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Original Research Paper

An empirical analysis of freight rate and vessel price volatility transmission in global dry bulk shipping market

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ABSTRACT

Global dry bulk shipping market is an important element of global economy and trade. Since newbuilding and secondhand vessels are often traded as assets and the freight rate is the key determinant of vessel price, it is important for shipping market participants to understand the market dynamics and price transmission mechanism over time to make suitable strategic decisions. To address this issue, a multi-variate GARCH model was applied in this paper to explore the volatility spillover effects across the vessel markets (including newbuilding and secondhand vessel markets) and freight market. Specifically, the BEKK parameterization of the multi-variate GARCH model (BEKK GARCH) was proposed to capture the volatility transmission effect from the freight market, newbuilding and secondhand vessel markets in the global dry bulk shipping industry. Empirical results reveal that significant volatility transmission effects exist in each market sector, i.e. capesize, panamax, handymax and handysize. Besides, the market volatility transmission mechanism varies among different vessel types. Moreover, some bilateral effects are found in the dry bulk shipping market, showing that lagged variances could affect the current variance in a counterpart market, regardless of the volatility transmission. A simple ratio is proposed to guide investors optimizing their portfolio allocations. The findings in this paper could provide unique insights for investors to understand the market and hedge their portfolios well.

1. Introduction

As closely related to global economy and international trade, the global dry bulk shipping industry is very volatile (Lun et al., 2006). The past decade has witnessed the great fluctuation of dry bulk shipping freight rates, newbuilding and secondhand dry bulk vessel prices. In the dry bulk market, vessels are also traded as assets by shipowners' investment

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or divestment strategies. Therefore, the time-varying characteristics of freight rates and vessel prices have made it hard for carriers and shipowners to predict market trend and to make operation decisions (Stopford, 1988).

Past research on dry bulk shipping market was mainly focused on freight rate and vessel price modeling, price volatility econometric modeling, etc. However, the research on the relationship among the freight rate volatility, newbuilding and secondhand vessel price volatility has been ignored. Volatility underlies the inherent uncertainty and risk of both freight rate market and vessel market. Within the whole dry bulk shipping market, the volatilities may intersect and interplay in both markets. According to the demand-supply theory, the vessel market was influenced by freight rate market, and the vessel market volatility was believed to be influenced by freight rate market volatility. The volatility transmission effect within the whole dry bulk shipping market is the main issue we try to address in this paper and empirical findings may provide a new perspective on market inherent risk management. This paper aims to fill the gap in the literature by exploring the volatility transmission effects among the freight rate market, newbuilding and secondhand vessel markets. We applied a 2-step research outline to address the problem. First, we will examine whether there exist volatility spillover effects among the 3 markets (freight rate market, newbuilding vessel market, secondhand vessel market). Second, a tri-variate GARCH model will be proposed to detect the volatility transmission directions within the 3 markets, whether the demand (freight rate volatility) leads the supply (newbuilding, secondhand vessel price volatility), or the vessel price volatility takes the lead.

The paper structure is laid out as follows. Section 1 provides the brief background of this research. Section 2 is the literature review. Section 3 gives the data properties. Methodology and empirical results are shown in Section 4. Section 5 lists discussion and model implication. Conclusions are remarked in Section 6.

2. Literature review

There is a considerable amount of literature on the study of freight rate and vessel price volatility. Traditional models such as ARIMA, ADF were applied to study freight rate volatility (Cullinane, 1992; Veenstra and Franses, 1997). However, since Kavussanos (1996a, 1996b) first introduced ARCH (Auto Regressive Conditional Heteroskedasticity) classic models into worldwide shipping market, the research on shipping freight rate and vessel price volatility has gained its popularity. A series of Kavussanos' researches have concluded that the dry bulk freight rates and secondhand vessel prices were time-varying; freight rates for larger vessel sizes showed greater fluctuation effects; freight rates and vessel prices were first order stationary; and derived class of GARCH models had been extensively applied in dry bulk shipping market research (Kavussanos and Alizadeh-M, 2001, 2002; Kavussanos and Visvikis, 2004; Kavussanos and Nomikos, 2000). Tvedt (2003) confirmed the stationarity of shipping freight rates and validated that the freight rate volatility tended to be reduced when transforming US dollar to Japanese Yen. Some other researches paid attention to the leverage effects on dry bulk freight markets, and revealed that the asymmetric impacts between past innovations and current volatility were internal nature and the asymmetric characters were distinct for different vessel sizes and different market conditions (Chen and Wang, 2004; Lu et al., 2008). A further research extended dry bulk freight rate conditional volatility and pointed that macroeconomic factors had important impacts on freight rate volatility (Drobetz et al., 2012).

Besides, a large body of research has been done on newbuilding and secondhand vessel price modeling. Specific econometric models were established to estimate newbuilding and secondhand vessel prices. Newbuilding (secondhand) vessel price and freight rates were confirmed to have the largest impacts on secondhand (newbuilding) vessel price; trading volume and trading activity also affect vessel prices (Adland and Koekebakker, 2007; Alizadeh and Nomikos, 2003; Jiang and Lauridsen, 2012; Lun and Quaddus, 2009; Mulligan, 2008; Syriopoulos and Roumpis, 2006; Tsolakis et al., 2003).

As shown above, extensive econometric models have been proposed in the dry bulk shipping research area. However, little has been done to explore the volatility transmission effects among the freight rate market, newbuilding and secondhand markets. Dai et al. (2014) investigated the price volatility transmission effect on the dry bulk vessel market, but neglected to incorporate the determinant factor-freight rate into the model. As the global dry bulk shipping market experienced a historical boom and recession in the past decade, it is crucial to examine the volatility transmission effect to understand the overall dry bulk shipping market risk well.

