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Shanghai Crude Oil Futures Yield Volatility Study

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Abstract: Since the listing of Shanghai crude oil futures in March 2018 its market performance has gradually attracted attention. The closing price data of the futures for the period from March 26, 2018 to April 17, 2023 are selected as observations, and a GARCH model is fitted to the futures log return series to analyze the development of Shanghai crude oil futures and its future trend. The study finds that extreme events such as the New Crown epidemic and the Russia-Ukraine conflict had led to high volatility of Shanghai crude oil futures, but the volatility gradually stabilized in the context of the double cycle at home and abroad. The study compares the effectiveness of the GARCH(1,1)-T model and the GARCH(1,1)-GED model in fitting the logarithmic returns of the Shanghai crude oil futures market. the GARCH(1,1)-T model is able to better capture the asymmetry of the market volatility and the phenomenon of sharp peaks and thick tails after taking into account the distributional characteristics of the residuals. In the paper, the closing price of Shanghai crude oil futures in the next 10 days is predicted according to the GARCH(1,1)-T model, and the short-term prediction effect is better.

Keywords: GARCH model, Shanghai crude oil futures market, short-term forecasting.

1. Introduction

The launch of China crude oil futures in 2018 marks an important progress in energy financialization. By providing a more comprehensive, transparent and efficient price discovery mechanism, promoting the diversification and marketization of the energy market, as well as facilitating the internationalization of China's capital market, China's crude oil futures play an important role in the field of energy financialization. This progress not only has a far-reaching impact on the development of China's energy market, but also provides useful reference and inspiration for the advancement of global energy financialization.

The Asian region's position in the global crude oil consumption market has been increasing, but the lack of a crude oil futures contract that can reflect the demand and supply situation in the Asian market limits the comprehensiveness and accuracy of international crude oil pricing. The launch of China's crude oil futures is of great significance to the pricing system of the international crude oil market.

As one of the core resources of global energy, the price fluctuation of crude oil has an important impact on the global economy and energy market. However, in the past, China's voice in the international crude oil market was relatively low and it lacked effective tools to participate in the pricing and trading of crude oil prices. However, with the listing and trading of crude oil futures on the Shanghai Futures Exchange, China's position in the crude oil market has undergone positive changes. The rapid development of China's crude oil futures not only reflects the increasing openness and innovation of China's financial market, but also the rise of China's economy and its significant influence on the global crude oil market. With the launch of China's crude oil futures, domestic enterprises and investors can more conveniently conduct crude oil trading and risk management, while also providing more reference basis for the formation of domestic crude oil prices.

The listing and trading of crude oil futures on the Shanghai Futures Exchange helps investors to better study and analyze the fluctuation patterns and characteristics of crude oil prices. Therefore, studying the price fluctuation of Shanghai crude oil futures is crucial for analyzing risks and formulating investment strategies and management methods. Therefore, it is of great theoretical and practical significance to further strengthen the research on Shanghai crude oil futures price fluctuations.

Currently, the research on the financial market of Shanghai crude oil futures has been quite in-depth in the academic world, with different research perspectives. In general, they can be summarized as follows: studies on the pricing efficiency and pricing capacity of Shanghai crude oil futures.Chen Yang, Fei Lv, Libing Fang, et al. [1] use the cointegration and Granger causality between the crude oil futures returns of the Shanghai International Exchange (SIX) and some representative spot markets as an entry point to explore the pricing efficiency of the emerging crude oil futures market, and find that the INE crude oil futures price can accurately reflect the fundamental information of the spot market. Qian Wang and Siyi Xiao [2] used vector error correction model, DAG technique and forecast error variance decomposition method based on DAG to study the dynamic leading relationship between China's crude oil futures price and the world's crude oil price under the background of Russia-Ukraine conflict. The results show that Shanghai crude oil futures have a long-term equilibrium relationship with other international crude oil prices; after the Russia-Ukraine conflict, China's crude oil futures market not only reflects the domestic oil market conditions, but also initially reflects the regional pricing power. Luo Changqing, Liu Lan, Zhu Huiming et al. [3] constructed a time-varying information share model based on a multi-scale analysis method, and found that the price of crude oil futures dominated the crude oil market, and the ability of each market to set prices was relatively stable during the sample period, but it was also affected by major events.

