

Volatility Asymmetry and Spillover Effects in Crude Oil Futures Market: Evidence from China

GAO Hui¹, & GAO Tian Chen²

¹ Shang Hai Futures Exchange, Shang Hai, China

² University of Sydney, Sydney, Australia

Correspondence: GAO Hui, Shang Hai Futures Exchange, Shang Hai, China. E-mail: gao_hui1018@163.com

The views expressed in this article are solely those of the author and do not represent the views of the author's institution.

Received: July 7, 2022

Accepted: xx, 2022

Available online: August 24, 2022

doi:10.11114/aef.v9i3.5693

URL: <https://doi.org/10.11114/aef.v9i3.5693>

Abstract

In order to study the international influence and function of domestic crude oil futures prices in depth, based on the daily data of 2018-2022, this paper uses Granger causality test, cointegration test, ECM model and several forms of GARCH model to make empirical research on the price correlation, volatility, asymmetry and risk spillover effects of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil futures in the three major foreign crude oil markets. The study found that there is a Granger causal relationship and a cointegration relationship between domestic and foreign crude oil futures prices. There are interactions in the crude oil futures markets at home and abroad, and there are different fluctuation patterns in the short-term fluctuation process. There are asymmetries, leverage effects and spillover effects in the volatility of the four crude oil futures markets at home and abroad with different intensities. The bearish news of the three foreign markets is greater than the impact of the bullish news than that of the domestic one. There are risk spillover effects and volatility effects between domestic and the three foreign crude oil futures markets, and the domestic spillover effect on foreign crude oil is greater than the spillover effect on domestic crude oil from abroad. The conclusion is that the international influence of domestic crude oil futures prices is stronger than that of Omani crude oil, and weaker than Brent and WTI crude oil. The leverage effect of the three foreign markets is greater than that of China, and the leverage effect of the Oman crude oil futures market is the strongest. The asymmetry and spillover effect of fluctuations in the domestic and foreign crude oil futures markets lead to the risk and speculation of the three foreign markets being greater than that of the domestic one, and the speculative arbitrage through the domestic and foreign crude oil markets may cause huge market risks, and it is suggested that the internationalization of the domestic futures market needs more systems and mechanisms to support the construction.

Keywords: volatility, cointegration, leverage effect, spillover effects, GARCH model

1. Introduction

After more than 30 years of development, Chinese futures market has made great achievements, but the pricing power and international influence of futures prices are still insufficient, and the opening up and international development of the futures market are relatively slow.

With the launch of international crude oil futures on March 26, 2018, the international energy trading center under the Shanghai Futures Exchange, the pace of internationalization of the domestic futures market has accelerated, and Subsequently, the three major domestic commodity futures exchanges have successively launched nine international commodity futures and options varieties. As the first international futures variety in China, crude oil futures are of great significance. After more than four years of operation of crude oil futures, the trading rules of the previous period have been continuously optimized, and the influence of crude oil futures prices has been expanding.

Due to the relatively short launch time of domestic crude oil futures, there are relatively few studies on the influence and function of domestic crude oil futures prices and the operation law, and only a few studies are involved in the research on the impact of domestic crude oil futures on the stock market, exchange rates and other aspects of domestic and foreign price relations, such as Zhang and Ji (2018), Wang (2019), Cao (2019), Gao.H and Gao.T.C. (2022) research involves the relationship between domestic crude oil futures and the stock market and exchange rate. Wen (2019), Bu, Li and Zhu (2020) research involves the relationship between domestic and foreign crude oil futures

prices, and the existing research on the influence and function of domestic crude oil futures prices and the law of market operation are insufficient. At present, the huge fluctuations in domestic and foreign crude oil prices have brought greater impacts to the domestic macroeconomic and futures markets, thus bringing certain risks to the operation of the national economy. It is extremely urgent to further study the international influence of domestic crude oil and the fluctuation law of domestic and foreign crude oil futures prices, reveal the inherent links between domestic and foreign crude oil, ensure the steady operation of the domestic macro economy and further promote the internationalization of the futures market.

Therefore, this paper mainly analyzes and empirically examines the correlation, volatility, asymmetry and risk spillover effects of domestic and foreign crude oil futures markets. We first analyze the causal relationship between domestic and foreign crude oil futures prices and the cointegration relation of the yield, determine whether there is a causal relationship and long-term equilibrium relationship between domestic and foreign crude oil markets futures price yields, and then use the Error Correct Model (ECM) to test the similarities and differences of short-term fluctuation patterns in domestic and foreign crude oil markets, and judge the short-term adjustment and response degree of domestic and foreign crude oil markets to market shocks. Describe the process of convergence of domestic and foreign crude oil futures markets to equilibrium. Finally, we use several conditional heteroscedasticity models to test the relationship between the domestic and foreign crude oil futures markets volatility, judge the risk characteristics and risk transfer process of domestic and foreign crude oil markets, and analyze the clustering and asymmetry of volatility between domestic and foreign crude oil markets by testing the "Leverage Effect" and "Spillover Effect". Through analysis, we can describe the long-term cointegration relationship and short-term dynamic fluctuation effect between domestic and foreign crude oil futures prices and yields, and can also judge the interaction and conductivity of domestic and foreign crude oil futures price yields and volatility. It can reveal the degree of constraint or flexibility of investment funds in the domestic and foreign crude oil markets in terms of liquidity, and in the process of portraying the asymmetric reaction of domestic and foreign crude oil markets in the formation of market information and the type of information, it can measure the risk characteristics and risk levels of time varying in domestic and foreign markets..

The second part of this paper gives a literature review, the third part gives the Methodology, mainly including the theoretical models and methods involved in the study. The fourth part gives empirical analysis, mainly including variable selection and data description, as well as various tests and ECM model establishment related to cointegration, and various Garch model establishment and analysis. The fifth part gives conclusion, summarizes the empirical findings of this paper and makes policy recommendations accordingly.

2. Literature Review

The domestic and foreign academic circles have a long history of research on the operation of the futures market, and there are many research results on the energy market, specific to the research of crude oil futures, in recent years, from the qualitative and quantitative point of view of research, a lot of results have been achieved.

Foreign research literature on oil price fluctuations and forecasts can be traced back to Hotelling (1930) proposing a model of depletable resources. More economic time series methods are currently used, including Granger (1969) causality method, Engle and Granger (1987) cointegration theory, Engle (1982) model of conditional heteroscedasticity (ARCH) and so on.

With the development of the ARCH model family since the 1980s, this model family has been widely used in the study of capital markets and futures derivatives, such as Theodossiou and Lee (1993) using the GARCH-M model to study the volatility spillover effect between major stock markets around the world. Mukherjee and Mishra (2006) used a univariate GARCH model to empirically study volatility spillover effects between Asian stock markets. Vasilikli et al. (2006) used the bivariate EGARCH model to study the correlation between the European bond markets. Similarly, scholars have used the ARCH model family to study the futures market from a dynamic point of view, such as Cecchetti, Cumby and Figlewski. (1988) and others who used the ARCH model to study the hedging ratio of US Treasury futures contracts. Baillie and Myers (1991) conducted empirical research on soybean contracts and corn contracts in the US futures market through the GARCH model. Michael, McKenzie and Heather Mitchell (2001) used the ARCH model, the GARCH model, and the AP-GARCH model to simulate the price volatility of all LME futures contracts. Allen and Cruickshank (2002) uses ARCH to model the volatility of commodity futures on the Sydney Mercantile Exchange, the London International Financial Futures and Options Exchange, and the Singapore International Financial Exchange. Rita Madarassy Akin (2003) used GARCH to perform a Samuelson effect test on 11 financial futures contracts. Xu and Fung (2005) uses a binary asymmetric GARCH model to study volatility spillover relationships between the Japanese and U.S. metal futures markets.