However, a lot of researches on volatility transmission across different assets or markets have been done in other financial sectors due to their important roles in portfolio risk management and market stability assessment. Most attention has been paid to the volatility spillovers between international stock markets with GARCH models (Cifarelli and Paladino, 2005; Kim and Rui, 1999; Wang et al., 2002). Other studies have focused on volatility spillovers between spot and futures market, such as stock indices (Booth and So, 2003), interest rates (Craln and Lee, 1995), foreign exchange (Wang and Wang, 2001), and real estate market (Wong et al., 2007).

3. Data property

In this paper, we choose the monthly data of world dry bulk one year time charter rates, newbuilding and secondhand vessel prices from Clarkson Intelligence Network during the period of 2001/12 to 2012/11. The raw data was pre-processed by log first order difference to show the characteristics of volatility. The vessel price volatility and freight rate volatility for all 4 vessel types are shown in Figs. 1–12 (in the figures, the X axis presents the year scale, the Y axis depicts the freight and price volatility, which is non-dimensional). As it can be seen from Fig. 1, the vessel prices are very volatile. The descriptive statistics of all 4 vessel types are listed in Table 1. In Table 1, V_{FC} is capesize freight rate volatility, V_{SC} is secondhand capesize vessel price volatility, V_{NC} is

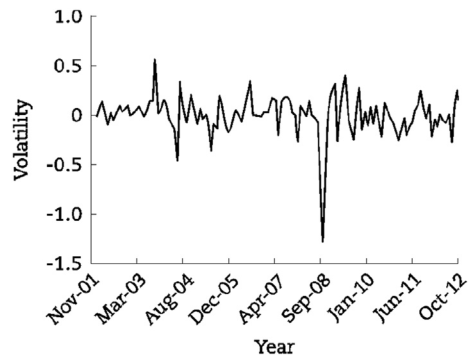

Fig. 1 – Capesize freight rate volatility.

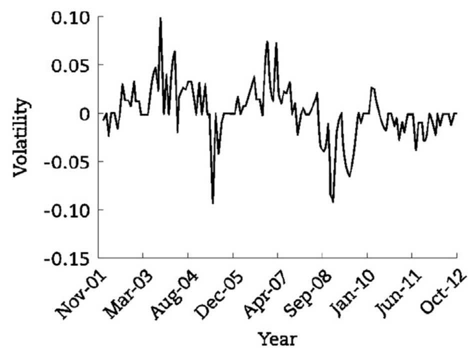

Fig. 2 – Capesize newbuilding vessel price volatility.

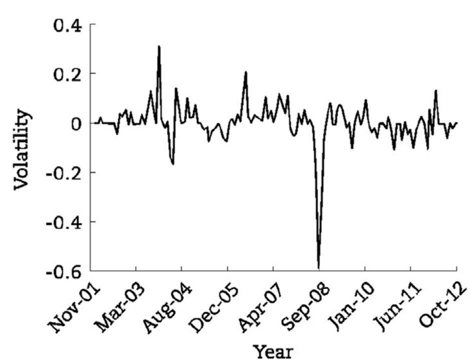

Fig. 3 – Capesize secondhand vessel price volatility.

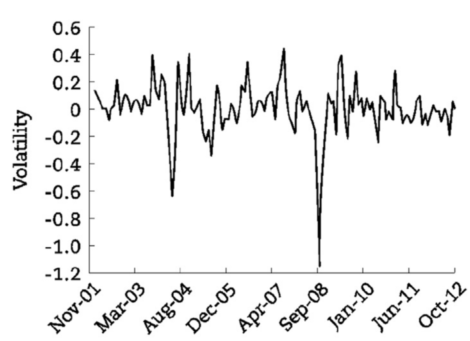

Fig. 4 – Panamax freight rate volatility.

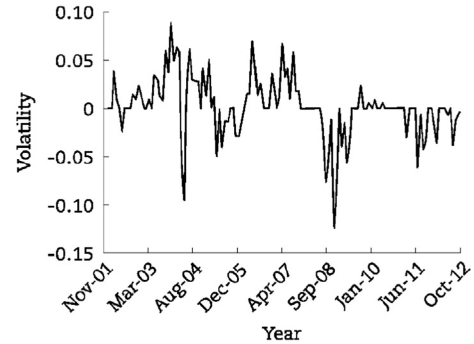

Fig. 5 – Panamax newbuilding vessel price volatility.

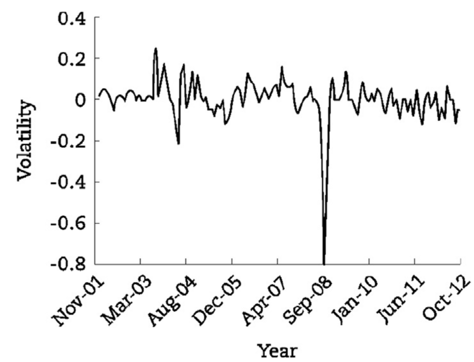

Fig. 6 – Panamax secondhand vessel price volatility.

