An Empirical Study of Volatility Spillover Effects between International Crude Oil Futures and Russian and Chinese Stock Markets: A Multivariate BEKK-GARCH Model based on Wavelet Multi-Resolution Analysis

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Keywords: International Crude Oil Futures, Russian and Chinese Stock Markets, Volatility Spillover Effects, Wavelet Multi-Resolution Analysis, Multivariate BEKK-GARCH Model.

Abstract: The strategic position of oil determines the high impact of crude oil on the macro economy. The volatility of crude oil futures prices affects the stock market, and China and Russia are typical representatives of crude oil importers and exporters respectively. This paper focuses on empirically studying the volatility spillover effects of international crude oil futures and the Chinese and Russian stock markets. This paper selects data on international crude oil futures prices, China-Russia stock market composite index and sectoral stock indices for the period from 24 April 2015 to 20 April 2018. The empirical results show that all industry stock indices are cointegrated with international crude oil futures prices, and the adjustment coefficients of international crude oil futures prices on the volatility of other industry stock indices are insignificant, except for CSI Industrial and Russian Energy.

1 INTRODUCTION

China is extremely dependent on imported crude oil and Russia is currently the world's largest crude oil reserve, which means that fluctuations in international crude oil prices will have a significant impact on the Chinese and Russian economies. Crude oil futures, which reflect the spot price, to some extent influence the stock market, which reflects the economic situation. Currently, there is a very limited literature that examines the impact of international crude oil futures prices on both composite and sectoral stock indices. This paper investigates the volatility spillover effects of international crude oil futures prices on Chinese and Russian composite and sectoral stock indices, and examines the linkage between crude oil and stock markets by comparing the effects of international crude oil futures prices on Chinese and Russian stock markets.

In this paper, different empirical models are used for further analysis according to the characteristics exhibited by the variable groups in the test to ensure the reliability of the results. In this paper, the international crude oil futures price is selected as the explanatory variable, and the Chinese and Russian stock market composite indexes and sector indices are selected as the explanatory variables to establish the corresponding variable groups. The test finds that all the data are not smooth, so this paper proposes two options: (1) to make first-order difference on the original data, establish VAR model and GARCH model, after that, the international crude oil futures price is wavelet transformed and multi-resolution processed, establish BEKK-GARCH model, and judge whether there is volatility spillover effect according to the Wald test results; (2) to make cointegration test on the original data and on the basis of this, Granger causality test results are used to divide the variable groups and establish VECM and ECM models respectively.

2 LITERATURE REVIEW

Most of the studies on the linkage between international crude oil futures and stock market in the established literature are based on stock pricing models. Huang, Masulis and Stoll (1996) suggest that changes in international crude oil futures prices have an impact on discount rates and firms' future cash flows. Leblanc and Chinn (2004) argue that the effect of international crude oil futures prices on inflation is choppy. Early studies on the linkage between

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DOI: 10.5220/0011739500003607
In *Proceedings of the 1st International Conference on Public Management, Digital Economy and Internet Technology (ICPDI 2022)*, pages 438-444
ISBN: 978-989-758-620-0

international crude oil futures prices and stock markets did not test for significant results. the multi-factor model used by Chen, Roll, and Ross (1986) was a sample of early studies on the impact of international crude oil futures prices on stock markets. Since then, Hamao (1990) and Ferson and Havey (1994) extended the model, but none of the studies on the U.S. and Japanese stock markets found a significant effect of international crude oil futures prices on the stock market. However, Jones and Kaul (1996) find significant effects of international crude oil futures prices on the Canadian and U.S. stock markets. Qian-Min Qi and Hong-Liang Zhu et al. (2011) and Xi Zhang and Jian-Yu Wang (2013) found that the fluctuations in international crude oil prices have a strong and long-lasting impact on the stock markets of the United Kingdom and the United States, but a smaller impact on the stock markets of China and India. Hui Zhang (2013), Shangqi Zhuge and Xiangchao Hao (2009) find a long-run cointegration relationship between Chinese stock market volatility and international crude oil futures price volatility between 2002 and 2010. Chunying Zhu (2015) establishes an asymmetric BEKK model and Wald test to find a two-way volatility spillover effect between the international crude oil futures market and the stock market. However, there are relatively few studies on the impact of international crude oil futures prices on various sectors of the stock market. Sadorsky (2001) finds that stock returns of oil companies are positively correlated with oil prices, while natural gas companies are negatively correlated with them. Jie-Nan Lao (2008) finds a significant positive effect of international crude oil futures prices on all primary sector indices. However, Hongfei Jin and Eminent Jin (2010) found that international crude oil futures prices have a significant negative effect on the automotive, construction, and financial sectors, while they have a significant positive effect on the crude oil and natural gas sectors by building a GED-GARCH (1,1)-M model. Using an ARMA-EGARCH-M model for the period 2009 to 2013, Dandan Dai (2014) finds that an increase in international crude oil futures prices has a positive impact on the extractive industries and a negative impact on the chemical industries, among others.

