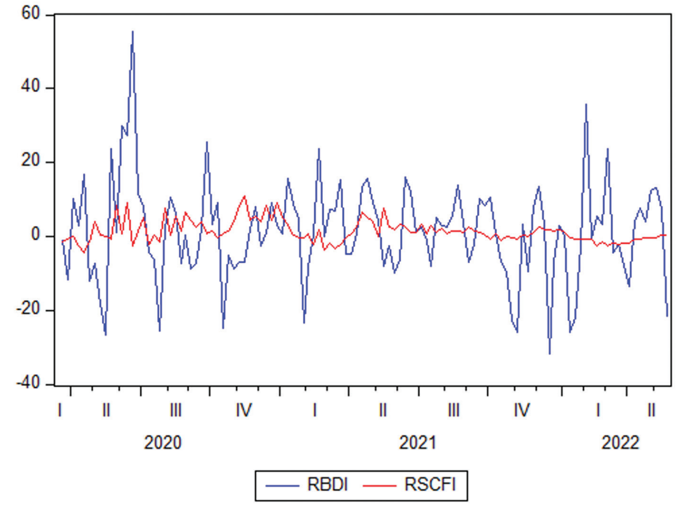

Figure 2. *Trends in SCFI and BDI percentage returns*

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index

Table 3. *Descriptive statistics of RSCFI and RBDI*

	R(SCFI)	R(BDI)
Mean	1.334630	1.266206
Median	0.730591	1.899155
Maximum	10.95791	55.46442
Minimum	-4.541441	-31.87212
Standard deviation	3.006210	13.51546
Skewness	0.968335	0.365936
Kurtosis	3.771197	4.896752
Jarque-Bera	20.64081	19.63320
Probability	0.000033	0.000055

Figure 2 shows that in both series, periods of extreme volatility are followed by more extreme volatility, and mild volatility is followed by mild volatility. In other words, volatility clustering is obvious, and is more pronounced in the dry bulk freight market than in the container freight market.

To conduct a time series analysis, the series must be free of unit roots and stationary. If not, they must be made stationary by differencing them until no unit roots remain. The stationarity of both return series were tested using the Augmented Dickey-Fuller unit root test, where the null hypothesis is the existence of a unit root [38]. Table 4 shows that the null hypothesis is rejected for both series and both series are I(0); in other words, they are stationary.

4. Results

After ensuring the stationarity of the return series, an asymmetric BEKK-GARCH(1,1) model is specified to analyze volatility transmission between the container and dry bulk freight markets during the COVID-19 pandemic. The order of the GARCH(p,q) model is selected based on the Akaike

Table 4. *ADF unit root test results*

	R(SCFI)	R(BDI)
ADF test statistic	-3.589952***	-6.148515***
1% level critical value	-3.489659	-3.491345
5% level critical value	-2.887425	-2.888157
10% level critical value	-2.580651	-2.581041
***: Indicates the null hypothesis of non-stationarity is rejected at the 1% level		

Information Criterion (AIC) developed by Akaike [39], which suggests that the optimal model produces the minimum AIC statistic. The criterion graphs of the models are given in Table 5 and estimation results are given in Table 6.

The results show that for both the dry bulk and container freight markets, volatility is significantly affected by past freight returns in the short run, with values of 0.3896 [A(1,1)] and 0.4637 [A(2,2)]. The transmission effects of volatility indicate that past SCFI volatility had a large and significant impact on the volatility of BDI during the COVID-19 pandemic, with a value of 0.9880 [A(2,1)]. Although not nearly as large in magnitude, volatility transmission from BDI to SCFI is also significant with a value of -0.747 [A(1,2)].

The results also reveal the long-run self-transmission effects of prior volatilities on current period volatilities for both BDI and SCFI, with values of 0.7558 [B(1,1)] and 0.7093 [B(2,2)], respectively. Both are significant and confirm the volatility clustering observed via visual inspection. Regarding the long-run mutual transmission effects of past volatility on current volatility, the results show that SCFI's past volatility has a significant long-run transmission effect on BDI's volatility with a value of −1.7415 [B(2,1)]. Although not nearly as large, volatility transmission from BDI to SCFI over the long run is also significant with a value of 0.0801 [B(1,2)]. Therefore, we conclude there is a significant, continuous, long-run bidirectional volatility transmission between the two indices.

Table 5. *Model comparison based on AIC statistics*

Model	AIC Statistic
BEKK-GARCH(1,1)	13.090*
BEKK-GARCH(1,2)	13.135
BEKK-GARCH(2,1)	13.161
BEKK-GARCH(2,2)	13.111
*: Refers to the model with minimum AIC statistic	

The results also highlight that SCFI returns exhibit a negative leverage effect, which means they were affected more by bad news during COVID-19. We also observe a bidirectional cross-market asymmetric response between the container and dry bulk freight markets. Asymmetric transmissions were significantly stronger from SCFI to BDI with a coefficient of 1.7845 [D(2,1)], compared to a small, but still significant 0.1054 [D(1,2)] value for BDI to SCFI. Additionally, when both dry bulk and container markets experienced simultaneous negative external shocks during the pandemic, these negative shocks clearly boosted the subsequent week's asset return covariance for both markets.