With regard to exploring the linkages between Shanghai crude oil futures prices and the global market, Chuanwang Sun et al. [4] examined whether there was a switch in the relationship between China's exchange rate, domestic crude oil prices, and international prices following the launch of futures at the Shanghai International Energy Exchange using an MS-VAR model. It is found that the impact is weak, although it is stronger on the market; since the launch of the new INE regime, there has been a significant positive price movement in the exchange rate fluctuation of the US dollar to the Chinese yuan (USD/CNY).Houyin Long et al. [5]. examine the energy transition effect of Shanghai crude oil futures and find that SC can mitigate the suppressed global price volatility during the transition process.The study also finds that there is a significant positive price shift in the exchange rate of the US dollar to the Chinese yuan (USD/CNY) since the launch of the new INE regime.Yang Jie and Feng Yun [6] constructed four kinds of indicators to quantitatively analyze the effectiveness of the Shanghai crude oil futures market based on the multiple fractal descending-trend volatility analysis and recursive graph method, respectively, and found that: in the same sample period, due to the institutional advantages of China's crude oil futures, the prudent and timely risk-control policy, and the strong and resilient economic fundamentals, the impact of extreme event shocks on the effectiveness of the international crude oil futures market is greater than the domestic market, thus, the negative impact of extreme events is greater than the domestic market. The negative impact of extreme event shocks on the effectiveness of the international crude oil futures market is greater than that of the domestic market, which makes the effectiveness of the Shanghai crude oil futures market higher than that of the Brent and WTI crude oil futures markets in different time scales.Yang Kun, Wei Yu, Li Shouwei et al. [7] introduce the geopolitical risk (GPR) index based on news reports, and use the great overlap discrete wavelet transform with nonparametric quantile causality test method to discuss in detail the nonlinear impact of geopolitical risk on the return and volatility of China's crude oil futures under different time scales and crude oil condition distributions.

Regarding the forecasting aspect of Shanghai crude oil futures, Daxiang Jin et al. [8] explore the predictability of China's crude oil futures volatility by considering the volatility of other energy sources, and the empirical results show that volatility can provide useful information for in-sample and out-of-sample forecasting.Yadong Huang et al. [9] construct different time-series forecasting models to analyze Shanghai futures' long-term trends to guide current price trading and propose an improved HW-Prophet.Yangli Guo et al. [10] explore whether incorporating jumps and jump sizes in the MIDAS modeling framework (Markov switching) enhances the prediction of actual volatility in China's crude oil futures market, and find that emphasizing the potential benefits of the integrated framework for accurate volatility.

In summary, the existing literature is already quite rich in analysis related to the Shanghai crude oil futures market. Although scholars have already conducted studies on pricing power, pricing efficiency, linkages with global markets, and price forecasting of Shanghai crude oil futures, the analysis and forecasting from the perspective of volatility are still insufficient, which affects our analysis and judgment of the overall performance and future trend of Shanghai crude oil futures. Volatility plays a key role in financial markets, especially in the pricing of financial derivatives, financial risk assessment, and asset portfolio analysis. In this paper, we analyze and forecast the logarithmic return of Shanghai crude oil futures using the GARCH model to provide short-term forecasts for investors of Shanghai crude oil futures, taking into account the background and status of the listing of Shanghai crude oil futures.

2. Model Profile

Volatility in financial markets is of great importance to investors and policymakers. Accurately predicting the volatility of financial time series can help investors to reduce risk, formulate effective investment strategies, and manage risk. In this regard, GARCH (Generalized Autoregressive Conditional Heteroskedasticity) models have shown significant advantages in recent years.

Compared with traditional linear models, GARCH models can well capture the phenomenon of volatility aggregation in the financial market, i.e., volatility is characterized by aggregation in time. Investors can utilize the advantages of the GARCH model to reduce risk, formulate investment strategies, and manage risk.