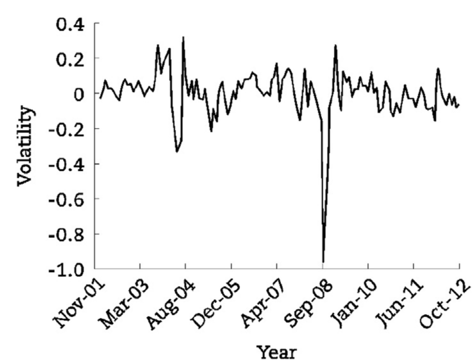

Fig. 7 – Handymax freight rate volatility.

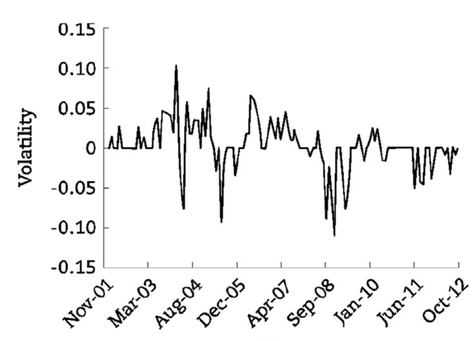

Fig. 8 – Handymax newbuilding vessel price volatility.

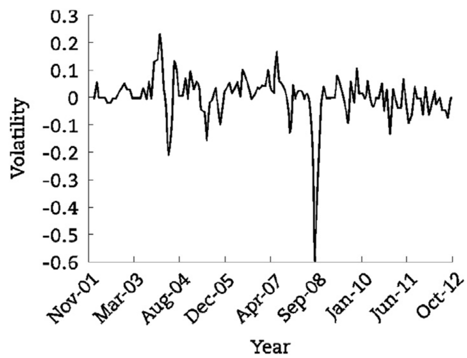

Fig. 9 – Handymax secondhand vessel price volatility.

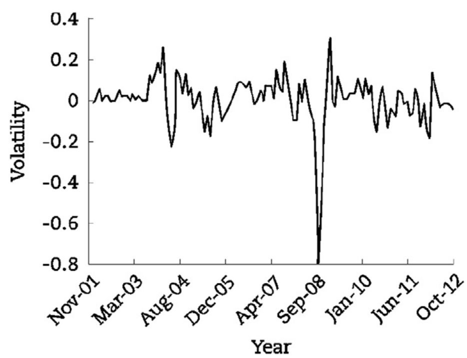

Fig. 10 – Handysize freight rate volatility.

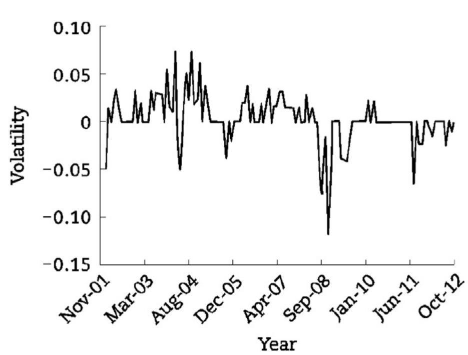

Fig. 11 – Handysize newbuilding vessel price volatility.

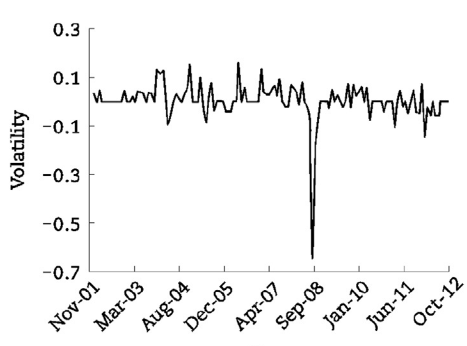

Fig. 12 – Handysize secondhand vessel price volatility.

Table 1 – Descriptive statistics of dry bulk time charter rates, newbuilding and secondhand vessel price volatility (monthly).

2001/12–2012/11	Mean	Std. dev.	Skewness	Kurtosis
V_{FC}	0.000957	0.189285	−2.02504	14.957490
V_{SC}	0.002606	0.088595	−2.76265	21.441780
V_{NC}	0.001978	0.027962	−0.29641	5.656030
V_{FP}	0.003333	0.187902	−1.88439	13.749700
V_{SP}	0.002063	0.099843	−4.06890	33.810470
V_{NP}	0.001755	0.031549	−0.62467	5.484351
V_{FM}	0.000909	0.138906	−2.87055	20.813190
V_{SM}	0.003143	0.084562	−3.04585	21.969280
V_{NM}	0.002186	0.030763	−0.62597	5.594470
V_{FS}	0.001613	0.117742	−2.81272	19.923430
V_{SS}	0.003215	0.075781	−4.70511	42.178560
V_{NS}	0.002568	0.025530	−0.93489	7.442105

newbuilding capesize vessel price volatility, V_{FP} is panamax freight rate volatility, V_{SP} is secondhand panamax vessel price volatility, V_{NP} is newbuilding panamax vessel price volatility, V_{FM} is handymax freight rate volatility, V_{SM} is secondhand handymax vessel price volatility, V_{NM} is newbuilding handymax vessel price volatility, V_{FS} is handysize freight rate volatility, V_{SS} is secondhand handysize vessel price volatility, V_{NS} is newbuilding handysize vessel price volatility.

From Table 1, statistics reveal that freight rate market is the most volatile among the 3 markets while newbuilding market is the least volatile one. In addition, Augmented Dickey–Fuller unit root test was applied to examine the stationarity of all price volatility. The findings confirm that time charter rates and vessel prices (both newbuilding and secondhand) are first-order difference stationary, that is, freight rate volatility and vessel price volatility are stationary. These findings laid out the foundation for our subsequent analysis.