In recent years, the ARCH model family has also been widely used in crude oil market research, such as partial research on the impact effect and related relationship between international oil prices and the gulf stock market, such as Fayyad and Daly (2011) studying the impact of oil price shocks on the returns of the Gulf state stock markets. Jouini and

Harrathi (2014) studied the conduction of shocks and volatility between the crude oil market and the stock markets of the Gulf States through BEKK-GARCH. Khalifa, Hammoudeh and Otranto. (2014) considering the transmission pattern between the crude oil market and the Gulf state market under the transfer of the existing mechanism. Balciir, Demirer and Ulussever. (2017) study argues that monitoring speculation in the crude oil market is intended to monitor the risk of volatility in the crude oil market that is transmitted to its stock market. Other studies on the relationship between international oil prices and China's stock market and stock indexes include Broadstock and Filis (2014) and Zhu. H. et al. (2016) and Fang and Egan (2018). Some of them also focus on the international crude oil futures price and the relationship between different international crude oil markets, such as Brunetti, Gilbert and Christopher (2000) to build the FI-GARCH model to study the relationship between the New York Commodity Futures Exchange and the international crude oil market. Lin, Tamvakis and Michael (2001) compared and correlated the prices of WTI crude oil futures contracts and Brent crude oil futures contracts through GARCH and VAR models respectively. Stelios and Cees (2008) uses the VAR-GARCH-BEKK model to study the volatility spillover effects of U.S. WTI crude oil futures and spot. Kaufmann.et al.(2009) studied the price spillover effects of different international crude oil futures markets and spot markets through empirical models. Boubaker and Raza (2017) obtained mean and volatile spillover effects between the crude oil market and the Brics market through multivariate GARCH and wavelet analysis. In the past two years, some scholars have adopted the Garch model method to conduct research on the relationship between international crude oil futures and stock markets, exchange rate relations and crude oil price laws, such as Mentawai, Mutawakil and Chris (2020) used the multivariate GARCH BEKK and TBEKK models to study the shock and volatility spillover effects of crude oil prices on Ghanaian exchange rates and stock markets .Ivanovski.et al.(2021) used a generalized autoregressive score (GAS) model to model and predict volatility and correlation between international oil prices and stock returns, studies have shown that the model is superior to the GCC-Garch model.Chuang and Yang(2022) used the multivariate GARCH-MIDAS model to study the determinants of volatility in the international crude oil market.

In the domestic study of the law of the crude oil market, a variety of time series and a variety of econometric models are used for research .For example, some studies of the relationship between domestic and foreign crude oil spot prices and macro factors, such as Yu (2015), Tian (2016). Some of the studies have studied the relationship between domestic and foreign crude oil markets and financial markets, such as Zhang and Zhou (2016), Li, Lu and Jiang (2018). Some studies have used time series models to study the relationship between spot prices of crude oil at home and abroad, such as Jia (2016) and Cui (2017). Some studies have used a variety of econometrics methods to analyze and predict the influencing factors of crude oil prices, such as Zhan (2016), Zhang (2016), Zhang (2017), Cheng (2018), MA, Zhang and Cao (2019).

In recent years, some scholars in China have also used ARCH model family to study the crude oil futures market, such as Dong and Zhang (2006) through the VAR-MGARCH model to analyze the fluctuation spillover reaction of the spot price of Daqing crude oil and the spot price of Brent crude oil in London. Pan and Zhang (2007) studied the spillover effects of fluctuations in the WTI crude oil and Daqing crude oil markets in New York, USA. Yao and Hu (2011) studied the volatility spillover effects between the international crude oil futures, exchange rates, and stocks.

Due to the relatively short launch time of domestic crude oil futures, there are relatively few quantitative research literature on domestic crude oil futures, mainly including: Zhang and Ji (2018) quantitatively analyzed the risk spillover relationship between China's crude oil futures and international benchmark oil, Shanghai Composite Index and RMB exchange rate. Wang (2019) used the VAR-GARCH-BEKK model to study the mean spillover effect and variance spillover effect of China's crude oil in the international market and the Asia-Pacific market. Wen (2019) used the wavelet coherence model and the GARCH-BEKK model to study the conduction relationship between marginal fundamentals and crude oil prices. Cao (2019) conducted a quantitative analysis of the changes in the relationship between crude oil futures, the US dollar exchange rate and the RMB exchange rate in Shanghai and New York in china. Bu, Li and Zhu. (2020) used long-term weak exogenous tests and price discovery models such as P-T and I-S to measure the international comparison between Shanghai crude oil futures and Oman crude oil futures and WTI and Brent crude oil futures, price leading relationships, and price discovery contributions. Gao.H. and Gao.T.C. (2022) quantitatively studied the overall impact of crude oil futures on the internationalization of the RMB using Granger causality, cointegration testing and error correction model.

In summary, from the existing literature at home and abroad, the quantitative research on the law of crude oil futures is basically based on a simple linear regression model and from the perspective of time series modeling, using a variety of econometric models for research, especially the development of cointegration theory and GARCH model, which provides a new idea for the study of the law of the crude oil futures market. The existing literature has less research on the domestic crude oil futures market, mainly because the domestic crude oil futures launch time is relatively short, from the existing literature, the study of the futures prices of the four major crude oil futures markets at home and abroad, the relationship between their yield and volatility is almost a blank. Therefore, this paper attempts to use cointegration theory, Granger causality test based on vector autoregression (VAR) and the method of the GARCH

model family to empirically study the relationship between futures price influence, yield and volatility in four major crude oil markets at home and abroad, in order to obtain useful conclusions and enlightenment

3. Methodology

3.1 Cointegration Test and ECM Model of Crude Oil Futures Price Yield

If it can be inferred that the logarithmic sequence of domestic and foreign crude oil futures prices is a I(1), the possible cointegration relationship between them can be further analyzed. The binary Error correction model of the stable sequence of the price yield of domestic and foreign crude oil futures (Brent, WTI, and Oman) can be expressed as:

$$R_{0t} = \gamma_i (LNP_{0t-1} - \beta_i LNP_{it-1} + C) + \alpha_1 R_{0t-1} + \alpha_2 R_{0t-2} + \phi_{i1} R_{it-1} + \phi_{i2} R_{it-2} + \varepsilon_{it} \quad (1)$$

Where γ_i is the adjustment parameters for error correction and ε_{it} is uncorrelated white noise sequences, where $i=1, 2,$

3. If the above ECM model is established, it means that the yield of crude oil futures prices at home and abroad is affected by the same error correction process, but has different adjustment speeds, has a common trend component in the return to long-term equilibrium, has similar cyclical characteristics, and may lead to different short-term fluctuation patterns due to different error correction coefficients. In ECM, a long-term modified relationship can be expressed as follows:

$$LNP_{0t} - \beta_i LNP_{it} + C = u_{it} \quad (2)$$

Where u_{it} is a stationary time series of zero means, where $i=1, 2, 3$. The above relationship indicates the cointegration relationship between domestic crude oil futures prices and foreign (Brent, WTI, Oman) crude oil futures prices, and the standardized cointegration vectors are: $(1, -\beta_i)'$

There are many methods for testing and estimating cointegration relations, the more commonly used ones are the Engle and Granger (1987) two-step method and Johansen (1988) maximum likelihood method (MLE), For a cointegration test for multiple variables, Johansen's test is superior to Engle and Granger's method. In this paper, the Johansen test is used.

According to Engle and Granger (1987) expression theorem, cointegration systems have three equivalent forms of expression: vector autoregressive VAR, moving average MA, and ECM, of which ECM can most directly describe the synthesis of short-term fluctuations and long-term equilibrium, and is the most commonly used. Engle and Granger (1987) proved that a cointegration sequence must be represented as an error-corrected representation. Therefore, when the variable sequence is cointegration, an error correction model should be established.

