Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 10, No. 1, 2023

Research on the Impact of Crude Oil Price Fluctuation Based on EGARCH Model

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Abstract: At present, the largest commodity futures variety in the global futures market is crude oil futures, which plays a role in price discovery, risk hedging, and stabilizing international crude oil prices. The fluctuation of its price is a key issue that governments, investors, and scholars around the world pay attention to. This paper establishes GARCH model and EGARCH model under three distribution states of t distribution, Normal distribution and GED distribution. Then, through model comparison, it was found that the EGARCH model with t-distribution had the best fitting effect. Finally, the EGARCH model under t distribution is predicted within and outside the sample. It is found that under the impact of the financial crisis in 2008 and the COVID-19 epidemic, the crude oil futures prices fluctuated rapidly and violently, indicating that global International incident have a great impact on crude oil futures prices. The innovation of the research lies in comparing crude oil futures under different distributions based on GARCH and EGARCH models, which depict the characteristics of asymmetry.

Keywords: WTI crude oil futures, Asymmetry, EGARCH model.

1. Introduction

Crude oil futures is a financial derivative, which refers to crude oil contracts traded in a standardized way in futures trading. Through crude oil futures trading, investors can buy and sell a certain amount of crude oil at a predetermined price at a certain time in the future, so as to avoid the risk of crude oil price fluctuations. With the increase of global oil trading and the continuous improvement of futures market, West Texas light and low sulfur crude oil futures (WTI) and North Sea Brent crude oil futures (Brent) have become benchmarks for international oil prices. Yang Jie et al. (2022) [1] believe that frequent fluctuations in crude oil prices, especially large fluctuations, are one of the important drivers of global economic fluctuations. Thai et al. (2023) [2] found that WTI crude oil price fluctuations responded positively to the impact of oil production, oil inventories and the US dollar index. Due to the status of the United States in the world, the large demand and supply of crude oil in the United States, and the bundling of crude oil prices and the US dollar, WTI crude oil futures prices have an important impact on the global crude oil market. Brent crude oil futures is also one of the important crude oil price benchmarks in the world, and its price has an important impact on the crude oil market in Europe, Africa and other regions. The research object of this paper is WTI crude oil futures price, for the following reasons. First of all, WTI crude oil price pricing is mainly determined by the U.S. market, while Brent crude oil is priced in the European market. The world's largest economy is the United States and is a crude oil exporter. In contrast, the United States has a much larger world position than European countries. Therefore, WTI crude oil futures prices have a broader influence in the global crude oil market, and their price fluctuations can better reflect the changes in the global crude oil market. Secondly, crude oil prices are bound to the US dollar. In the presence of US dollar hegemony, WTI crude oil futures prices are the pricing benchmark of the international crude oil market, and their fluctuations will attract the attention and reaction of global investors, thus affecting the economies and financial markets of various countries. To sum up, WTI crude oil futures prices have a greater impact on the global economy, so this paper selects WTI crude oil futures prices as the research object.

Due to the important position of WTI crude oil futures market in the global economy, a large number of scholars are studying its price and its volatility. Foreign scholars have rich research on this, Yu et al. (2022) [3] used different time series prediction models to study the long-term trend of crude oil futures. Kun and Hong (2022) [4] believe that the integrated model does not necessarily improve the prediction effect of crude oil futures prices. Ling (2023) [5] investigates whether the global policy uncertainty index information can predict the volatility of oil futures through Midas models, and concludes that it can effectively predict the volatility of crude oil futures. Zhi et al. (2023) [6] used dynamic model averaging and dynamic model selection methods to test the predictability of geopolitical risks from crude oil exporting and importing countries to crude oil futures fluctuations, and found that the GPR index information of crude oil exporting and crude oil importing countries can predict futures fluctuations.