Table 2 tabulates the cross-correlations between freight rate and vessel prices (newbuilding and secondhand) volatility in capesize market. In Table 2, t is time. The cross-correlation statistics of other vessel types are listed in Tables 3–5.

Table 2 – Freight rate and vessel price volatility correlations in capesize sector.

Lag i	$V_{FC\ t}$, $V_{SC\ t-i}$	$V_{FC\ t}$, $V_{SC\ t+i}$	$V_{FC\ t}$, $V_{NC\ t-i}$	$V_{FC\ t}$, $V_{NC\ t+i}$	$V_{SC\ t}$, $V_{NC\ t-i}$	$V_{SC\ t}$, $V_{NC\ t+i}$
0	0.5306	0.5306	0.2362	0.2362	0.3204	0.3204
1	0.7568	0.2060	0.2351	0.1853	0.2580	0.2572
2	0.2854	0.1160	0.1977	0.3120	0.1904	0.3498
3	−0.0638	0.0016	0.0885	0.2075	0.0749	0.3966
4	−0.0959	−0.0139	−0.0353	0.1773	0.0827	0.2306
5	−0.0607	0.0171	−0.0358	0.1501	0.0667	0.1551
6	−0.0346	−0.0170	−0.0002	0.0606	0.0617	0.1335
7	−0.0155	−0.1369	0.1323	0.1590	0.0291	0.1234
8	−0.1493	0.0825	0.0151	0.2241	0.0567	0.2540
9	−0.0915	0.1061	0.0416	0.2930	0.0890	0.3349
10	0.1196	0.0546	0.0098	0.2493	0.1037	0.2743
11	0.0960	0.0225	0.0123	0.2478	0.0441	0.1833
12	−0.0180	−0.0184	0.0285	0.0723	0.0267	0.1953

Table 3 – Freight rate and vessel price volatility correlations in panamax sector.

Lag i	$V_{FP\ t}$, $V_{SP\ t-i}$	$V_{FP\ t}$, $V_{SP\ t+i}$	$V_{FP\ t}$, $V_{NP\ t-i}$	$V_{FP\ t}$, $V_{NP\ t+i}$	$V_{SP\ t}$, $V_{NP\ t-i}$	$V_{SP\ t}$, $V_{NP\ t+i}$
0	0.5239	0.5239	0.4567	0.4567	0.4610	0.4610
1	0.7500	0.1760	0.3714	0.3873	0.2826	0.3662
2	0.3125	0.0018	0.1270	0.3655	0.0336	0.3332
3	0.0655	−0.0004	0.0124	0.2276	0.0346	0.4686
4	−0.0037	−0.0249	0.0349	0.1037	0.0223	0.2502
5	−0.0042	0.0375	−0.1522	0.1805	−0.0044	0.0872
6	−0.0373	−0.1052	−0.1709	0.0564	0.0138	0.1907
7	−0.0424	−0.1781	−0.0258	0.1096	0.0031	0.1136
8	−0.2072	0.0716	0.0128	0.1281	0.0176	0.1158
9	−0.1254	0.1466	−0.0210	0.1054	0.0776	0.1281
10	0.0918	0.1091	−0.0408	0.0222	−0.0546	0.0739
11	0.1456	0.0161	−0.0644	0.0648	−0.0233	0.0470
12	−0.0345	−0.1297	−0.0202	0.0000	−0.0099	0.0571

Table 4 – Freight rate and vessel price volatility correlations in handymax sector.

Lag i	$V_{FM\ t}$, $V_{SM\ t-i}$	$V_{FM\ t}$, $V_{SM\ t+i}$	$V_{FM\ t}$, $V_{NM\ t-i}$	$V_{FM\ t}$, $V_{NM\ t+i}$	$V_{SM\ t}$, $V_{NM\ t-i}$	$V_{SM\ t}$, $V_{NM\ t+i}$
0	0.5251	0.5251	0.4799	0.4799	0.3973	0.3973
1	0.8197	0.2154	0.2976	0.3653	0.1917	0.4790
2	0.4467	0.0425	0.0464	0.4462	−0.0138	0.3523
3	0.0582	0.0251	−0.0348	0.2446	0.0758	0.3834
4	−0.1097	−0.0021	−0.0284	0.0865	0.0951	0.2260
5	−0.1693	0.0639	−0.0147	0.1240	0.0357	0.0805
6	−0.0302	−0.0558	−0.0406	0.1764	0.0257	0.1112
7	0.0064	−0.0853	−0.0207	0.1897	−0.0097	0.1884
8	−0.0040	0.0674	−0.0458	0.1993	0.0305	0.2218
9	−0.0819	0.0840	−0.0479	0.0888	−0.0154	0.1469
10	0.0595	0.1058	−0.0197	0.0585	−0.0013	0.0648
11	0.0445	0.0145	−0.0734	0.0897	0.0111	0.0742
12	−0.0064	−0.0116	−0.0234	0.0640	0.0411	0.0342

Table 5 – Freight rate and vessel price volatility correlations in handysize sector.