Most of the early literature assumed a stable linear relationship between macroeconomics and international crude oil futures prices, but studies have shown that the relationship is nonlinear and asymmetric. In addition, some literature selects the composite index as the explanatory variable without considering the possible correlation between it and international crude oil futures prices, and when studying the impact of international crude oil futures prices on industry stock indices, most of the literature uses a uniform model to analyze all data without considering the variability among data, and the results obtained are prone to bias. At the same time, many studies only analyze the linkage between international crude oil futures prices and a country's stock market. In contrast, this paper studies the linkage between international crude oil futures prices and the stock markets of China and Russia, and investigates the impact of international crude oil futures prices on the stock indices of both industries.

3 THE IMPACT OF CRUDE OIL ON THE STOCK

This paper focuses on the macroeconomic and industry-specific effects on the stock market respectively, namely how the discount rate changes and how the future cash flows of firms change when oil prices fluctuate.

3.1 Impact of Crude Oil Futures Prices on The Stock Market as A Whole

Crude oil price fluctuations act on the stock market by trading currencies and influencing the macroeconomy. The interaction of national monetary policies affects the trading of crude oil. As the number of net crude oil importers exceeds the number of net crude oil exporters, crude oil prices rise, consumption levels in net importing countries decrease, the purchasing power of currencies falls, inflationary pressures rise and the global economy generally declines.

3.2 Impact of Crude Oil Prices on Related Industries

In this paper, five industries that are closely linked to crude oil are selected to analyse the impact of higher crude oil prices on specific industries. When crude oil prices rise, it will be good news for crude oil miners and coal miners in the extractive industry and negative news for other resource miners; it will have a negative effect on the manufacturing industry; the electricity, heat, gas and water production and supply industry will see an increase in supply costs and a decrease in corporate profits; companies in the construction industry will see a decrease in future cash flows; the transport, storage and postal industry

will see an increase in operating costs, resulting in overall profits in the transport industry decline.

4 EMPIRICAL ANALYSIS AND RESULTS

This paper focuses on the linkages between international crude oil futures prices and the Russian and Chinese stock markets, specifically the impact of international crude oil futures prices on the stock market composite stock index as well as the stock market sector stock index, and therefore the corresponding indicators are selected for the study respectively. Daily frequency data from April 24, 2015 to April 20, 2018 are used in this paper.

Brent Crude Oil Futures Price is used as the international crude oil futures price, with data from wind database, and SHA and RTS are used as the broad indices of Chinese and Russian stock markets respectively, data from Bloomberg database.

As for ZZCP, ZZFZ, ZZGY. ZZJZ, ZZJT, ZZNY, ZZRL, RCP, RFZ, RGY, RJZ, RYS, RNY and RRL, these specific indexes are gathered from Wind and Bloomberg.

Firstly, the Jarque-Bera test was performed on the 17 variables mentioned above, and the correlation statistics showed that the subjects were characterised by "spikes and thick tails", which did not follow a normal distribution and had a wide range of fluctuations. Secondly, the smoothness test shows that the 17 variables are non-stationary at 1% significance level. In view of this, this paper proposes two options for further research: 1. first-order differencing of the original data; 2. cointegration test of the original data.

4.1 First-Order Differential

After first-order differencing of the raw data, the original hypothesis of a unit root was rejected at the 1% significance level for all 17 variables selected. The results of the Granger causality test after first order differencing of the data show that there is a two-way Granger causality between Brent crude oil futures price and Russian RTS; Brent crude oil futures price is the Granger cause of CSI energy (ZZNY), CSI fuel (ZZRL), Russian car allocation (RCP) and Russian energy (RNY); while Russian textile (RFZ), Russian Fuel (RRL) are Granger causes of Brent crude oil futures prices; there is no Granger causality between Brent crude oil futures prices and the remaining nine variables.

The results of the VAR regression of Brent crude oil futures price and Russian RTS index with two-way Granger causality show that: 1. Brent crude oil futures price has a significant negative effect on itself at the first and second lags. 2. Russian RTS index has an opposite effect on itself at the first and second lags, with the effect at the first lag being larger and more significant; 3. RTS index lagged first and lagged second have comparable influence on Brent crude oil futures price, while the coefficient of lagged second is more significant; 4. Brent crude oil futures price lagged first and lagged second have great influence on RTS index and have opposite effects.