The GARCH model proposed by Boller is as follows:

$$y_t = X_t^{'}\delta + \varepsilon_t$$

$$h_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_i h_{t-j}^2$$

It consists of a mean equation and a conditional variance equation, y_t is the dependent variable, X_t is the explanatory variable or the lag term of y_t, and δ_t is the vector of parameters to be estimated, $h_t = \sigma_t^2 = Var_{t-1}(\varepsilon_t)$.

3. Research Design and Data Testing

3.1. Research design

In this paper, 1220 closing price data of Shanghai crude oil futures from March 26, 2018 to March 31, 2023 are used as a test set for trend analysis, while the best GARCH model fitting is selected based on data characteristics. Finally, a total of 10 dates of closing prices from April 3, 2023 to April 17, 2023 are selected as the test set to test the model fitting effect.

3.2. Smoothness test

First, time series of closing price series, log closing price series and log yield series of Shanghai crude oil futures from March 26, 2018 to March 31, 2023 are plotted for preliminary analysis (see Figures 1, 2 and 3).

Figure 1. Time series of Shanghai crude oil futures closing prices

Figure 2. Time series of logarithmic series of Shanghai crude oil futures closing price

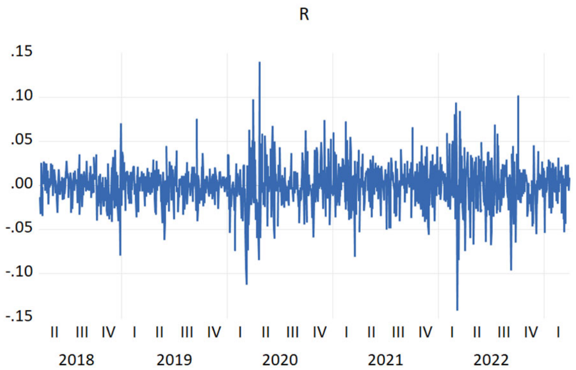

Figure 3. Logarithmic yield time series

Shanghai crude oil futures closing prices have two sharp fluctuations in early 2020 and early 2022, due to the New Crown epidemic and the outbreak of the Russian-Ukrainian conflict, respectively, suggesting that extreme event shocks can have an impact on affecting the smoothness of the Shanghai crude oil futures market. At the same time, we can observe a trend of gradual stabilization of volatility, which can be attributed to the implementation of the domestic and international double-loop policy and the adaptive adjustment of the market. First of all, the implementation of domestic and international double-cycle policies has had a positive impact on the volatility of the Shanghai crude oil futures market. The domestic circular policy effectively reduces market uncertainty by providing a stable macroeconomic environment and strong policy support. At the same time, the promotion of external circular policies has provided a more stable and predictable environment for international trade and market cooperation. The positive impact of these policies is gradually reflected in the reduced volatility of the Shanghai crude oil futures market.

The logarithmic series of Shanghai crude oil futures closing price is still highly volatile with an intercept term. After preliminary judgment, the logarithmic yield series of Shanghai crude oil futures oscillates around the mean value, and there is volatility aggregation, which is a smooth time series; meanwhile, there may be ARCH effect.

The unit root test is performed on the closing price series, the closing price logarithmic series and the logarithmic yield series of Shanghai crude oil futures, and the results are shown in Table 1.

Table 1. Unit root test of Shanghai crude oil futures closing price

ADF test statistic		t-statistic	Prob.*
closing price sequence		-1.6816	0.4404
logarithmic closing price series		-1.4963	0.5354
logarithmic yield series		-34.6292	0.0000
test threshold	1% level	-3.4355	
	5% level	-2.8637	
	10% level	-2.5680	

The unit root test results of the closing price series and closing price logarithmic series of Shanghai crude oil futures show that the t-statistics are -1.686 and -1.4963 respectively, which are higher than the critical value of -3.4355 at the 1% level, so the original hypotheses of the existence of the unit root of the closing price series and the closing logarithmic series of Shanghai crude oil futures cannot be rejected, and the data smoothing process needs to be carried out for the closing price logarithmic series.