At the same time, many empirical studies show that leverage effect often occurs in the volatility of the return series of financial assets. Therefore, when establishing the volatility model, we must fully consider the leverage impact of asset returns, fully fit asset returns, and establish a more accurate volatility model. Because leverage is a big factor, Nelson (1991) [7] introduced asymmetry into the GARCH model and proposed a new arch form. After that, some scholars have made a lot of supplements to the asymmetric GARCH family, and verified the excellent performance of the model in volatility fitting and prediction through examples. Basel M.A and Valentina (2005) [8] examined the relative out of sample prediction ability of different GARCH models and found that the asymmetric GARCH model fit better.

Domestic scholars also have a lot of research on crude oil futures. Many scholars use neural networks, machine learning and empirical mode methods to study the fluctuation of crude oil futures prices. Lin Yu et al. (2022) [9] found that the crude oil price forecast model based on data decomposition, reinforcement learning integration strategy and error correction technology has the most prominent forecast effect. Zhang Yaojie and Wang Yudong (2022) [10] reviewed many literature on crude oil price forecasting by machine learning, and concluded that machine learning can improve the forecasting effect of crude oil prices. Zhao Xing et al. (2022) [11] proposed a new empirical mode model to predict the price fluctuation of international crude oil futures in a more timely and accurate manner. In terms of quantitative models, it is mainly the research on GARCH models and their extensions, which can well characterize the heteroscedasticity and volatility aggregation of asset returns. Zhang Yuejun et al. (2007) [12] concluded that the GED distribution of GARCH model can better fit the volatility of China's oil prices than the normal distribution. Liu Hong (2009) [13] used GARCH model to analyze the price fluctuation of international crude oil futures, which has the characteristics of peak and thick tail, volatility aggregation and so on. Kou Honghong et al. (2022) [14] confirmed the volatility spillover effect in the stock market and crude oil market through the estimation results of DCC March model. Li Zheng et al. (2021) [15] used single factor and two factor mixed volatility garch-midas models to study the fluctuation of geopolitical risks on international crude oil prices.

In recent years, a large number of domestic scholars have also used EGARCH model to study the leverage effect of financial assets. Chen langnan and Huang jiekun (2002) [16] studied the asymmetric impact of volatility in China's stock market by dividing volatility periods. Niu Huawei and Xu Zhong (2020) [17] studied the reaction of Shanghai crude oil spot market to futures listing and trading based on VAR model and EGARCH model, and found that crude oil futures played a certain role in promoting the volatility of China's crude oil spot market, but it was relatively short-lived. There are also a large number of scholars studying the leverage effect of other financial assets. Wang pengwu (2020) [18] studied the asymmetric characteristics of yield volatility by using GJR GARCH model and EGARCH model respectively. Zhang Shengjie (2020) [19] established an asymmetric GARCH family model and found that the leverage effect of the main board of Shanghai Stock Exchange is not obvious, while the leverage effect of small and medium-sized board, Shenzhen main board and gem is obvious. Guo Baocai and Xiang Lin (2022) [20] concluded that the index return of Shanghai and Shenzhen 300 long-term volatility mainly comes from continuous volatility.

At present, the empirical mode method is mostly used in the research on the fluctuation of crude oil futures price, and the quantitative GARCH model is less used. Moreover, the research on crude oil futures price fluctuation based on GARCH model is mostly based on normal distribution, and there is little research on the leverage effect of EGARCH model on crude oil futures price fluctuation under different distribution states. The innovation of this paper is that based on GARCH model and EGARCH model, the fluctuation of crude oil futures price is studied under different distributions, and the effect of information shock in three states is discussed. At the same time, EGARCH model depicts the characteristics of asymmetry. According to ll value and information criteria, the best fitting model is selected, and then the price fluctuation of WTI crude oil futures is predicted in sample and out of sample.

2. Theoretical Model and Data Selection

2.1. Modeling

The traditional linear regression model generally believes that the random disturbance term is homovariance. However, in the time series of financial assets, the random error term can not meet the above conditions. Time series data of financial assets usually have the characteristics of conditional heteroscedasticity, peak and thick tail. The conditional heteroscedasticity model breaks the limitation of the traditional linear regression model and can better explain the nonlinear correlation of the daily value of exchange rate. Therefore, GARCH family has been widely used in financial time series analysis.