The impulse response results show that the RTS Index has a two-period lag to the Brent crude oil futures price; the Brent crude oil futures price has no lag to the RTS Index, has an immediate impact and lasts for about four periods; in the long run, both the RTS Index and the Brent crude oil futures price are in a stable state and the impact effect is largely unchanged. The results of the variance decomposition are consistent with these findings.

In this paper, Breusch-Godfrey Serial Correlation LM Test is chosen to test for serial correlation, and the results show that the variable groups dSHA & dBrent, dZZCP & dBrent, dZZFZ & dBrent, dZZJZ & dBrent and dZZJT & dBrent have serial correlation.

This paper performs an ARCH effect test on the regression equations, and the results show that ARCH effects exist for all variable groups except CSI Textiles and Brent Crude Oil futures prices. For CSI Textiles and Brent Crude Oil futures prices, direct OLS regressions are done and Wald tests show that there is no significant relationship between the two. For the variable groups with ARCH effect, the ARCH effect was eliminated for each variable group after the GARCH model was built.

To further investigate the volatility spillover effect of Brent crude oil futures price fluctuations on the stock indices of China and Russia, a BEKK-GARCH model is chosen for this paper, with the following expressions:

$$Y_t = \varphi_0 + \varphi_1 Y_{t-1} + \cdots + \varphi_p Y_{t-p} + \varphi_0 X_t + \varepsilon_t, p > 0$$
$$H_t = CC' + B' H_{t-1} B + A' \varepsilon_{t-1} \varepsilon_{t-1}' A \quad (1)$$

where Y_t is the stock price index, X_t is the crude oil futures price, $H_t = \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix}$ is the conditional covariance matrix, A and B are both 2*2 order parameter matrices, A reflects the ARCH effect of volatility, B reflects the GARCH effect of volatility, and C is a 2*2 order upper triangular matrix.

The conditional covariance matrix can be expanded as follows.

$$h_{11,t} = C_{11}^2 + \beta_{11}^2 h_{11,t-1} + 2\beta_{11}\beta_{21} h_{12,t-1} + \beta_{21}^2 h_{22,t-1} + \alpha_{11}\alpha_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{21}^2\varepsilon_{2,t-1}^2 + 2\alpha_{11}\alpha_{21} h_{12,t-1}$$

$$h_{22,t} = C_{21}^2 + C_{22}^2 + \beta_{12}^2 h_{11,t-1} + 2\beta_{12}\beta_{22} h_{12,t-1} + \beta_{22}^2 h_{22,t-1} + \alpha_{12}^2\varepsilon_{1,t-1}^2 + 2\alpha_{11}\alpha_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{22}^2\varepsilon_{2,t-1}^2$$

$$h_{12,t} = C_{11}C_{21} + \beta_{11}\beta_{12} h_{11,t-1} + (\beta_{12}\beta_{21} + \beta_{11}\beta_{12}) h_{12,t-1} + \beta_{21}\beta_{22} h_{22,t-1} + \alpha_{11}\alpha_{21}\varepsilon_{1,t-1}^2 + (\alpha_{12}\alpha_{21} + \alpha_{11}\alpha_{22})\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \alpha_{21}\alpha_{22}\varepsilon_{2,t-1}^2 \quad (2)$$

where $h_{11,t}$ denotes the conditional variance of the stock price index at moment t, $h_{11,t}$ denotes the conditional variance of the crude oil futures price at moment t, and $h_{12,t}$ denotes the conditional covariance between the stock price index and the crude oil futures price.

The BEKK-GARCH model finds the coefficients of A (1,2) and B (1,2) are significant, indicating that there are volatility spillovers between the Brent crude oil futures price and the China and Russia composite stock indices as well as the sector stock indices. Comparing B (1,1) with B (2,2), we find that B (1,1) > B (2,2) for the combinations of SSE, CSI Auto, Russian Textile, Russian Construction, Brent Crude Oil futures prices. Indicating that equity indices react faster and with shorter periods than Brent Crude Oil futures prices to shocks. In the other combinations, B (1,1) < B (2,2) indicates that the stock index is more volatile than the Brent crude oil futures price and has a longer reaction period to information shocks.

Wavelet transform and multi-resolution can transform the time and frequency of a time series and study the morphology of a subspace series satisfying the multi-resolution condition on different subspaces. In this paper, the discrete wavelet transform is used to stratify and process the raw data, and the binary orthogonal wavelet multi-resolution analysis method is used to wavelet decompose the raw data into short-, medium- and long-term data. The time scales for the short-term data (high frequency signals) are 2 days 4 days. For the medium term are 8 days and 16 days and for the long term is 32 days.