3.2 Domestic and Foreign Crude Oil Futures Price Yield GARCH-M Model

The Conditional Heteroscedastic Variance Model (ARCH) can effectively characterize the degree of volatility of risk and return, and makes these volatility and risk measures time-varying, reflecting the dynamic impact of new information acquisition and the emergence of new shocks. Engle (1982) proposed the GARCH model, which can be generalized to the effect of permissible conditional variance on yields, so the GARCH-M (p,q) model for the rate of return on crude oil futures prices is set as follows:

$$R_t = \alpha + \lambda \sigma_t^2 + \sum_{i=1}^m \theta_i R_{t-i} + \sum_{j=1}^n \eta_j \varepsilon_{t-j} \quad (3)$$

Where R_t is the crude oil futures price yield, σ_t^2 is the conditional variance, ε is the residuals, λ and θ, η are the parameters. When the risk (volatility) increases, the level of returns in the crude oil market increases, the coefficient of the corresponding conditional variance in the equation $\lambda > 0$. When the risk increases, the level of return in the crude oil market decreases, the corresponding conditional variance coefficient $\lambda < 0$.

3.3 Asymmetric Leverage Effect Model of Domestic and Foreign Crude Oil Futures Price Returns

The leverage effect reflects the unidirectional nature of volatility transmission, or a certain degree of difference in risk attitudes, and the leverage effect can be achieved by introducing a certain asymmetry into the GARCH model, or it can

be achieved through threshold regression, which is called the TARCh model in this case. The TARCh or Threshold ARCH model was introduced independently by Zakoian (1994) and Glosten, Jagannathan and Runkle. (1993). The variance equation for the Crude oil futures price yield is set as follows:

$$\sigma_t^2 = \beta + \sum_{i=1}^q \phi_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \varphi_j \sigma_{t-j}^2 + \omega D_{t-1} \varepsilon_{t-1}^2 \tag{4}$$

Where D_{t-1} is a dumb variable representing the direction of change in the absolute residuals, when $\varepsilon_{t-1} < 0$ then $D_{t-1} = 1$ Otherwise $D_{t-1} = 0$. In the model, good news ($\varepsilon_{t-1} > 0$) and bad news ($\varepsilon_{t-1} < 0$) have different effects on

the conditional variance: The good news has a $\sum \phi_i$ shock, The bad news has a $\sum \phi_i + \omega$ shock. If $\omega > 0$, there is a leverage effect, if $\omega \neq 0$, the information is asymmetrical.

Due to the asymmetry of market fluctuations and reactions, there are many structural forms and representation methods, and there are some forms of promotion of GARCH models, such as EGARCH model, which are widely used. Based on the EGARCH model proposed by Nelson (1991), we set the conditional variance equation for the crude oil futures prices yield as follows:

$$\ln \sigma_t^2 = \omega + \beta \ln \sigma_{t-1}^2 + \alpha \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| + \gamma \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \tag{5}$$

If $\gamma \neq 0$, there is asymmetry in the impact reaction, then

$$f \left(\frac{\varepsilon_t}{\sigma_t} \right) = \alpha \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| + \gamma \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \tag{6}$$

Where $f(\bullet)$ is the information shock curve.

3.4 Spillover Effect Model of Domestic and Foreign Crude Oil Futures Prices Yield

When there is a large fluctuation in the foreign (domestic) crude oil futures market, it will cause investors to change their investment behavior in the domestic (foreign) crude oil futures market, and transmit this fluctuation to other futures markets, that is, the "spillover effect" of the crude oil futures market. In order to describe the correlation between volatility between domestic and foreign crude oil futures markets, we use the volatility spillover effect model proposed by Harmo and Masulis. (1990) to analyze the short-term dependence and interaction between the volatility of domestic and foreign crude oil futures markets, so the short-term spillover effect from foreign crude oil futures market (B) to domestic crude oil futures market (A) can be set as follows:

$$\sigma_{At}^2 = \beta + \sum_{i=1}^q \phi_i \varepsilon_{At-i}^2 + \sum_{j=1}^p \varphi_j \sigma_{At-j}^2 + \sum_{l=1}^r \zeta_l \varepsilon_{Bt-l}^2 \tag{7}$$

Where ε_{Bt-l}^2 is the yield shock or disturbance of the previous L period in the B market, which is the absolute volatility degree that has been realized in reality, and if the coefficient of these disturbance terms is statistically significantly positive, it indicates that there is a significant spillover effect.

Theoretically, the shorter the sample time interval for studying the relationship between variables, the richer the corresponding sample size and the richer the information contained in the entire sample. Due to the short launch time of domestic crude oil futures, the use of daily data can better study the operation law of domestic crude oil futures prices, and avoid the use of limited samples in other long time intervals to affect the effect of the study. Therefore, the samples used in this study are all daily data.

4. Empirical Analysis

4.1 Variables and Data

4.1.1 Selection and Description of Variables

Crude oil futures of China were listed and traded in 2018, after several years of development, the market is becoming more and more mature, the influence is gradually expanding, and therefore, we choose the crude oil futures price launched by the International Energy Center in the previous period as the domestic crude oil futures price variable. For foreign crude oil futures markets, the current international crude oil trading is based on three major crude oils, namely Brent in the United Kingdom, WTI in New York and Oman crude oil on the Asian Dubai Commodity Exchange, and the price comparison between them is the main factor that determines the global crude oil flow. Therefore, foreign crude oil futures prices we choose representative Brent crude oil, WTI crude oil, Oman crude oil futures prices as foreign crude oil futures price variables.

Data selection: Daily data on the consecutive closing prices of Crude Oil Futures in Shanghai International Energy Exchange Center, continuous closing prices of ICE Brent Crude Oil Futures, consecutive closing prices of NYMEX Light Crude Oil (WTI) Futures, and consecutive closing prices of Oman Crude Oil Futures in DME in Dubai. Time period: 2018.3.26-2022.6.16.

For futures prices, each futures contract will expire at a certain time, in order to overcome the discontinuity of futures prices, we select the daily closing price series of futures contracts with the largest trading volume as representatives to form a futures price continuous price contract. Since the domestic crude oil futures price data we selected does not match the foreign futures price data at certain specific times, we delete the mismatched data and get the continuous time series data of domestic and foreign futures price data. Finally, we selected a total of 1017 consecutive daily price data of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil futures.

We define the crude oil futures price yield as a first-order difference in the logarithm of the crude oil futures price:

$$R_t = LNP_t - LNP_{t-1} \tag{8}$$

Among them P_t are crude oil futures prices. When the price fluctuation of crude oil futures is not very violent, it is approximately equal to the daily rate of change of crude oil futures prices, corresponding to the overall income level of the crude oil futures market.

Since there is no unified qualitative conclusion on the statistical nature of the crude oil futures price yield series, there are still different views on whether the crude oil futures price yield is strong effective, weak effective, or invalid, so we investigate the changes in the daily yield series R_t , the absolute daily yield series $|R_t|$ and the daily average square yield series R_t^2 of crude oil futures prices. When the sample size is relatively large, according to the large number theorem and the market weak type, it can be seen that the average yield of the overall crude oil futures price in the sample range is:

$$\bar{R}_t = \frac{1}{T} \sum_{t=1}^T R_t \approx 0 \tag{9}$$

Where T is the sample size. Suppose ε_t represents a deviation from the daily yield of the crude oil futures price from the sample mean, then:

$$\varepsilon_t = R_t - \bar{R}_t \approx R_t \tag{10}$$

$$|\varepsilon_t| = |R_t - \bar{R}_t| \approx |R_t| \tag{11}$$

$$\varepsilon_t^2 = (R_t - \bar{R}_t)^2 \approx R_t^2 \tag{12}$$

Therefore, the daily yield R_t , daily absolute yield $|R_t|$, and daily average square yield R_t^2 of crude oil futures prices respectively indicate that the two-way change of crude oil futures prices around the mean, absolute changes, average square fluctuations, and the fluctuations they embody gradually increase. In particular, the mean square yield actually

represents the current fluctuation variance of the daily yield series of crude oil futures prices, which is a measure of current risk.