Firstly, the GARCH (1.1) model can better characterize the yield series with conditional heteroscedasticity characteristics. When the random error term of the mean equation is found to have arch effect, the GARCH model can be used to fit its conditional variance. The usual format for the GARCH (P, q) model is:

$$r_t = \mu_t + \varepsilon_t \tag{1}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \alpha_2\varepsilon_{t-2}^2 \text{B} + \alpha_q\varepsilon_{t-q}^2 + \beta_1\sigma_{t-1}^2 + \beta_2\sigma_{t-2}^2 + \text{B} + \beta_p\sigma_{t-p}^2 \tag{2}$$

In the above formula, the mean equation is (1.1) and (1.2) is the conditional variance equation. Is the order of the autoregressive GARCH term,,,.$p\alpha_0 \geq 0\alpha_i \geq 0\beta_i \geq 0$

Secondly, because the financial time series has the characteristics of asymmetry, Nelson immediately proposed the EGARCH model, which can better characterize the asymmetric impact of the series, and does not need to limit that the coefficient is nonnegative. For the EGARCH (P, q) model, its conditional variance is shown in formula (3):

$$\ln\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q}\beta_i \ln\sigma_{t-i}^2 + \sum_{i=1}^{p}\left(\alpha_i\left|\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right| + \gamma_i\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right) \tag{3}$$

In the above formula, the conditional variance of logarithms is on the left; It is the arch effect coefficient, which depicts the impact of previous periods on the volatility of current information; Is the leverage effect coefficient, then there is leverage effect;, There is no leverage; Is an unknown parameter.$\alpha_i\gamma_i\gamma_i \neq 0\gamma_i = 0\beta_i$

2.2. Data sources

This paper collects the daily value data of WTI crude oil futures from January 2, 1997 to December 9, 2022 as a sample, totaling 6626, excluding the negative data on April 20, 2020, totaling 6625. The data comes from Yingwei financial information network. The closing price time series of WTI crude oil futures daily value data is recorded as WTI, and the data excluding negative values are used for model fitting and model prediction.

3. Empirical Analysis

First of all, we observe the daily closing price data of WTI crude oil futures and obtain its time series chart, as shown in Figure 1.

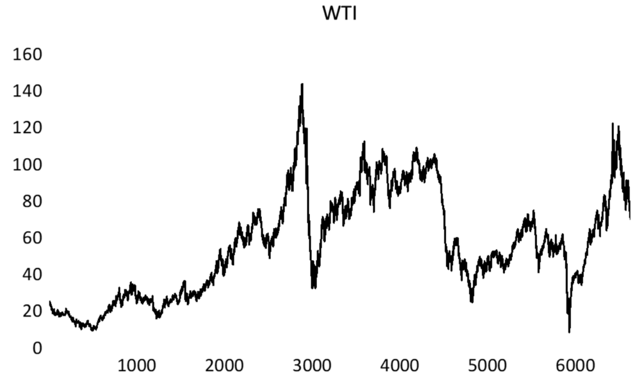


Figure 1. Time series of closing price of WTI crude oil futures

Then the log difference of WTI time series is carried out to obtain the time series diagram of yield series R, which shows that WTI crude oil futures prices have volatility clusters, large fluctuations with small fluctuations, that is, the time series of crude oil futures has the characteristics of "volatility aggregation". As shown in Figure 2.

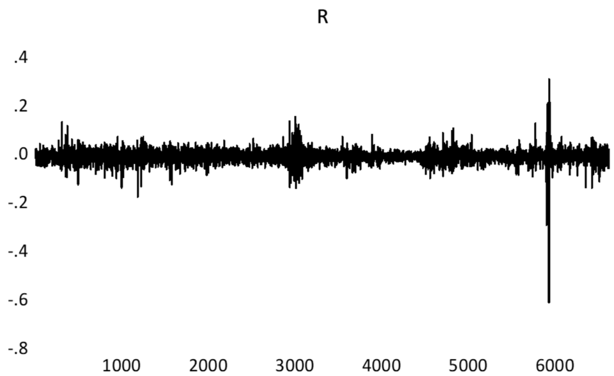


Figure 2. Time series chart of crude oil futures yield R

Below, we take the WTI crude oil futures yield series as the research object, and first observe its descriptive statistical characteristics, as shown in Table 1.