Lag i	$V_{FS\ t}$, $V_{SS\ t-i}$	$V_{FS\ t}$, $V_{SS\ t+i}$	$V_{FS\ t}$, $V_{NS\ t-i}$	$V_{FS\ t}$, $V_{NS\ t+i}$	$V_{SS\ t}$, $V_{NS\ t-i}$	$V_{SS\ t}$, $V_{NS\ t+i}$
0	0.4456	0.4456	0.4574	0.4574	0.4303	0.4303
1	0.6575	0.2718	0.3412	0.4371	0.1860	0.3873
2	0.4353	0.1665	0.0751	0.4430	0.1193	0.2731
3	0.0911	0.0546	0.0816	0.2049	0.1013	0.4082
4	−0.0751	0.0449	−0.0514	0.0377	0.0836	0.1802
5	−0.2022	0.0477	−0.1183	0.0465	−0.0028	0.0822
6	−0.0585	−0.0812	−0.0717	0.1124	0.0220	0.0886
7	−0.0370	0.0463	−0.1028	0.1988	0.0231	0.0805
8	−0.0718	0.1307	−0.0889	0.2674	0.0153	0.1889
9	−0.0493	0.1173	−0.0904	0.2820	0.0225	0.2308
10	0.0040	0.0453	−0.0717	0.2025	−0.0294	0.1474
11	0.0164	−0.1322	−0.0666	0.0937	−0.0124	0.0976
12	−0.0290	−0.0254	−0.0428	0.0794	−0.0295	0.0611

4. Methodology

4.1. *Tri-variate GARCH model*

Traditional uni-variate GARCH model has always been applied for examining time series volatility characteristics, as financial data always show volatility clustering and fat tail effects. However the limitation of uni-variate GARCH is that it cannot investigate the dynamic volatility interactions among different time series. Multi-variate GARCH models, developed by Bollerslev et al. (1988), have been widely applied to test the volatility transmission effects among different markets by modeling the covariance structure of error terms.

Primarily, the BEKK GARCH model has proven its efficiency in many related literature for detecting volatility transmission effects across financial markets (Dai et al., 2014; Hassan and Malik, 2007). In this paper, the purpose of using a multi-variate GARCH model is to simultaneously estimate the mean and conditional variance of freight and vessel price volatility, thus avoiding the generated regressor problem associated with a two-step estimation process found in some past literature. Hence, the BEKK parameterization of the multi-variate GARCH model, which does not impose the restriction of constant correlation among variables over time, is employed in this paper. Through our preliminary research, we have found that a GARCH (1, 1) model is suitable for the time series data of freight rate and vessel price volatility, thus, in this paper, the BEKK GARCH (1, 1) model (Engle and Kroner, 1995) is applied to capture the volatility transmission effects.

The conditional mean equations of freight rate volatility and vessel price volatility are listed below.

$$f_t = \mu + \alpha_i f_{t-1} + \beta_i n_{t-1} + \gamma_i s_{t-1} + \epsilon_{f_t} \tag{1}$$

$$n_t = \mu + \alpha_i f_{t-1} + \beta_i n_{t-1} + \gamma_i s_{t-1} + \epsilon_{n_t} \tag{2}$$

$$s_t = \mu + \alpha_i f_{t-1} + \beta_i n_{t-1} + \gamma_i s_{t-1} + \epsilon_{s_t} \tag{3}$$

where f_t, n_t, s_t, f_{t-1}, n_{t-1}, s_{t-1} are freight rate volatility, newbuilding vessel price volatility and secondhand vessel price volatility at time t and t−1, μ is the constant coefficient, α_i, β_i, γ_i are correlation coefficients, ϵ_{f_t}, ϵ_{n_t}, ϵ_{s_t} are the conditional variance coefficients for freight rate, newbuilding price and secondhand price, respectively.

The equations assume a first order autoregressive (AR (1)), in which the freight rate volatility (newbuilding/secondhand vessel price volatility) is a function of its own past volatility and the volatility of the other 2-time series. This could be justified by the relatively strong correlation between the 3 markets in Table 2.

$$\begin{bmatrix} \epsilon_{f_t} \\ \epsilon_{n_t} \\ \epsilon_{s_t} \end{bmatrix} \Bigg| T_{t-1} \sim N(0, H_t), \quad H_t = C'C + A'\epsilon_{t-1}\epsilon'_{t-1}A + B'H_{t-1}B \tag{4}$$

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \quad C = \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \tag{5}$$

where T_{t-1} means that all information is available up to time t−1, $N(0, H_t)$ means ϵ_t follows the normal distribution with a variance of H_t, ϵ_{t-1}, H_{t-1} are the conditional variance and variance matrix at time t−1, C is a 3×3 lower triangular matrix with six parameters, A is a 3×3 square matrix of parameters and shows how conditional variances are correlated with past squared errors. The elements of matrix A measure the effects of shocks or 'news' on conditional variances, B is also a 3×3 square matrix of parameters and shows how past conditional variances affect current levels of conditional variances.

$$\begin{aligned}h_{11,t} = {} & a_{11}^2\epsilon_{1,t-1}^2 + 2a_{11}a_{12}\epsilon_{1,t-1}\epsilon_{2,t-1} + 2a_{11}a_{31}\epsilon_{1,t-1}\epsilon_{3,t-1} + a_{21}^2\epsilon_{2,t-1}^2 \\ & + 2a_{21}a_{31}\epsilon_{2,t-1}\epsilon_{3,t-1} + a_{31}^2\epsilon_{3,t-1}^2 + b_{11}^2h_{11,t-1} + 2b_{11}b_{12}h_{12,t-1} \\ & + 2b_{11}b_{31}h_{13,t-1} + b_{21}^2h_{22,t-1} + 2b_{21}b_{31}h_{23,t-1} + b_{31}^2h_{33,t-1}\end{aligned} \tag{6}$$