4.1.2 Times Series Plots of Variables and Basic Judgments

Below we make a time series chart of each time series to make a basic judgment on the yield and volatility of crude oil futures prices at home and abroad.

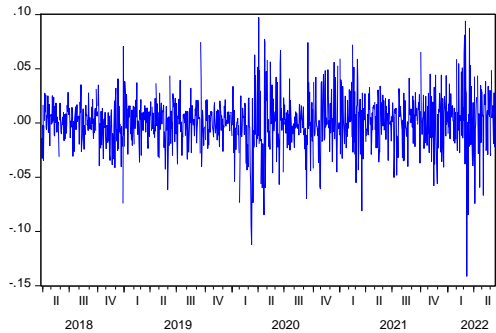


Figure 1. domestic crude oil futures prices yield

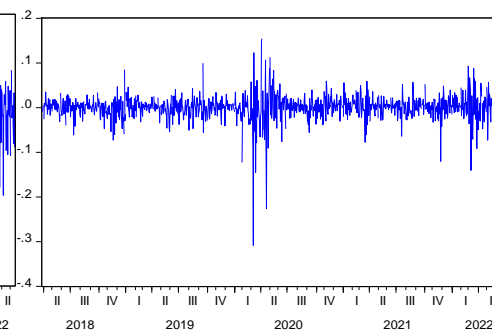


Figure 2. Brent crude oil futures prices yield

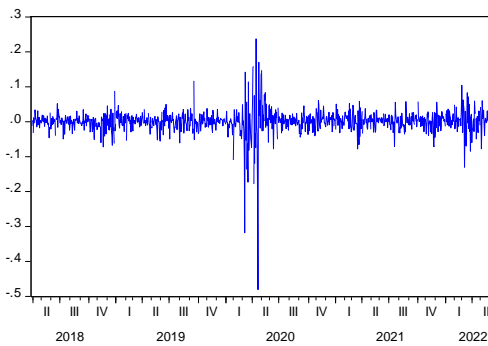


Figure 3. WTI Crude Oil Futures Price Yield

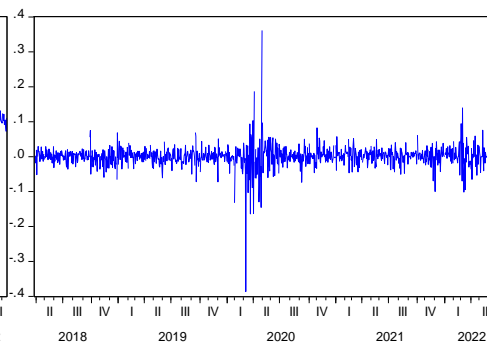


Figure 4. Oman Crude Oil Futures Price Yield

As can be seen from the figure 1- figure 4, there are a number of abnormal peaks in the series of crude oil futures price yields at home and abroad, and the fluctuations show obvious volatility clustering phenomena, indicating that the daily fluctuations of the futures price yield series in the four crude oil futures markets at home and abroad are sudden and significant, and the volatility has a conditional heteroscedasticity phenomenon. It can be assumed that the disturbances that occur in the series of yields on the price of the four futures are not white noise processes.

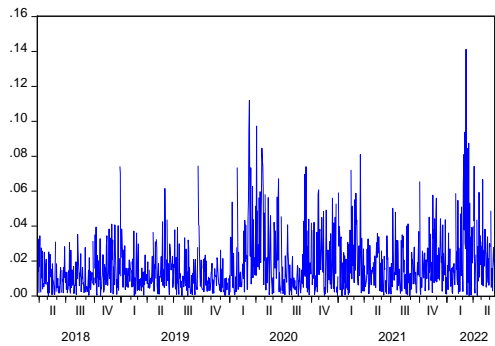


Figure 5. Domestic crude oil futures price daily absolute yield

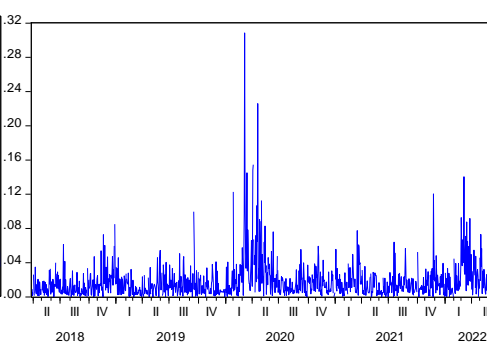


Figure 6. Brent crude oil futures price daily absolute yield

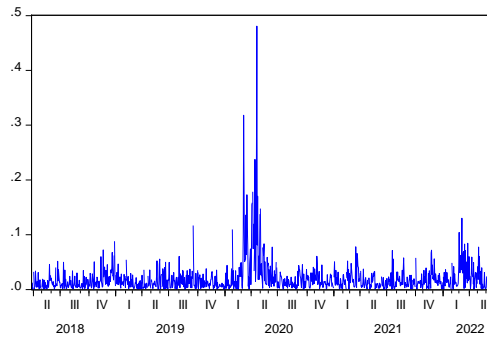


Figure 7. WTI crude oil futures prices daily absolute yield

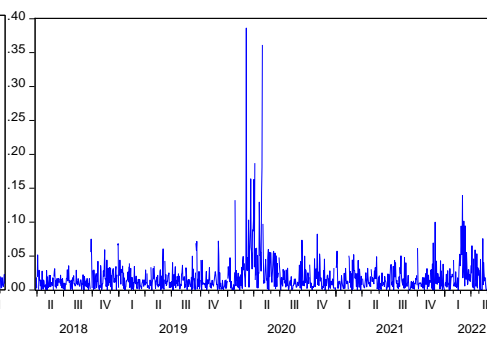


Figure 8. Oman crude oil futures prices daily absolute yield

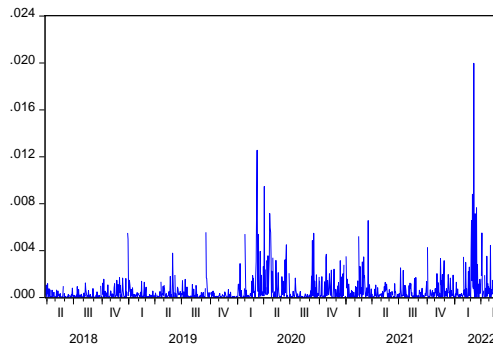


Figure 9. Domestic crude oil futures prices daily mean square yield

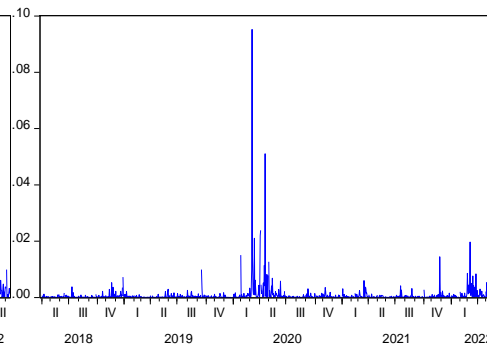


Figure 10. Brent crude oil futures prices daily mean square yield

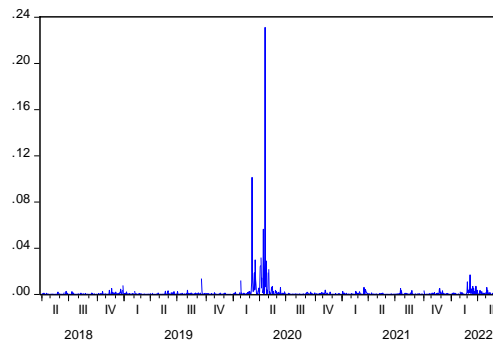


Figure 11. WTI Crude Oil Futures Price daily mean square yield

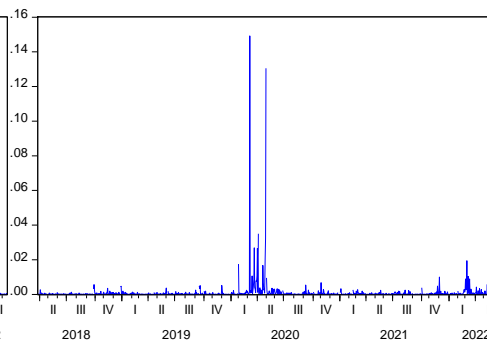


Figure 12. Oman crude oil futures prices daily mean square yield

From the comparison of various yield series charts of futures prices above Figure5- Figure 10, it is found that when abnormal fluctuation values and volatility cluster ranges occur, the four futures markets have similar fluctuation patterns, indicating that there may be a certain degree of correlation between them and the spillover effect of fluctuation effects. Below we use the futures price daily yield series to build a time series model to analyze the bidirectional fluctuations of the yield series and their effects.