Table 1. Descriptive statistical **characteristics** of WTI crude oil futures price sample data

mean value	minimum value	Max	standard deviation	skewness	kurtosis	J-B	Prob
0.00016	-0.6017	0.3196	0.0270	-1.6512	52.9326	691150.3	0.0000

As can be seen from table 1, because the skewness of the sample is - 1.6512 less than 0, the yield distribution of WTI crude oil futures has the characteristics of left long tail and left skew distribution. The kurtosis of the sample is 52.9326, which is much greater than 3, so compared with the normal distribution, the distribution of WTI crude oil futures yields has peak and thick tail. At the same time, the p value of J-B test is 0.0000, which rejects the original hypothesis, so the sample can not be considered to obey the normal distribution.

ADF method is used to test the stability of crude oil futures yield series, and the results are shown in Table 2.

Table 2. Stability test of sample data

1% threshold	5% threshold	10% threshold	T Statistics	Prob	result
-3.4312	-2.8618	-2.5669	-40.17509	0.0001	stable

It can be seen that the yield series of crude oil futures is stable and can be used for volatility modeling.

Then, GARCH (1, 1) model and EGARCH (1, 1) model under three different distribution states are used to fit the sample data within the sample, and the results are shown in Table 3.

Table 3. Estimated results of **GARCH** (1, 1) model and EGARCH (1, 1) model for sample data

model	Distribution hypothesis	Parameter value			
		α_0	α_1	β_1	γ_1
GARCH	T distribution	0.00001 (0.0000)	0.07953 (0.0000)	0.90795 (0.0000)	
	GED distribution	0.00001 (0.0000)	0.08574 (0.0000)	0.90171 (0.0000)	
	Normal distribution	0.00001 (0.0000)	0.09537 (0.0000)	0.89249 (0.0000)	
EGARCH	T distribution	-0.19952 (0.0000)	0.12688 (0.0000)	0.98662 (0.0000)	-0.05422 (0.0000)
	GED distribution	-0.21667 (0.0000)	0.13968 (0.0000)	0.98568 (0.0000)	-0.05814 (0.0000)
	Normal distribution	-0.24165 (0.0000)	0.15578 (0.0000)	0.98378 (0.0000)	-0.06685 (0.0000)

Note: the value in brackets is the p value of the parameter.

As can be seen from table 3, in the GARCH model under three distributions, it shows that the yield of crude oil futures is stable in the short term, that is, the volatility has high sustainability. In the EGARCH model under the three distributions, it also shows that the yield of crude oil futures is stable in the short term, that is, the volatility has high sustainability. In the EGARCH model under the three distributions, it is significantly less than 0, which is in line with the theoretical logic, indicating that there is indeed a leverage effect in the fluctuation of crude oil futures prices, that is, the impact of negative fluctuations is greater than that of positive fluctuations. In the three distribution states, the asymmetric parameter value in the normal distribution is the largest, the GED distribution is the second, and the t distribution is the smallest. In the EGARCH model, the positive and negative shocks under the t distribution have an impact coefficient on the volatility of crude oil futures yields of and, respectively; The positive and negative shocks under the GED distribution have an impact coefficient on the volatility of crude oil futures yields of and, respectively; The positive and negative shocks under the normal distribution have an impact on the volatility of crude oil futures yields, and $\alpha_1 + \beta_1 < 1 \alpha_1 + \beta_1 + \gamma_1 < 1 \gamma_1 \alpha_1 + \gamma_1 = 0.07266 \alpha_1 - \gamma_1 = 0.1811 \alpha_1 + \gamma_1 = 0.08154 \alpha_1 - \gamma_1 = 0.19782 \alpha_1 + \gamma_1 = 0.08893 \alpha_1 - \gamma_1 = 0.22263$