$$\begin{aligned}h_{22,t} = {} & a_{12}^2\epsilon_{1,t-1}^2 + 2a_{12}a_{22}\epsilon_{1,t-1}\epsilon_{2,t-1} + 2a_{12}a_{32}\epsilon_{1,t-1}\epsilon_{3,t-1} + a_{22}^2\epsilon_{2,t-1}^2 \\ & + 2a_{22}a_{32}\epsilon_{2,t-1}\epsilon_{3,t-1} + a_{32}^2\epsilon_{3,t-1}^2 + b_{12}^2h_{11,t-1} + 2b_{12}b_{22}h_{12,t-1} \\ & + 2b_{12}b_{32}h_{13,t-1} + b_{22}^2h_{22,t-1} + 2b_{22}b_{32}h_{23,t-1} + b_{32}^2h_{33,t-1}\end{aligned} \tag{7}$$

$$\begin{aligned}h_{33,t} = {} & a_{13}^2\epsilon_{1,t-1}^2 + 2a_{13}a_{23}\epsilon_{1,t-1}\epsilon_{2,t-1} + 2a_{13}a_{33}\epsilon_{1,t-1}\epsilon_{3,t-1} + a_{23}^2\epsilon_{2,t-1}^2 \\ & + 2a_{23}a_{33}\epsilon_{2,t-1}\epsilon_{3,t-1} + a_{33}^2\epsilon_{3,t-1}^2 + b_{13}^2h_{11,t-1} + 2b_{13}b_{23}h_{12,t-1} \\ & + 2b_{13}b_{33}h_{13,t-1} + b_{23}^2h_{22,t-1} + 2b_{23}b_{33}h_{23,t-1} + b_{33}^2h_{33,t-1}\end{aligned} \tag{8}$$

where $h_{11,t}$, $h_{22,t}$, $h_{33,t}$, $h_{11,t-1}$, $h_{22,t-1}$, $h_{33,t-1}$ describe the conditional variance (volatility) of the freight rate market, newbuilding vessel market and secondhand vessel market at time t and t−1, $h_{12,t-1}$, $h_{13,t-1}$, $h_{23,t-1}$ describe the conditional covariances between freight rate market and newbuilding vessel market, between freight rate market and secondhand vessel market, and between newbuilding vessel market and secondhand vessel market at time t−1, respectively, $\epsilon_{1,t-1}^2$, $\epsilon_{2,t-1}^2$, $\epsilon_{3,t-1}^2$ denote the deviations from the mean due to some unanticipated events in the freight market, newbuilding vessel market and secondhand vessel market at time t−1, $\epsilon_{1,t-1}\epsilon_{2,t-1}$, $\epsilon_{1,t-1}\epsilon_{3,t-1}$, $\epsilon_{2,t-1}\epsilon_{3,t-1}$ denote the cross market influence effects of freight rate market and newbuilding vessel market, freight rate market and secondhand vessel market, and newbuilding vessel market and secondhand vessel market at time t−1, respectively.

4.2. *Empirical results*

We applied the tri-variate GARCH (1, 1) model on dry bulk capesize market for instance. The estimation results based on BEKK parameterization for each variance equation are reported in Table 6, and the estimation results of other vessel types are listed in Tables 7–9. Detailed explanation of coefficients in variance equations are given in Section 5.1.

5. Discussion and model implication

5.1. *Discussion*

Noted from Table 6, in the first column, the freight rate volatility is significantly influenced by the news generated from the secondhand vessel market (as the coefficient $\epsilon_{1,t-1}\epsilon_{3,t-1}$ is significant). It reveals that shocks from the dry bulk capesize secondhand vessel market can induce volatility shocks in the freight rate market. For the newbuilding vessel market, the price volatility is significant indirectly affected by freight rate volatility and secondhand vessel price volatility (see the significant $\epsilon_{1,t-1}\epsilon_{2,t-1}$, $\epsilon_{2,t-1}\epsilon_{3,t-1}$ coefficient terms). Besides, as $\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{33,t})$ is negative, it means that the news from secondhand market tends to have negative impacts on freight rate volatility. While in the secondhand vessel market, lagged shocks from the freight market and newbuilding vessel market jointly induce volatility changes in secondhand vessel market (see the

Table 6 – Estimation results of tri-variate GARCH model (capesize).

Independent variable	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\epsilon_{1,t-1}^2$	0.0065*	0.0015	8.21E-05
$\epsilon_{1,t-1}\epsilon_{2,t-1}$	0.0063	0.0384*	−5.54E-02
$\epsilon_{1,t-1}\epsilon_{3,t-1}$	0.1430*	−0.0013	−3.17E-03*
$\epsilon_{2,t-1}^2$	1.6525	0.2465*	9.3544
$\epsilon_{2,t-1}\epsilon_{3,t-1}$	2.2751	−0.0172*	1.0711*
$\epsilon_{3,t-1}^2$	0.7830	0.0003	0.0307*
$h_{11,t-1}$	0.6796*	0.0015	0.0077
$h_{12,t-1}$	−0.0256*	0.0384*	0.0894
$h_{13,t-1}$	−1.0763*	−0.0013	0.0266*
$h_{22,t-1}$	0.0308	0.2465*	0.2600
$h_{23,t-1}$	0.2290	−0.0172*	0.1548
$h_{33,t-1}$	0.4261	0.0003	0.0230

Note: *Significant at 5% critical level.

Table 7 – Estimation results of tri-variate GARCH model (panamax).