Granger causality tests were conducted on the short-, medium- and long-term Brent crude oil futures price data and the raw data with the composite and sectoral indices of both China and Russia stock markets, and found that only the three variable groups of RTS index and Brent crude oil futures price, RTS index and Brent crude oil futures price short term, and SHA index and Brent crude oil futures price had bivariate Granger The regression results of the BEEK-GARCH model are shown in the figure below.

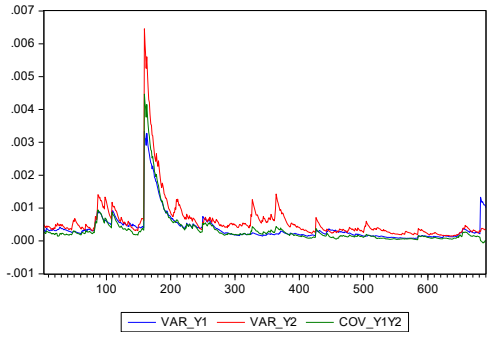

Figure 1: RTS & BRENT.

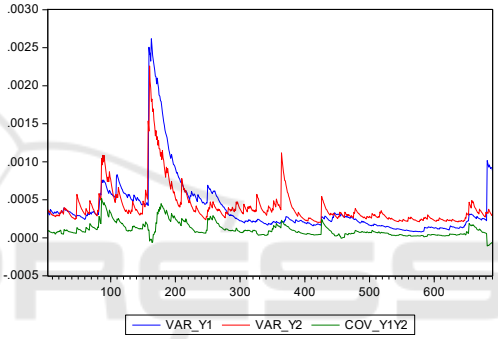

Figure 2: RTS & BRENT short-term.

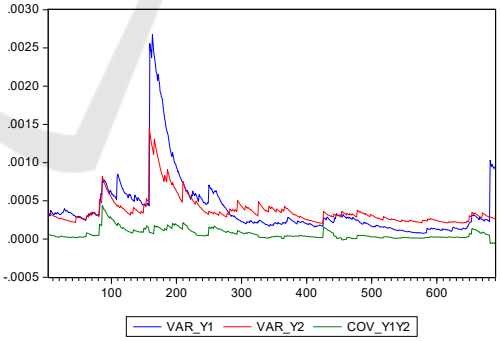

Figure 3: SHA & BRENT.

Wald tests were conducted on two variable groups, RTS index and Brent crude oil futures price and SHA index and Brent crude oil futures price, to determine the direction of the volatility spillover effect, and the results are shown in Table 1.

Table 1: Wald test results.

Original hypothesis	No two-way volatility spillover between Brent crude oil futures prices and the RTS Index $H_0: \alpha_{12} = \alpha_{21} = \beta_{12} = \beta_{21} = 0$		No unidirectional volatility spillover effect of the RTS Index on Brent crude oil futures prices $H_0: \alpha_{12} = \beta_{12} = 0$		No unidirectional volatility spillover effect of Brent crude oil futures prices on the RTS Index $H_0: \alpha_{21} = \beta_{21} = 0$	
	F-value	Significance level	F-value	Significance level	F-value	Significance level
S	749.0268	0.0000	282146.2	0.000	941138.14	0.0000
$d1$	2526.654	0.0000	1761374	0.0000	34865.67	0.0000
$d2$	7973.026	0.0000	1848848	0.0000	296475.1	0.0000
$d3$	0.2450	0.9128	0.3120	0.7319	7.42e-009	0.9999
Original hypothesis	No two-way volatility spillover between Brent crude oil futures prices and the RTS Index $H_0: \alpha_{12} = \alpha_{21} = \beta_{12} = \beta_{21} = 0$		No one-way volatility spillover from SSE Composite to Brent crude oil futures prices $H_0: \alpha_{12} = \beta_{12} = 0$		No unidirectional volatility spillover effect of Brent crude oil futures prices on the RTS Index $H_0: \alpha_{21} = \beta_{21} = 0$	
	F-value	Significance level	F-value	Significance level	F-value	Significance level
S	6551.491	0.0000	401.2298	0.000	973683.0	0.0000
$d1$	1.026588	0.3268	2.568956	0.4456	1.50792	0.5566
$d2$	0.8561	0.5029	0.6122	0.6250	0.2567	0.7736
$d3$	0.2380	0.9356	0.4569	0.7259	8.602e-011	0.9999

The results show that there is a two-way volatility spillover effect between the raw series of Brent crude oil futures prices and the data at $d1$ and $d2$ levels and the RTS Index, while there is no two-way volatility spillover effect between the data at the remaining levels of Brent crude oil futures prices and the RTS Index; while only the raw series of Brent crude oil futures prices has a two-way volatility spillover effect with the Shanghai Composite Index.