The logarithmic yield series is obtained by differentiating the logarithmic series of closing prices, and the t-statistic value of the ADF unit root test is -34.6416, which is smaller than the critical value of -3.4355 at the 1% level, so the original hypothesis that there is a unit root in the logarithmic yield series of Shanghai crude oil futures is rejected.

3.3. Basic statistical characteristics of data

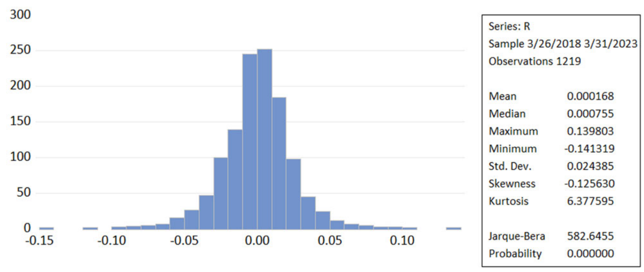

Figure 4. Descriptive statistics of logarithmic returns

The descriptive statistics of the logarithmic return series of Shanghai crude oil futures are shown in Fig. 4. The mean value of the logarithmic return of Shanghai crude oil futures during the sample period is 0.0002, the standard deviation is 2.4385%, the skewness is -0.1256, and the kurtosis is 6.3776, which is higher than that of the peak 3 of the normal distribution, which indicates that the logarithmic return of Shanghai crude oil futures has the characteristics of "sharp peaks and thick tails" and "thick tails". This indicates that the logarithmic return of Shanghai crude oil futures has the characteristic of "sharp peak and thick tail". This means that there are more extreme values and large fluctuations in the logarithmic return of Shanghai crude oil futures, which tends to produce more extreme events than the normal distribution. The JB normality test statistic is 582.6455, and the concomitant probability is approximated to be 0, which indicates that the distribution of the logarithmic return of Shanghai crude oil futures differs significantly from that of the normal distribution.

3.4. Autocorrelation test

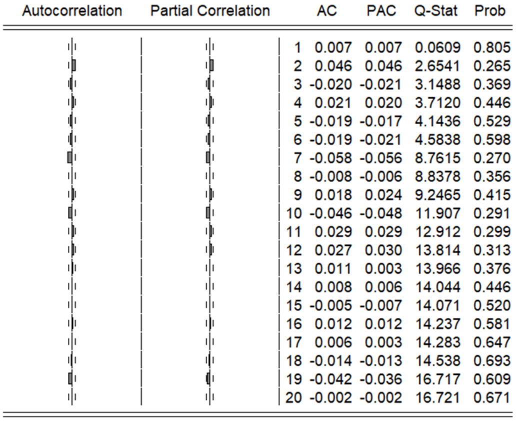

Figure 5. Correlation Chart

A correlation plot of the log return series of Shanghai crude oil futures was drawn (see Figure 5). Autocorrelation analysis was performed and it was found that the autocorrelation of the log yield series itself is weak. This means that the correlation between the current yield values and the past yield values is low, and the price movements are to some extent random and unaffected by historical yields.

However, when we analyze the squared residuals of the logarithmic yield series, we find a strong autocorrelation (see Figure 6). While the squared residuals reflect the variance of price fluctuations, the autocorrelation indicates whether changes in the variance are influenced by past variances. This implies a degree of persistence and inertia effect in the variance of price fluctuations, i.e., there is a high correlation between the current value of the variance and the past value of the variance.