Independent variable	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\epsilon_{1,t-1}^2$	0.0147	0.0005	4.07E-03
$\epsilon_{1,t-1}\epsilon_{2,t-1}$	0.0053	0.0212*	−9.76E-02
$\epsilon_{1,t-1}\epsilon_{3,t-1}$	0.3959*	0.0031	−6.77E-02*
$\epsilon_{2,t-1}^2$	0.6737	0.2375	0.5846
$\epsilon_{2,t-1}\epsilon_{3,t-1}$	2.6837	0.0685*	0.8108*
$\epsilon_{3,t-1}^2$	2.6726	0.0049	0.2811*
$h_{11,t-1}$	0.0827	0.0007	0.0058
$h_{12,t-1}$	−0.0155	−0.0299*	0.0560
$h_{13,t-1}$	0.1306	−0.0046	−0.0723
$h_{22,t-1}$	4.9111	0.3063*	0.1342
$h_{23,t-1}$	−1.0066	0.0952*	−0.3468
$h_{33,t-1}$	0.0516	0.0074	0.2239*

Note: *Significant at 5% critical level.

Table 8 – Estimation results of tri-variate GARCH model (handymax).

Independent variable	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\epsilon_{1,t-1}^2$	0.0226*	0.0001	2.87E-03
$\epsilon_{1,t-1}\epsilon_{2,t-1}$	0.0033	0.0064	−1.86E-02
$\epsilon_{1,t-1}\epsilon_{3,t-1}$	0.2323*	0.0015	−2.47E-02*
$\epsilon_{2,t-1}^2$	1.1242	0.0868*	0.0302
$\epsilon_{2,t-1}\epsilon_{3,t-1}$	1.6390	0.0395*	0.0801
$\epsilon_{3,t-1}^2$	0.5974	0.0045	0.0532*
$h_{11,t-1}$	0.0006	0.0785	0.0363
$h_{12,t-1}$	−0.0133	0.0007	0.3047
$h_{13,t-1}$	0.0302	−0.0943	−0.2258
$h_{22,t-1}$	4.7873	1.44E-06	0.6389
$h_{23,t-1}$	−2.7740	−0.0004	−0.9469*
$h_{33,t-1}$	0.4017	0.0283	0.3508

Note: *Significant at 5% critical level.

Table 9 – Estimation results of tri-variate GARCH model (handysize).

Independent variable	$h_{11,t}$	$h_{22,t}$	$h_{33,t}$
$\epsilon^2_{1,t-1}$	0.0253*	0.0016	5.06E-04
$\epsilon_{1,t-1}\epsilon_{2,t-1}$	0.0129*	0.0147	1.64E-02
$\epsilon_{1,t-1}\epsilon_{3,t-1}$	0.2493*	0.0035	6.85E-03
$\epsilon^2_{2,t-1}$	0.9042	0.0327	0.1329
$\epsilon_{2,t-1}\epsilon_{3,t-1}$	1.4908	0.0157*	0.1110*
$\epsilon^2_{3,t-1}$	0.6145	0.0019	0.0232*
$h_{11,t-1}$	0.0169	0.0363	0.0234
$h_{12,t-1}$	−0.0495*	−0.0721*	−0.0811
$h_{13,t-1}$	−0.0746	0.0521	−0.2016
$h_{22,t-1}$	5.1053	0.0358	0.0702
$h_{23,t-1}$	1.2960	−0.0518	0.3491
$h_{33,t-1}$	0.0823	0.0187	0.4339*

Note: *Significant at 5% critical level.

significant $\epsilon_{1,t-1}\epsilon_{3,t-1}$, $\epsilon_{2,t-1}\epsilon_{3,t-1}$ coefficient terms). To summarize the results, with the significance of $\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{11,t})$, $\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{33,t})$, bilateral volatility transmission effects are found between freight market and secondhand vessel market. While as $|\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{11,t})| > |\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{33,t})|$ $(0.1430 > 3.17\text{E}-03)$, we can conclude that the volatility spillover effect from secondhand vessel market to the freight market takes the dominant. Similarly, the volatility transmission direction is from newbuilding to the secondhand market as the directional spillover effect gets stronger $(|\epsilon_{2,t-1}\epsilon_{3,t-1}(h_{33,t})| > |\epsilon_{2,t-1}\epsilon_{3,t-1}(h_{22,t})|\ (1.0711 > 0.0172))$. There only exists unidirectional transmission effect between freight market and newbuilding market that volatility transferred from freight market to newbuilding market, but not vice versa. Generally, it is believed that the demand (freight rate) would influence the supply (newbuilding/secondhand vessels), however, by our analysis, the results are partially consistent with the theory. A possible explanation may be that from the perspective of demand-supply, newbuilding market is the real supply market, as many speculative transactions are made in the secondhand market, that the information from the freight market takes the lead and induces volatility change in the newbuilding market. While as the newbuilding market underlies the intrinsic market value, news spreads from newbuilding market to secondhand market and causes volatility spillover. Although bilateral volatility transmission effects are detected between freight and secondhand markets, the spillover effect is much stronger from the secondhand vessel market to the freight market. This could be explained that after the 2008 world financial crisis, the global dry bulk shipping market has been totally distorted, the freight rate could not reflect the real demand status, or even, in turn, the freight rate volatility could be determined by the instant secondhand vessel transaction price volatility.

The variance coefficients (GARCH terms) also reveal that there exist variance transmission effects among the 3 markets. The freight sector is positively affected by the lagged variance of its own (see significant coefficient $h_{11,t}$), and negatively affected by the newbuilding and secondhand vessel markets (as $h_{12,t-1}$, $h_{13,t-1}$ are both significant). The variance of newbuilding price volatility is affected by the lagged variances from all the 3 sectors (see the significant $h_{12,t-1}$, $h_{22,t-1}$, $h_{23,t-1}$ terms). While the variance of secondhand price volatility is affected by the lagged variance of freight rate volatility.