The conditional covariance plot of the Brent crude oil futures price and the RTS Index shows that the covariance curve is extremely similar to the trend of the variance curves of the Brent crude oil futures price and the RTS Index, indicating that the volatility spillover effect is strong, especially in the short term, and the volatility spillover effect is more obvious. The volatility spillover effect of Brent crude oil futures price on the SSE Composite Index is less than that of the RTS Index, although there is a relationship between the two. The correlation coefficients between Brent crude oil futures prices and the RTS Index and SSE Composite Index are largely positive, implying that volatility in international crude oil futures prices is likely to increase the volatility of the Russian and Chinese stock indices.

4.2 Co-Integration

In order to prevent the loss of long-run relationships between the data due to first-order differences, this paper uses a cointegration approach to investigate whether there is a long-run relationship between the variables. This paper uses the two-step E-G method to conduct co-integration tests and regressions. The results show that all coefficients are significant and positive, except for the coefficients between the SSE Index, CSI Textile and Brent Crude Oil Futures Price, which are not significant, indicating that in the long run, the stock indices and international crude oil futures prices show a positive relationship.

Granger causality tests were conducted on the groups of variables with long-term relationships, and it was found that RTS Index, SSE Composite Index and Brent crude oil futures price have Granger bi-directional causality; while Brent crude oil futures price is the Granger cause of CSI Energy and CSI Fuel; CSI Textile, CSI Industry, Russian Industry, Russian Construction, Russian Energy and Russian Transportation are the Granger causes of Brent crude oil futures The price of Brent crude oil futures is the Granger cause of VECM models were developed for the groups of variables with Granger two-way causality: Brent crude oil futures price and RTS index, and Brent crude oil futures price and SSE Composite Index. Both the impulse response and variance decomposition results show that the international crude oil futures price explains the volatility of the Russian RTS Composite Index and most of the sectoral indices quite strongly, but explains the volatility of the SSE Index less strongly. The part of the volatility of CSI Industrial, CSI Transportation and CSI Textile that can be explained

by crude oil futures prices is similarly small, while crude oil futures prices explain more strongly the volatility of CSI Auto Allocation and CSI Transportation, indicating that crude oil futures prices have a stronger impact on the Auto Allocation and Transportation sectors. Conversely, the volatility of international crude oil futures prices was less strongly explained by the Chinese stock market composite index and industry indices.

After testing the existence of a long-run equilibrium relationship between the variables, in order to investigate the speed of adjustment of the variables when they deviate from the stochastic trend, this paper constructs an error correction model through a first-order linear autoregressive distribution lag model. The ECM model based on cointegration theory is built according to the E-G two-step method for the group of variables that do not have Granger two-way causality. In the ECM model, all error correction coefficients are negative, indicating that the stock market has a reverse correction function. The results obtained for each variable group are relatively similar, with the absolute values of the error correction coefficients being small, implying that the backward adjustment of the error correction term is limited if the current period's volatility deviates from the long-term equilibrium, i.e. the error in crude oil futures prices has a small and weak adjustment to the volatility of the current period's explanatory variables. The results of the parametric tests show that the adjustment coefficients of crude oil futures prices on the volatility of other industry indices are insignificant, except for China Industry and Russian Energy, indicating that China Industry and Russian Energy are correlated with international crude oil futures prices in the long run.

5 CONCLUSIONS

The crude oil futures market could reflect the economic situation. This paper finds that the Russian composite stock index is more influenced by the international crude oil futures prices and the effectiveness of the Russian stock market is more pronounced. The fluctuation of international crude oil futures price explains more strongly the fluctuation of RTS index. The empirical results show that the sensitivity to information, reaction speed and digestion cycle of the composite stock index and sector index of the Chinese stock market are weaker than those of the Russian stock market. Therefore, the relevant regulators of China's stock market should strengthen the monitoring of large capital flows to eliminate malicious manipulation of stock prices. In the short term, the rise in international crude oil futures prices will increase the volatility of the Shanghai Stock Exchange Index, the China Industrial Sector Index and the Russian Energy Sector Index; in the long term, all indices show a cointegration relationship with international crude oil futures prices. Thus, stabilizing international crude oil futures prices has a positive effect on stabilizing stock prices. The government needs more to prevent speculative behaviour and sound financial regulatory system.

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