At the same time, the information shock curves of EGARCH model in three distribution cases are drawn as follows:

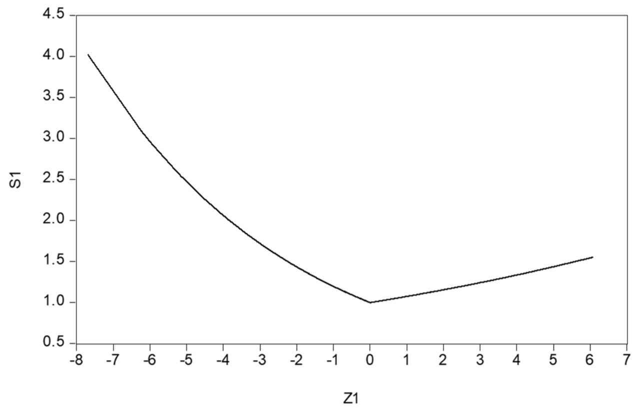


Figure 3. Information shock curve under t distribution

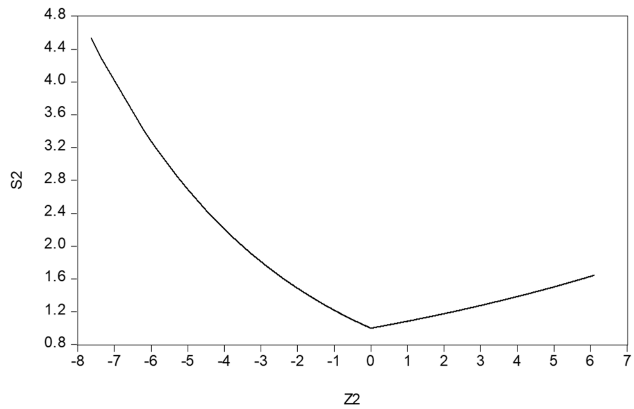


Figure 4. Information **shock** curve under GED distribution

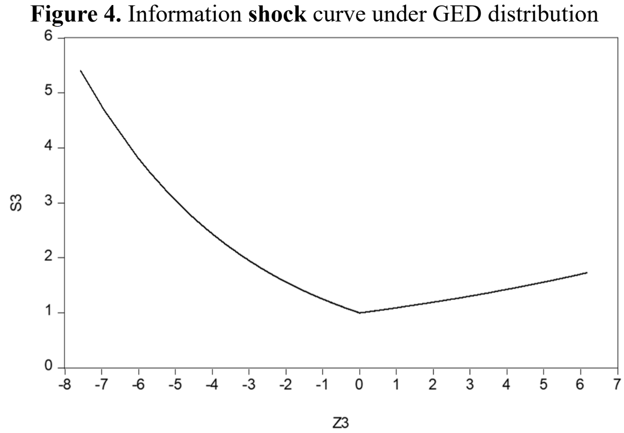


Figure 5. Information shock curve under normal distribution

From the information shock curves in three states, we can see the strong asymmetric response of conditional fluctuations to shocks, and explain the necessity of asymmetric models. Under the three distribution states, it shows that the impact of negative shocks on crude oil futures price fluctuations is much greater than that of positive shocks on crude oil futures price fluctuations, which is consistent with financial theory. The asymmetric effect of normal distribution is greater than that of t distribution and GED distribution.