To ensure the robustness of our results, the residuals of the estimation must be free of any ARCH effects, i.e., they should be homoscedastic. We conduct an ARCH-LM test proposed by Engle [40] on the residuals of our estimation. The null hypothesis, which states the residual series are homoscedastic, cannot be rejected as depicted in Table 7.

5. Conclusion

The findings in this study indicate that although the container and dry bulk freight shipping markets mutually

Table 6. *Asymmetric BEKK-GARCH(1,1) model estimation results*

Variable	Coefficient	p-value	Variable	Coefficient	p-value
Mean (RBDI)	1.3914	0.4897	B(1,1)	0.7558***	0.0000
Mean (RSCFI)	1.2169***	0.0000	B(1,2)	0.0801***	0.0000
C(1,1)	2.5261*	0.0837	B(2,1)	-1.7415***	0.0000
C(2,1)	-0.3515	0.2155	B(2,2)	0.7093***	0.0000
C(2,2)	-0.0000	0.9999	D(1,1)	-0.1702	0.4436
A(1,1)	0.3896***	0.0001	D(1,2)	0.1054***	0.0089
A(1,2)	-0.0747***	0.0024	D(2,1)	1.7845*	0.0681
A(2,1)	0.9880**	0.0264	D(2,2)	-0.4044*	0.0573
A(2,2)	0.4637***	0.0000			
Summary statistics					
Log likelihood			-729.1575		
SIC			0.0000067		
***, **, and * refer to significance at the 1%, 5%, and 10% levels, respectively					

Table 7. *ARCH-LM test results*

Lags	Statistics	Significance
2	0.267	0.76620
5	0.249	0.93926
10	1.426	0.18153

transmit volatility to each other, the transmission from the container market to the dry bulk market is much stronger. Therefore, we can conclude that both indices have significant continuous volatility transmission effects both in the short and long run. These results support the price formation hypothesis by showing a lead-lag relationship between the container and dry bulk freight markets. The results are also consistent with previous studies as they suggest dry bulk freight rates will follow container freight rates in a strengthening economy, as was seen during the pandemic when the massive increase in e-commerce volumes and international demand resulting from supply chain distortions increased freight rates and created enormous market pressures in the shipping industry. The results may indicate the existence of a leverage effect during the COVID-19 period, in which negative shocks or bad news generate more volatility for container and dry bulk freight markets than positive shocks, indicating overreaction. The explanation for this phenomenon may be the capital intensity and capital structure of shipping companies, since French et al. [41] state that bad news increases the riskiness of firms with higher debt-to-equity ratios and greatly increases the return volatility of the markets in which those firms operate This appears to explain the negative leverage effect of the container freight market, as studies by Drobetz et al. [42] and Yeo [43] on the capital structures of the top 115 and top 130 shipping firms, respectively, showed an average debt-to-equity ratio of 1.74 for the shipping industry.

The weak form of the EMH suggests there should be no volatility transmission between these markets [32,44]. However, our results show strong mutual volatility transmissions between the container and dry bulk freight markets, meaning they can be used as predictive indicators for each other. The volatilities of both are also heavily affected by their own past volatilities, which mean that historical freight values can be used to predict future freight values. This indicates inefficiencies in both the container and dry bulk freight markets.

This study contributes to the literature in two ways. First, previous studies attempted to explain the volatility transmission mechanism among freight markets using variance causality and diagonal autoregressive methods. However, transmission effects mostly reside in off-diagonal matrices, which we modeled in our research.

Second, to the best of our knowledge, no previous study has examined the disruptive effects of COVID-19 on the freight markets by considering volatility transmission, i.e., the spread of financial disturbances or shocks from one market or institution to another, which can lead to a wider systemic crisis. The results in this study shed light on the pandemic's significant adverse effects on the container and dry bulk freight markets.

Participants in the shipping markets should consider the volatility transmission effects shown here when planning and imposing shipping policies on either the container or bulk market to better anticipate the effects of those policies on the other market. From an efficient market perspective, regulators and policy makers should consider regulatory actions to support market efficiency in dry bulk and container freight markets, and future research could focus on efficiency guidelines for these markets. Future research could extend this study by including other segments of the freight market or by focusing on other aspects of the shipping markets such as the sale and purchase markets. Also, as a byproduct of our estimation process, our model can be used to generate hedge ratios between container and dry bulk freight markets as fresh observations become available.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept design: R. Memişoğlu, S. Sigalı, Data Collection or Processing: R. Memişoğlu, Analysis or Interpretation: R. Memişoğlu, Literature Review: R. Memişoğlu, S. Sigalı, Writing, Reviewing and Editing: R. Memişoğlu, S. Sigalı.

Funding: The author(s) received no financial support for the research, authorship, and/or publication of this article

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