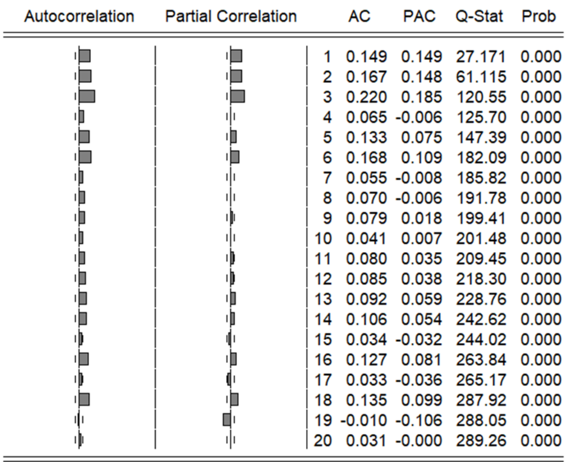

Figure 6. Residual squared correlation diagram

Further, we consider the possibility of an ARCH effect in the yield series. This effect may be due to factors such as investor risk aversion or changes in market sentiment. Therefore, we need to conduct an ARCH effect test to determine whether it exists or not.

3.5. ARCH effect test

Table 2. ARCH effect test

Heteroscedasticity test: ARCH			
F-statistic	27.6575	**Prob. F(1,1216)**	0.0000
Obs*R-squared	27.0869	**Prob. Chi-Square(1)**	0.0000

ARCH (Autoregressive Conditional Heteroskedasticity) effect is a statistical model used to test the heteroskedasticity in the series, which is mainly used in the financial field to model and analyze the financial time series data such as stock returns, exchange rate changes, etc. The results of the ARCH effect test show that the value of the LM statistic is 27.6575, and the accompanying probability is close to 0, which is smaller than the significance level of 0.05. Therefore, we can reject the original hypothesis that there is no ARCH effect in the logarithmic return series of Shanghai crude oil futures.

4. An Empirical Analysis of The Volatility of Logarithmic Yield of Shanghai Crude Oil Futures

4.1. GARCH modeling

4.1.1. Model Selection

In practice, residual series tend to have spiky thick tails or skewed distributions, which makes the validity of GARCH models questionable. Compared with the normal distribution, the t-distribution has larger tail probabilities and better reflects extreme events in financial time series. Therefore, introducing the t-distribution into the GARCH model can more accurately capture the characteristics of volatility. In addition, the GED distribution is suitable for characterizing data with different sharpness and thick tails. By introducing the GED distribution, anomalies in financial time series can be better modeled.

In this study, we will use the t-distribution and the GED distribution to fit these residual series and calculate the corresponding parameter estimates. By comparing the fitting results using different forms of distributions, we can assess their performance in capturing volatility characteristics. In this paper, we use the GARCH(1,1) family of models for the fitting, and the results are detailed in Tables 3 and 4.

Table 3. GARCH(1,1)-T model fitting results

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.0010	0.0006	1.8443	0.0651
	Variance Equation			
C	0.0000	0.0000	2.6040	0.0092
RESID(-1)^2	0.1004	0.0215	4.6803	0.0000
GARCH(-1)	0.8757	0.0253	34.6782	0.0000
T-DIST. DOF	6.1468	1.2041	5.1048	0.0000
R-squared		-0.0013		
Akaike info criterion		-4.7858		
Schwarz criterion		-4.7649		

Table 4. GARCH(1,1)-GED model fitting effects

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.0011	0.0006	1.9442	0.0519
	Variance Equation			
C	0.0000	0.0000	2.6818	0.0073
RESID(-1)^2	0.1062	0.0227	4.6861	0.0000
GARCH(-1)	0.8646	0.0276	31.2982	0.0000
GED PARAMETER	1.3777	0.0760	18.1331	0.0000
R-squared			-0.0014	
Akaike info criterion			-4.7840	
Schwarz criterion			-4.7630	

In the GARCH(1,1)-T and GARCH(1,1)-GED models, both the ARCH and GARCH terms in the yield conditional variance equations are significantly non-zero, indicating volatility clustering of the yield series.The sum of the coefficients of the ARCH term and the GARCH term are 0.9761 and 0.9708, respectively, which are less than 1. Thus, the GARCH(1,1)-T and GARCH(1,1)-GED processes are smooth but indicate high volatility persistence.