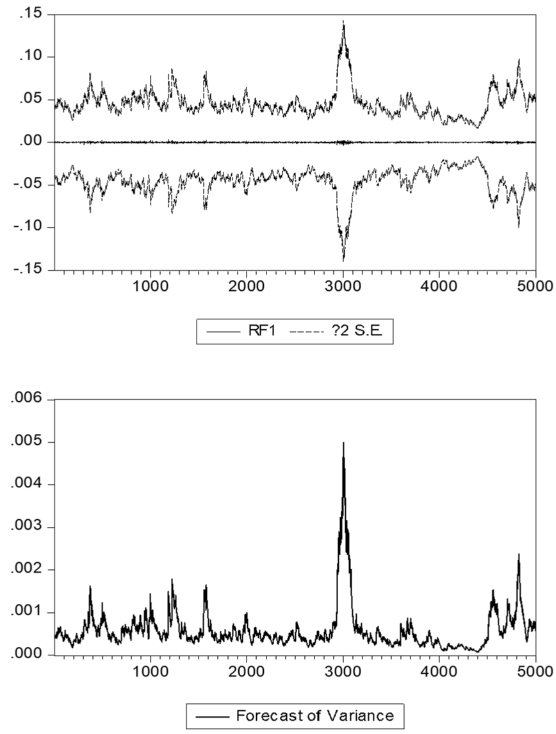
Table 4. Model comparison

model	Distribution hypothesis	Ll	AIC	BIC	HQ
GARCH	T distribution	16002.18	-4.83049	-4.82433	-4.82837
	GED distribution	15977.83	-4.82314	-4.81698	-4.82101
	Normal distribution	15833.58	-4.77988	-4.77495	-4.77811
EGARCH	T distribution	16037.61	-4.84089	-4.83370	-4.83841
	GED distribution	16009.10	-4.83228	-4.82510	-4.82980
	Normal distribution	15874.41	-4.79191	-4.78575	-4.78978

Note: the value in brackets is the p value of the parameter.

According to the greater the LL value, the better, the smaller the AIC, BIC and HQ, it can be seen that the optimal model is the EGARCH model in the state of t distribution. The intra sample fitting of EGARCH model is better than that of GARCH model under three distributions. It shows that EGARCH model has a better in-sample fitting effect on crude oil futures returns after fully considering leverage effect.

Finally, for sample prediction, we divide the sample into two segments, the first segment is 1-5000 sample data, and the second segment is 5000-6625 sample data. We establish EGARCH model under t distribution for the first segment of data. First of all, the first to 5000 sample data are predicted within the sample, and the static prediction method is adopted. The prediction results are shown in the following figure:

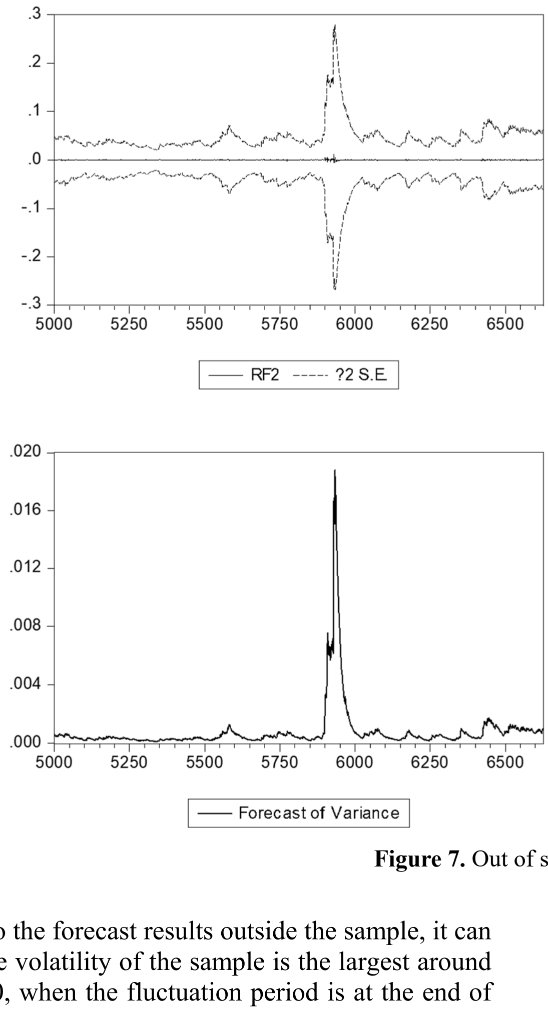


Forecast: RF1	
Actual: R	
Forecast sample: 1 5000	
Adjusted sample: 3 5000	
Included observations: 4998	
Root Mean Squared Error	0.024276
Mean Absolute Error	0.017610
Mean Abs. Percent Error	100.6025
Theil Inequality Coefficient	0.979347
Bias Proportion	0.000000
Variance Proportion	0.961154
Covariance Proportion	0.038846

Figure 6. Intra sample forecast

According to the forecast results in the sample, the volatility of the sample is the largest around 2800 to 3000, which is in the 2008 financial crisis, indicating that the 2008 financial crisis has a great impact on crude oil futures prices, resulting in huge fluctuations in their prices.