4.2 Cointegration Related Tests and ECM Model Empirical Results

4.2.1 Unit Root Tests

There are many unit root test methods, generally DF, ADF test and Philips nonparametric test (PP test). This article uses the most commonly used Engle and Granger(1987) residual-based ADF test. Under the premise of ensuring that the residual terms are not correlated in the test, we use the AIC criterion and the SC criterion to determine the hysteresis order, when both values are the minimum, then the hysteresis order is the optimal. The specific test results are as follows:

Table 1. ADF unit root test results of domestic and foreign crude oil futures price variables

Variable	Augmented Dickey-Fuller test statistic	Test type (c,t,n)	1% level	5% level	10% level	Durbin-Watson stat	whether or not stable
LNP0	-0.974	(c,t,2)	-3.967	-3.414	-3.129	1.999	NO
LNP1	-1.114	(c,t,0)	-3.967	-3.414	-3.129	2.009	NO
LNP2	-1.604	(c,t,21)	-3.967	-3.414	-3.129	1.9901	NO
LNP3	-1.947	(c,t,17)	-3.967	-3.414	-3.129	1.992	NO
Δ LNP	-20.983	(0,0,1)	-3.437	-2.864	-2.568	1.999	YES
Δ LNP1	-31.988	(0,0,0)	-3.437	-2.864	-2.568	2.000	YES
Δ LNP2	-6.087	(0,0,21)	-3.437	-2.864	-2.568	2.004	YES
Δ LNP3	-6.221	(0,0,21)	-2.567	-1.941	-1.616	1.9823	YES

Note: P0 represents the domestic crude oil futures price, P1 represents Brent crude oil futures price; P2 represents WTI crude oil futures price and P3 represents Oman crude oil futures price. LN represents the logarithm and Δ represents the first-order difference. C represents the intercept, t represents the time trend, n represents the order of lag, and the following are similar.

The above Table 1 unit root test results show that the time series data of the four crude oil futures price variables at home and abroad are non-stationary sequences at the 1%, 5% and 10% significance levels, and the first-order difference is a stationary series at the 1%, 5% and 10% significance levels, so it can be judged that the price series of crude oil futures in the four markets at home and abroad are all first-order single integer I(1) through the test.

4.2.2 Granger Causality Test

We conduct a Granger causality test on domestic and foreign crude oil futures prices, and study the guidance of domestic crude oil futures prices to foreign crude oil futures price variables. Since the causality test is sensitive to the lag order, in the actual test, according to the AIC, SC criterion, the optimal lag order is the smallest value of the two. The specific test results are as follows:

Table 2. Granger causality test results for various variables

Null Hypothesis	Sample	F-Statistic	Prob.
LNP1 does not Granger Cause LNP0	1014	188.712	0.000
LNP0 does not Granger Cause LNP1		4.050	0.007
LNP2 does not Granger Cause LNP0	1015	204.979	0.000
LNP0 does not Granger Cause LNP2		3.267	0.039
LNP3 does not Granger Cause LNP0	1014	5.942	0.001
LNP0 does not Granger Cause LNP3		4.454	0.004
LNP3 does not Granger Cause LNP1	1014	1.078	0.358
LNP1 does not Granger Cause LNP3		178.352	0.000
LNP3 does not Granger Cause LNP2	1014	2.309	0.075
LNP2 does not Granger Cause LNP3		130.072	0.000

From the above Table 2 test results, it can be seen that under the significance level of 1%, Brent crude oil futures price (LNP1), WTI crude oil futures price (LNP2), Oman crude oil futures price (LNP3) have a strong guiding effect on the domestic crude oil futures price (LNP0), and the domestic crude oil futures price only has a strong guiding effect on Brent crude oil and Oman crude oil futures prices, and does not have a guiding effect on WTI crude oil futures prices. Only at the 5% significance level, the domestic crude oil futures price and the foreign three market crude oil futures prices have a bidirectional guiding effect. Oman crude oil futures prices at the 1%, 5% significant level, does not have a guiding effect on Brent and WTI crude oil futures prices. It shows that the domestic crude oil futures price is greatly affected by the international crude oil futures price, and the domestic crude oil futures price has a certain pricing power, and the pricing power and influence are stronger than Oman crude oil, weaker than Brent crude oil and WTI crude oil.

4.2.3 Long-term Cointegration Test

We conduct Johansen maximum likelihood estimation test for domestic crude oil futures prices and crude oil futures prices in three foreign crude oil markets, the test takes into account the situation containing constants, according to the SC standard, AIC standard to determine the equation form of the best hysteresis order, the hysteresis order is selected 0, the test results are as follows Table 3:

Table 3. Cointegration test results between domestic crude oil and three foreign crude oil futures prices

Cointegration relation	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.	The number of cointegration relationships
Domestic crude oil futures prices versus Brent crude oil futures prices	0.060	64.465	20.262	0.000	None *
Domestic crude oil futures prices and WTI crude oil futures prices	0.041	43.986	20.262	0.000	None *
Domestic crude oil futures prices versus Oman crude oil futures prices	0.022	24.027	20.262	0.014	None *
Oman crude oil futures prices	0.001	1.228	9.165	0.919	At most 1

Note: * denotes rejection of the hypothesis at the 0.05 level

The cointegration test results show that there is a unique cointegration relationship, then the cointegration relationship between the domestic crude oil futures price and Brent crude oil futures prices, WTI crude oil futures prices, and Omani crude oil futures prices is estimated to be as follows:

$$\mu_t = LNP_{0t} - 0.908 LNP_{1t} - 2.283 \tag{13}$$

$$v_t = LNP_{0t} - 0.857 LNP_{2t} - 2.570 \tag{14}$$

$$w_t = LNP_{0t} - 0.919 LNP_{3t} - 2.250 \tag{15}$$

Then the cointegration equation corresponding to the maximized feature root is as follows (the values in the equation parentheses are standard deviations, the following are similar):

$$LNP_{0t} = 0.908 LNP_{1t} + 2.283 \tag{16}$$

(0.036) (0.151)

$$LNP_{0t} = 0.857 LNP_{2t} + 2.570 \tag{17}$$

(0.055) (0.223)

$$LNP_{0t} = 0.919 LNP_{3t} + 2.250 \tag{18}$$

(0.065) (0.270)

We can see from the cointegration equation that there is a significant long-term co-directional change relationship between domestic crude oil futures prices and three foreign crude oil futures prices, and the magnitude of change is not much different (0.908, 0.857, 0.919), and the co-directional change relationship between domestic and WTI crude oil prices is slightly weaker than that of Brent crude oil and Oman crude oil, and the co-directional change relationship between domestic and Oman crude oil futures prices is the strongest.