The results show that both models capture the volatility clustering of the return series well. However, by comparing the information criterion values of the two models, we find that the GARCH(1,1)-T model has smaller AIC and SC values, indicating that it outperforms the GARCH(1,1)-GED model in terms of fitting effectiveness. This implies that the t-distribution assumption explains the volatility better when considering the thick-tailed feature of asset returns. Therefore, the GARCH(1,1)-T model performs better in fitting the return series.

4.1.2. Residuals ARCH-LM test backtest

Table 5. GARCH(1,1)-T model residual ARCH test

Heteroscedasticity test: ARCH			
F-statistic	0.4369	**Prob. F(1,1216)**	0.5087
Obs*R-squared	0.4375	**Prob. Chi-Square(1)**	0.5083

In order to verify the validity of the GARCH(1,1)-T model, the residuals are backtested by ARCH-LM test, and the results are shown in Table 5. The test results show that the value of the LM statistic is 0.4369 and the concomitant probability approximates 0.5087, which is greater than the significance level of 0.05, therefore, it is not possible to reject the original hypothesis that the logarithmic return of Shanghai crude oil futures does not have significant ARCH effect, which suggests that heteroscedasticity has been eliminated after fitting GARCH(1,1)-T model, which can be carried out the next model forecast. It indicates that after fitting the GARCH(1,1)-T model to the logarithmic return of Shanghai crude oil futures, the heteroskedasticity has been eliminated and the next model prediction can be carried out.

4.2. Model projections

4.2.1. Analysis of GARCH(1,1)-T model prediction results

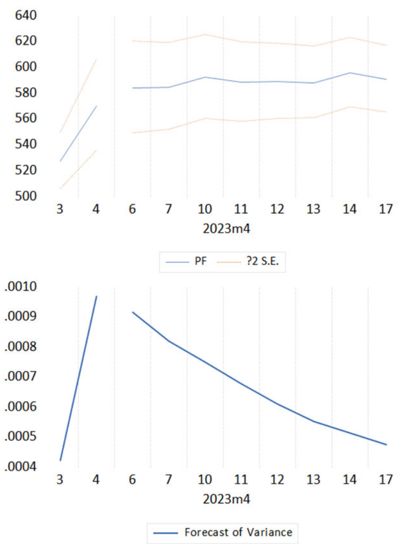

Figure 7. Ten-period prediction results of GARCH(1,1)-T model

Table 6. Indicators for comparison of projected results

Comparative indicators	value
RMSE	14.4156
MAE	8.3466
MAPE	1.4411

The GARCH(1,1)-T model was used to successfully predict the closing prices for the ten trading days from 3 April 2023 to 17 April 2023 with high prediction accuracy and good model fit (see Figure 7 and Table 6). The results of this study indicate that the GARCH(1,1)-T model has potential for practical application in the prediction of closing prices in financial markets.

4.2.2. comparative analysis

Figure 8. Forecast vs. actual Shanghai crude oil futures closing prices

The closing price of Shanghai crude oil futures predicted by the GARCH(1,1)-T model is combined with the real value of the test set, and the comparative time series is plotted (see Fig. 8). The results show that the predicted value of Shanghai crude oil futures closing price is very close to the real value, and the short-term prediction effect of GARCH(1,1)-T model is better.

5. Conclusion

The logarithmic return series of Shanghai crude oil futures has "sharp peaks and thick tails" and heteroskedasticity, i.e., it shows non-normal and non-constant characteristics in terms of extreme events and volatility. The volatility pattern of Shanghai crude oil futures can be obtained through basic mining, showing relatively stable volatility pattern and market response. Although there may be some fluctuations in the short term, the overall trend is upward. Compared with the GARCH(1,1)-GED model, the use of the GARCH(1,1)-T model can reflect its volatility trend well, and the average percentage error of the prediction model is only 1.4411%. The static prediction results and the numerical values of the prediction indexes validate the model's accuracy and reliability in predicting the volatility of Shanghai crude oil futures. The results of this study are of great practical significance for the volatility analysis and risk management of Shanghai crude oil futures market.

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