Then, the 5000 to 6625 sample data are predicted outside the sample, and the static prediction method is adopted. The prediction results are shown in the following figure:



Forecast: RF2	
Actual: R	
Forecast sample: 5000 6625	
Included observations: 1626	
Root Mean Squared Error	0.034073
Mean Absolute Error	0.018644
Mean Abs. Percent Error	100.9208
Theil Inequality Coefficient	0.979407
Bias Proportion	0.000005
Variance Proportion	0.961771
Covariance Proportion	0.038224

Figure 7. Out of sample forecast

According to the forecast results outside the sample, it can be seen that the volatility of the sample is the largest around 5850th to 5900, when the fluctuation period is at the end of 2019, and the outbreak of covid-19 is December 11, 2019. The two times are consistent, indicating that the impact of covid-19 on crude oil futures prices in 2019 is obvious, resulting in rapid fluctuations in their prices. This is consistent with Zhao Lutao (2023) [21]'s research on the covid-19 epidemic and the conflict between Russia and Ukraine, as well as the sharp fluctuations in the crude oil market caused by various unexpected factors, and the high volatility results after the sharp rise in international oil prices in the first half of the year.

Judging from the two large fluctuations, we can see that crude oil futures prices are highly sensitive to international events, that is to say, when a major disaster occurs, crude oil futures prices will fluctuate rapidly.

4. Conclusion

This paper mainly studies the price volatility of WTI crude oil futures and analyzes it through EGARCH model. EGARCH model is an extension of GARCH model, which can model leverage effect, so as to better characterize the volatility of financial time series data. In this paper, we fit GARCH (1.1) model and EGARCH (1.1) model in three different distribution states within samples, and find that the leverage coefficient of EGARCH model is significantly not zero, indicating that there is leverage effect in crude oil futures prices. At the same time, we also draw the information shock curve of EGARCH model under three distribution states, and find that the impact of negative shocks on crude oil futures prices is much greater than that of positive shocks. In terms of model comparison, we use ll value and information criterion to compare the models, and find that EGARCH model in t distribution has the best fitting effect. This shows that when modeling the volatility of crude oil futures prices, we should consider its thick tail, and the use of t distribution can better describe the characteristics of its peak thick tail. As a kind of financial time series data, crude oil futures have asymmetry in addition to peak and thick tail volatility and volatility clusters. To some extent, the asymmetry of volatility shows that investor sentiment is more sensitive to negative shocks. Then, we divide the sample into two sections for in-sample prediction and out of sample prediction, and find that crude oil futures prices are highly sensitive to international events. Especially under the impact of the financial crisis in 2008 and the covid-19 epidemic in 2019, its price volatility is rapid and sharp. This result shows that the government should adjust its policies in time to deal with its volatility and avoid social panic.

Finally, we believe that when modeling crude oil futures price volatility, macroeconomic impact, high-frequency information, intra day price information and other factors should be taken into account to make the volatility model more accurate and more accurate for theoretical and practical guidance. For example, in terms of macro-economy, inflation, interest rates, stock market changes and other factors can be considered, which often have an important impact on crude oil futures prices. In terms of high-frequency information, minute level price data can be considered to more accurately describe price volatility. In terms of intra day price information, volatility models can be used to predict the fluctuation range of prices to help traders formulate more effective trading strategies.

To sum up, this paper studies the price volatility of WTI crude oil futures and finds that there are asymmetry and leverage effects, which is of great significance for understanding the price volatility of crude oil futures. It has certain reference value for policy making and investment decision-making. These findings are of great significance to investors, governments and financial institutions, and can help them better understand and cope with the volatility of crude oil futures prices.

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