4.2.4 ECM Model Estimate Results

From the above cointegration test, it can be seen that there is a cointegration relationship between domestic and foreign crude oil futures prices, therefore, we have established an error correction model (ECM) between the domestic crude oil and Brent crude oil, WTI crude oil, Oman crude oil futures price yield, the results is as follows Table 4:

Table 4. ECM estimates results

ECM	R0	R1	R0	R2	R0	R3
EC	-0.025 (0.007)	-0.008 (0.011)	-0.017 (0.005)	0.004 (0.009)	-0.022 (0.008)	0.001 (0.011)
R0 (-1)	-0.217 (0.032)	0.160 (0.047)	-0.133 (0.032)	0.178 (0.055)	-0.050 (0.039)	0.095 (0.053)
R0 (-2)	-0.010 (0.026)	0.024 (0.038)	0.001 (0.027)	-0.001 (0.047)	0.018 (0.039)	0.169 (0.052)
R1(-1)	0.506 (0.023)	-0.044 (0.034)				
R1(-2)	0.142 (0.028)	-0.126 (0.040)				
R2(-1)			0.363	0.004		

			(0.019)	(0.033)		
R2(-2)			0.049	-0.080		
			(0.022)	(0.038)		
R3(-1)					0.073	-0.047
					(0.030)	(0.040)
R3(-2)					0.0483	-0.170
					(0.030)	(0.040)
R-squared	0.363	0.013	0.293	0.011	0.021	0.020
Adjusted R-squared	0.360	0.009	0.290	0.007	0.018	0.016
S.E. of regression	0.384	0.824	0.426	1.270	0.590	1.045
Sum squared resid	0.020	0.029	0.021	0.035	0.024	0.032
Log likelihood	143.717	3.285	104.617	2.896	5.529	5.176
Durbin-Watson stat	2555.809	2168.639	2503.097	1949.460	2338.189	2048.067
Mean dependent var	-5.031	-4.268	-4.927	-3.835	-4.602	-4.030
S.D. dependent var	-5.007	-4.243	-4.903	-3.811	-4.578	-4.005
Akaike info criterion	0.001	0.001	0.001	0.001	0.001	0.001
Schwarz criterion	0.024	0.029	0.024	0.036	0.024	0.032

Note: Among them, R0, R1, R2 and R3 respectively represent the price yield of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil futures, the positive numbers in parentheses represent the standard deviation and the negative numbers represent the lag order. EC represents an error correction term, the following is similar.

According to the above error correction equation calculation, to solve the unconditional mathematical expectation of the yield series, it is possible to obtain the long-term equilibrium crude oil futures price yield levels of domestic crude oil, Brent crude oil, WTI, Oman crude oil market, respectively:

$$\bar{R}_0 = 0.056\%, \bar{R}_1 = 0.013\%, \bar{R}_2 = -0.002\%, \bar{R}_3 = 0.001\%$$

From the above results, it can be seen that there is almost no significant difference in the long-term futures price yield between the domestic crude oil futures market and the Brent crude oil futures market, and there is a significant difference in the long-term futures price yield between the domestic crude oil futures market and the WTI crude oil and Oman crude oil futures markets, and the long-term price yield of the domestic crude oil futures market is stronger than that of the three foreign crude oil futures markets. The price yields of crude oil futures in all four markets are affected by the long-term equilibrium relationship, but the marginal contribution of the correction item to the domestic crude oil futures price yield and Brent crude oil futures price yield is negative, while the correction item is a positive marginal contribution to the WTI crude oil futures and Oman crude oil futures price yields. In the ECM model, there is an interaction between domestic crude oil futures and three foreign crude oil futures prices yields, because the lag coefficient appears to be somewhat significant and not significant, reflecting the interaction between short-term fluctuations. Therefore, the ECM model shows that there is a long-term cointegration trend between the yields of crude oil futures prices at home and abroad, but there are different fluctuation patterns in their short-term fluctuation processes.

4.3 GARCH Model Family Empirical Results

We use the GARCH model to test the conditional heteroscedasticity of the crude oil futures price yield series, first use the partial autocorrelation function (PACF) and the autocorrelation function (ACF) to determine the order of the AR process and the MA process in the mean equation, and then determine the order of the ARCH term and the GARCH term in the variance equation according to the characteristics of the absolute residuals sequence, and after analysis and comparison, finally determine the mean equation of the domestic crude oil futures price return series as ARMA(22,22), The equation of variance is GARCH(1,1). The mean equation for Brent crude oil, WTI crude oil, Oman crude oil futures price yield series are all ARMA(17,17) and the variance equation are all GARCH(1,1). The following GARCH-M model, leverage effect model and spillover effect model for estimating the price returns of crude oil futures at home and abroad are as follows:

4.4 Domestic and Foreign Crude Oil Futures Price Yield GARCH-M Model Estimates

Our empirical estimates of the GARCH-M model of the price yield of domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures are as follows In Table 5 (estimates of non-main parameters are omitted, the values in parentheses are standard deviations, the following are similar):

Table 5. GARCH-M estimates of crude oil futures price yields in four crude oil futures markets

Variable	R0	R1	R2	R3
σ_t^2	0.054 (0.033)	0.096 (0.031)	0.095 (0.032)	0.109 (0.032)
AR(17)		0.890 (0.021)	0.899 (0.019)	0.870 (0.028)
MA(17)		-0.899 (0.020)	-0.905 (0.018)	-0.886 (0.025)
AR(22)	-0.476 (0.136)			
MA(22)	0.546 (0.129)			
R-squared	0.004	0.001	0.003	0.001
Adjusted R-squared	0.002	-0.001	0.001	-0.002
S.E. of regression	0.025	0.029	0.036	0.033
Sum squared resid	0.595	0.831	1.276	1.060
Log likelihood	2381.638	2358.342	2295.048	2272.038
Durbin-Watson stat	1.964	1.973	1.923	1.969
Mean dependent var	0.001	0.001	0.001	0.001
S.D. dependent var	0.025	0.029	0.036	0.033
Akaike info criterion	-4.780	-4.709	-4.583	-4.537
Schwarz criterion	-4.750	-4.680	-4.553	-4.507
Hannan-Quinn criter.	-4.769	-4.698	-4.571	-4.525

Note: Among them, R0, R1, R2 and R3 respectively represent the price yield of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil futures, σ_t^2 represents crude oil futures price yield condition variance, $t=0,1,2,3$. The following is similar.

From the above Table 5 estimates, it can be seen that the coefficients of domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures condition variance item GARCH are estimated to be 0.054, 0.096, 0.095, 0.109, respectively, and the domestic crude oil futures price yield conditional variance coefficient is not significant, while the foreign Brent crude oil, WTI crude oil, Oman crude oil futures price yield conditional variance coefficient is significant, which reflects the positive correlation between the return and risk of the four crude oil futures markets at home and abroad. There is a positive risk premium for the return, there is a certain risk reward in all four markets, and volatility increases the current yield, of which the domestic crude oil futures risk premium is the smallest, indicating that investors in the three foreign crude oil markets have a stronger risk appetite than domestic investors. After the launch of domestic crude oil futures, after continuous optimization of market operation, the market risk return shows the same positive correlation relationship with the international market, the market gradually matures, due to the difference in the risk premium of the income between the domestic and foreign three crude oil futures markets, so there are theoretical arbitrage opportunities for crude oil futures at home and abroad, and at the same time, investment through the three foreign crude oil markets faces greater investment risks than in China.