For other vessel types, similar effects have been examined by the tri-variate GARCH model (the estimation results are listed in Tables 7–9). In the panamax sector, there exist 2 bilateral volatility transmission effects, between the freight market and the secondhand market, and between the newbuilding and the secondhand market. As $|\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{11,t})| > |\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{33,t})|$ $(0.3959 > -6.77\text{E}-02)$ and $|\epsilon_{2,t-1}\epsilon_{3,t-1}(h_{22,t})| < |\epsilon_{2,t-1}\epsilon_{3,t-1}(h_{33,t})|$ $(0.0685 < 0.8108)$, volatility spills from the freight market to the newbuilding market, from the newbuilding market to the secondhand market, and, volatility transfers from secondhand market to the freight market. While in the panamax sector, the variance volatility transmissions are from the freight market and the secondhand market to the newbuilding market. In the handymax sector, volatility transmissions are from the secondhand market to freight and newbuilding markets with the significance of $\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{11,t})$ and $\epsilon_{2,t-1}\epsilon_{3,t-1}(h_{22,t})$. Besides, the variance transmission is from the newbuilding market to secondhand market. However, volatility in the freight market could be induced by both volatilities from newbuilding and secondhand markets in the handysize sector with significance of $\epsilon_{1,t-1}\epsilon_{2,t-1}(h_{11,t})$ and $\epsilon_{1,t-1}\epsilon_{3,t-1}(h_{11,t})$. Between the newbuilding and secondhand markets, a bilateral transmission exists, however, the volatility spillover effect from the newbuilding market is stronger than that from the secondhand market. Within the handysize sector, the variance spills over from the freight market to the newbuilding market.

All the empirical findings are partially consistent with past research (Dai et al., 2014). However, some conclusions are against the previous findings and need further specification. In this paper, we hold the view derived from the past researches and models, the proposed tri-variate GARCH model incorporates the supply and demand aspects (as freight rate, newbuilding vessel price, and secondhand vessel price), which could make our hypothesis more reliable. Besides, the freight rate volatility was believed to spill over to the newbuilding/secondhand markets, and the similar phenomena were detected by our model. The exceptions may be explained that after the 2008 world financial crisis, the global dry bulk shipping market was totally distorted, freight rates could not reflect the real demand status, or even the freight rates were partially determined by the secondhand vessel transaction price level, which could lead to the spillover from the secondhand market to the freight market.

5.2. *Model implication*

Investment decisions regarding asset pricing, risk management and portfolio management are always critical and hard to make for investors in the world dry bulk sector. With accurate estimation of the time-varying covariance of newbuilding and secondhand vessel price volatility, it could help make better investment decisions (Hassan and Malik, 2007). Therefore, in this paper, we follow the applications proposed by Kroner and Ng (1998) to outline a simple implication to guide risk and portfolio management in the dry bulk market.

We propose the risk minimizing portfolio weight in newbuilding/secondhand vessel asset management as

$$\omega_{23,t-1} = \frac{h_{22,t-1} - h_{23,t-1}}{h_{22,t-1} - 2h_{23,t-1} + h_{33,t-1}} \tag{9}$$

where $\omega_{23,t-1}$ is the portfolio weight for newbuilding vessel market relative to secondhand vessel market at time $t-1$. Given a mean-variance utility function, the optimal portfolio holdings of the newbuilding sector are

$$\omega_{23,t-1} = \begin{cases} 0 & \omega_{23,t-1} < 0 \\ \omega_{23,t-1} & 0 \le \omega_{23,t-1} \le 1 \\ 1 & \omega_{23,t-1} > 1 \end{cases} \tag{10}$$

Eq. (9) presents that the proposed weight coefficient $\omega_{23,t-1}$ is a function of conditional variances/covariances of newbuilding and secondhand price volatilities for each time period. In the capesize sector, the average weight $\omega_{23,t-1}$ in our model is 1, which implies that the optimal portfolio investment strategy for investors currently is to purchase newbuilding vessels without purchasing any secondhand vessels. This example presents that the simple ratio $\omega_{23,t-1}$ could be a useful tool for investors making decisions.

6. Conclusions

In this paper, we studied the volatility dynamics and examined the volatility transmission effect on the world dry bulk shipping market using monthly data of the freight rate, newbuilding vessel price and secondhand vessel price from December, 2001 to November, 2012. Overall, our empirical estimation results prove the existence of significant bilateral and unidirectional interactions among the freight rate market, newbuilding vessel and secondhand vessel market.

Our research has extended the literature by introducing the tri-variate GARCH model, which could incorporate 3 independent variables, freight volatility, newbuilding price volatility and secondhand price volatility. By uncovering the potential dynamic volatility transmissions between different markets, this paper has revealed that each market interacted with others in terms of volatilities and variances. In addition, we proposed a simple but useful investment ratio to inform shipowners and investors to optimize their portfolio management regarding the time-varying vessel prices. This could help investors to consider all the market sectors when making decisions, because some news influencing a certain market sector would eventually affect all market sectors through the market interdependence.

The findings may be important for the risk and portfolio management in the global dry bulk shipping market. Since we have realized that there are certain volatility transmissions among different market sectors, investors could take actions to hedge the risks and optimize their portfolio allocations.

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