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

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Abstract: At present, the largest commodity 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) and concluded that machine learning can improve the literature on crude oil price forecasting by machine learning, Zhang Yaojie and Wang Yudong (2022) [10] reviewed many correction technology has the most prominent forecast effect. oil price forecast model based on data decomposition, reinforcement learning integration strategy and error correction technology has the most prominent forecast effect. 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:

\[ r_t = \mu_t + \epsilon_t \]

\[ \sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2 + \gamma_i \frac{\epsilon_{t-i}}{\sigma_{t-i}} \sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2 + \gamma_i \frac{\epsilon_{t-i}}{\sigma_{t-i}} \]

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., \( \alpha_0 \geq 0 \), \( \beta_i \geq 0 \)

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 expressed in formula (3):

\[ \ln(\sigma_t^2) = \alpha_0 + \sum_{i=1}^{q} \beta_i \ln(\sigma_{t-i}^2) + \sum_{i=1}^{p} \alpha_i \frac{\epsilon_{t-i}}{\sigma_{t-i}} + \gamma_i \frac{\epsilon_{t-i}}{\sigma_{t-i}} \]

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. \( \alpha_i \gamma_i \neq 0 \), \( \gamma_i = 0 \beta_i \)

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.
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.

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

<table>
<thead>
<tr>
<th>mean value</th>
<th>minimum value</th>
<th>Max</th>
<th>standard deviation</th>
<th>skewness</th>
<th>kurtosis</th>
<th>J-B</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00016</td>
<td>-0.6017</td>
<td>0.3196</td>
<td>0.0270</td>
<td>-1.6512</td>
<td>52.9326</td>
<td>691150.3</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>1% threshold</th>
<th>5% threshold</th>
<th>10% threshold</th>
<th>T Statistics</th>
<th>Prob</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.4312</td>
<td>-2.8618</td>
<td>-2.5669</td>
<td>-40.17509</td>
<td>0.0001</td>
<td>stable</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>model</th>
<th>Distribution hypothesis</th>
<th>Parameter value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\alpha_0$</td>
<td>$\alpha_1$</td>
</tr>
<tr>
<td>GARCH</td>
<td>T distribution</td>
<td>0.000001 (0.0000)</td>
<td>0.07953 (0.0000)</td>
</tr>
<tr>
<td></td>
<td>GED distribution</td>
<td>0.000001 (0.0000)</td>
<td>0.08574 (0.0000)</td>
</tr>
<tr>
<td></td>
<td>Normal distribution</td>
<td>0.000001 (0.0000)</td>
<td>0.09537 (0.0000)</td>
</tr>
<tr>
<td></td>
<td>T distribution</td>
<td>-0.19952 (0.0000)</td>
<td>0.12688 (0.0000)</td>
</tr>
<tr>
<td></td>
<td>GED distribution</td>
<td>-0.21667 (0.0000)</td>
<td>0.13968 (0.0000)</td>
</tr>
<tr>
<td></td>
<td>Normal distribution</td>
<td>-0.24165 (0.0000)</td>
<td>0.15578 (0.0000)</td>
</tr>
</tbody>
</table>

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, 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

\[ \alpha_1 + \beta_1 < 1 \alpha_1 + \beta_1 + \gamma_1 < 1 \gamma_1 \alpha_2 + \gamma_1 = 0.07266 \alpha_2 - \gamma_1 = 0.1811 \alpha_2 + \gamma_1 = 0.08154 \alpha_3 - \gamma_1 = 0.19782 \alpha_3 + \gamma_1 = 0.0893 \alpha_3 - \gamma_1 = 0.2263 \]

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](image)

![Figure 4. Information shock curve under GED distribution](image)

![Figure 5. Information shock curve under normal distribution](image)

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>
<thead>
<tr>
<th>Table 4. Model comparison</th>
</tr>
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<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>GARCH</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
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<tr>
<td>EGARCH</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

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:
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:

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 AIC 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.

References