4.5 Domestic and Foreign Crude Oil Futures Price Yield TARCh Model Estimate

Below, we use the above TARCh model to make a model empirical estimate of the leverage effect of domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures market, and the variance equation estimate results are shown in Table 6:

Table 6. TARARCH model estimates of crude oil futures price yields in four crude oil futures markets

Variable	σ_0^2	σ_1^2	σ_2^2	σ_3^2
C	2.21E-05 (5.59E-06)	3.76E-05 (6.18E-06)	4.99E-05 (8.05E-06)	6.55E-05 (7.94E-06)
$\varepsilon_t^2(-1)$	0.117 (0.023)	0.106 (0.021)	0.123 (0.021)	0.140 (0.028)
$\varepsilon_t^2(-1)*(\varepsilon_t(-1) < 0)$	0.050 (0.028)	0.187 (0.028)	0.200 (0.029)	0.483 (0.047)
$\sigma_t^2(-1)$	0.826 (0.024)	0.759 (0.022)	0.726 (0.023)	0.621 (0.020)
R-squared	0.005	0.005	0.007	0.007
Adjusted R-squared	0.003	0.003	0.005	0.005
S.E. of regression	0.025	0.029	0.036	0.033
Sum squared resid	0.595	0.828	1.271	1.053
Log likelihood	2382.735	2366.645	2303.314	2294.776
Durbin-Watson stat	1.963	1.971	1.925	1.970
Mean dependent var	0.001	0.001	0.001	0.001
S.D. dependent var	0.025	0.029	0.036	0.033
Akaike info criterion	-4.780	-4.724	-4.597	-4.580
Schwarz criterion	-4.746	-4.690	-4.563	-4.546
Hannan-Quinn criter.	-4.767	-4.711	-4.584	-4.567

Note: σ_0^2 、 σ_1^2 、 σ_2^2 、 σ_3^2 represents the variance of the futures yield of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil Respectively. $\varepsilon_t^2(-1)$ represents the residual squared lag of one order; $\varepsilon_t^2(-1)*(\varepsilon_t(-1) < 0)$ represents dummy variable; $\sigma_t^2(-1)$ represents the variance of one period of lag. t=0,1,2,3.

From the above Table 6 estimate results, it can be seen that the coefficient before the dummy variable is positive, which is 0.050, 0.187, 0.200, 0.483, of which the dummy variable coefficient of the leverage effect model of the domestic crude oil futures market is not significant enough, while the dummy variable coefficient of Brent crude oil, WTI crude oil, Oman crude oil futures market leverage effect model is significant, indicating that the "leverage effect" existing in the domestic crude oil futures market is not significant, and the impact of market bearish news cannot be significantly stronger than the impact of bullish news. The "leverage effect" in the foreign Brent crude oil, WTI crude oil, Oman crude oil futures market is significant, and the impact of market bearish news can be significantly stronger than the impact of bullish news, of which the leverage effect of the Omani market is the most significant.

Therefore, Brent crude oil, WTI crude oil, Oman crude oil futures market futures price fluctuations have a "leverage effect", bearish news can produce greater fluctuations than the same amount of good news, when there is good news, respectively, in the domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures prices bring 0.050, 0.187, 0.200, 0.483 times the impact; When there is a bearish message, it brings 0.167 (0.117+0.050), 0.293 (0.106+0.187), 0.323 (0.123+0.200), and 0.623 (0.140+0.483) times, respectively. The leverage effect of crude oil futures price fluctuations in the domestic crude oil market is weak, and the impact of bearish news and bullish news on the market is weaker than that of the three foreign crude oil markets.

4.6 Domestic and Foreign Crude Oil Futures Price Yield EGARCH Model Estimates

The following is an estimate of the EGARCH model of domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures market crude oil futures price yield, estimated models are EGARCH(1,1), EGARCH(1,1), EGARCH(2,1), EGARCH(2,2), respectively, the specific estimation of the variance equation results are as follows Table 7:

Table 7. EGARCH model estimates of crude oil futures price yields in four crude oil futures markets

Variable	$\ln \sigma_0^2$	$\ln \sigma_1^2$	$\ln \sigma_2^2$	$\ln \sigma_3^2$
C	-0.637 (0.108)	-0.650 (0.079)	-0.557 (0.072)	-0.694 (0.102)
$ \varepsilon_t(-1)/\sigma_t(-1) $	0.280 (0.034)	0.292 (0.023)	0.448 (0.032)	0.624 (0.039)
$ \varepsilon_t(-2)/\sigma_t(-2) $			-0.172 (0.039)	-0.257 (0.070)
$\varepsilon_t(-1)/\sigma_t(-1)$	-0.039 (0.017)	-0.110 (0.013)	-0.101 (0.013)	-0.154 (0.023)
$\ln \sigma_t^2(-1)$	0.944	0.943	0.952	0.657

	(0.012)	(0.009)	(0.008)	(0.093)
$\ln \sigma_t^2 (-2)$				0.286
				(0.091)
R-squared	0.012	0.004	0.005	0.002
Adjusted R-squared	0.010	0.002	0.003	0.0002
S.E. of regression	0.024	0.029	0.036	0.033
Sum squared resid	0.591	0.829	1.274	1.058
Log likelihood	2378.563	2368.086	2290.949	2302.931
Durbin-Watson stat	1.964	1.969	1.928	1.938
Mean dependent var	0.001	0.005	0.001	0.0001
S.D. dependent var	0.025	0.029	0.036	0.033
Akaike info criterion	-4.772	-4.727	-4.570	-4.592
Schwarz criterion	-4.737	-4.693	-4.531	-4.548
Hannan-Quinn criter.	-4.759	-4.714	-4.556	-4.576

Note: σ_0^2 、 σ_1^2 、 σ_2^2 、 σ_3^2 represents the variance of the futures yield of domestic crude oil, Brent crude oil, WTI crude oil and Oman crude oil Respectively. ε_t represents the residual; σ_t represents the S.D. Negative numbers in parentheses are hysteresis orders .t=0,1,2,3.

From the above Table 7 estimates, it can be seen that the estimates of the asymmetric term coefficients are less than zero, which are -0.039, -0.110, -0.101, -0.154 and are significant, indicating that there is asymmetry and leverage in the domestic and foreign crude oil futures markets, of which the leverage effect of the domestic crude oil futures market is the weakest, the leverage effect of the Oman crude oil futures market is the strongest, and the model estimation results are basically consistent with the TARCh model estimates. The following respectively make the domestic and foreign crude oil futures market information impact response curve as shown in Figure 13-16:

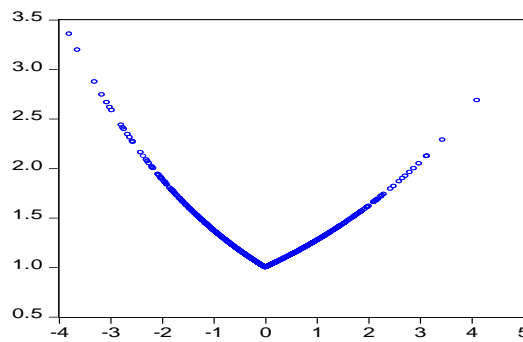


Figure 13. Domestic crude oil market information shock curve

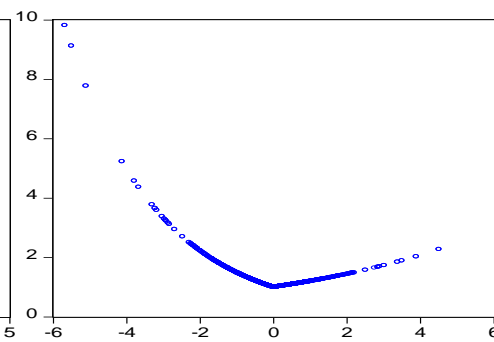


Figure 14. Brent crude oil market information shock curve

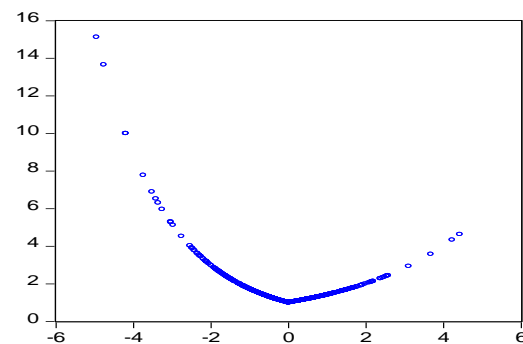


Figure 15. WTI crude oil market information shock curve

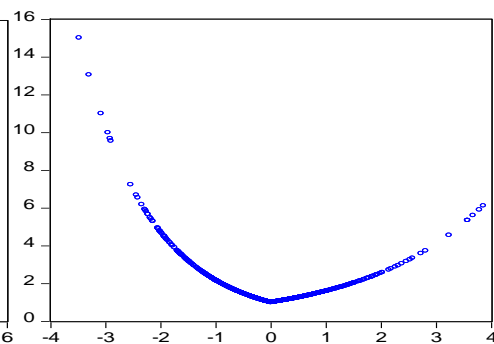


Figure 16. Oman crude oil market information shock curve

From the above Figure13- Figure 16, we can see the asymmetric impact of market news on volatility. Obviously, the impact of bearish news in domestic and foreign crude oil futures markets is greater than the impact of bullish news,

however, the three major foreign crude oil futures markets have a greater impact than the domestic crude oil futures market, and the impact of bullish news in the domestic market is basically close to the impact of bearish news. The enlightenment from the gap in the degree of impact of news in the domestic and foreign crude oil markets is that the risk of foreign crude oil futures markets is greater than the risk of domestic crude oil futures markets, so there is a greater risk of cross-market arbitrage.

4.7 Domestic and Foreign Crude Oil Futures Price Yield Spillover Effect Model Estimation

We first do a Granger causality test on the conditional variance of the Garch-M model of crude oil futures prices yields at home and abroad, and the lag order is selected 4, and the test results are as follows in Table 8:

Table 8. Granger causality test of the conditional variance of crude oil futures prices yield

Null Hypothesis	Sample	F-Statistic	Prob.
GARCH02 does not Granger Cause GARCH01	992	108.489	3.E-43
GARCH01 does not Granger Cause GARCH02		4.140	0.016
GARCH03 does not Granger Cause GARCH01	992	56.857	4.E-24
GARCH01 does not Granger Cause GARCH03		3.758	0.024
GARCH04 does not Granger Cause GARCH01	992	27.985	2.E-12
GARCH01 does not Granger Cause GARCH04		11.789	9.E-06

Note: Among them, GARCH01, GARCH02, GARCH03, and GARCH04 are the conditional variance of the Garch-M model of domestic crude oil, Brent crude oil, WTI crude oil, and Oman crude oil futures prices yield, respectively.

From the above Table 8 Granger causality test results, it can be seen that at the significance level of 5%, the volatility of domestic crude oil futures price yields and Brent crude oil, WTI crude oil, Oman crude oil futures price yields volatility are mutually causal relationship, and Brent crude oil and WTI crude oil futures price yields volatility on the domestic crude oil price yield volatility guidance effect is stronger than the domestic crude oil futures price yield fluctuation on Brent crude oil and WTI crude oil futures price yield fluctuation guide. It shows that the risks of domestic and foreign crude oil futures markets have a strong mutual influence, and the domestic crude oil futures market risks have a stronger impact on the Oman crude oil futures market than Brent crude oil and WTI crude oil futures markets. Therefore, the risk transmission of crude oil futures at home and abroad is asymmetrical.

The following detailed estimates of the spillover effect models of the domestic crude oil and Brent crude oil, WTI crude oil and Oman crude oil futures markets respectively are shown in table 9 below:

Table 9. spillover effect model estimate of domestic crude oil and three foreign crude oil futures markets

Variable	σ_1^2	σ_1^2	σ_1^2
$\sigma_1^2(-1)$	0.852 (0.001)	0.852 (0.001)	0.852 (0.001)
$\varepsilon_1^2(-1)$	0.138 (0.0004)	0.138 (0.0003)	0.138 (0.0003)
$\varepsilon_2^2(-1)$	-1.21E-04 (0.0001)		
$\varepsilon_3^2(-1)$		-8.38E-05 (4.88E-05)	
$\varepsilon_4^2(-1)$			-1.41 E-04 (6.54E-05)
R-squared	0.999	0.999	0.999
Adjusted R-squared	0.999	0.999	0.999
S.E. of regression	1.34E-05	1.34E-05	1.34E-05
Sum squared resid	1.78E-07	1.78E-07	1.78E-07
Log likelihood	9732.520	9733.383	9734.216
Durbin-Watson stat	0.046	0.049	0.052

Mean dependent var	0.001	0.001	0.001
S.D. dependent var	0.001	0.001	0.001
Akaike info criterion	-19.596	-19.598	-19.600
Schwarz criterion	-19.581	-19.583	-19.585
Hannan-Quinn criter.	-19.591	-19.592	-19.594

Note: σ_1^2 represents the conditional variance of the domestic crude oil futures prices yield, $\varepsilon_i^2 (i = 1, 2, 3, 4)$ represents domestic crude oil, Brent crude oil, WTI crude oil, Oman crude oil futures price yield disturbance, respectively, the positive data in parentheses is the standard deviation, and the negative value is the lag order.

The following detailed estimates of the spillover effect model of Brent crude oil, WTI crude oil, Oman crude oil futures market and domestic crude oil futures market are shown in Table 10 below:

Table 10. spillover effect model estimate of three foreign crude oil futures markets and domestic crude oil markets

Variable	σ_2^2	σ_3^2	σ_4^2
$\sigma_1^2(-1)$	0.776 (0.001)	0.710 (0.0004)	0.652 (0.0004)
$\varepsilon_1^2(-1)$	0.005 (0.000813)	0.012 (0.001)	0.012 (0.001)
$\varepsilon_2^2(-1)$	0.197 (0.0002)		
$\varepsilon_3^2(-1)$		0.245 (0.0002)	
$\varepsilon_4^2(-1)$			0.378 (0.0002)
R-squared	0.999	0.999	0.999
Adjusted R-squared	0.999	0.999	0.999
S.E. of regression	3.04E-05	4.75E-05	4.91E-05
Sum squared resid	9.21E-07	2.24E-06	2.40E-06
Log likelihood	8964.617	8520.858	8486.242
Durbin-Watson stat	0.105	0.195	0.190
Mean dependent var	0.001	0.001	0.001
S.D. dependent var	0.002	0.004	0.004
Akaike info criterion	-17.959	-17.070	-17.001
Schwarz criterion	-17.944	-17.055	-16.986
Hannan-Quinn criter.	-17.954	-17.064	-16.995

Note: σ_2^2 、 σ_3^2 、 σ_4^2 represents Brent crude oil, WTI crude oil, Oman crude oil futures yield conditional variance, respectively, t=2,3,4.

The above conditional variance model shows that the earlier stage absolute disturbance of Brent crude oil, WTI crude oil and Oman crude oil futures price yield has a negative impact on the current yield fluctuation of domestic crude oil futures prices, compared with the fluctuation of Brent crude oil and Oman crude oil futures price yield fluctuations on domestic crude oil futures price yield fluctuations stronger than WTI crude oil. The earlier stage absolute disturbance of the domestic crude oil futures price yield has a positive impact on the current price yield fluctuations of Brent crude oil, WTI crude oil and Oman crude oil, and in comparison, the fluctuation of domestic crude oil futures price yield on WTI crude oil and Oman crude oil futures price yield fluctuations is greater than that of Brent crude oil. This shows that there are spillover effects between domestic and foreign crude oil futures markets, and the spillover effect of the domestic crude oil futures market on the foreign crude oil futures market is stronger than that of the foreign crude oil futures market on the domestic crude oil futures market. The asymmetry of spillover effects between domestic and foreign crude oil markets shows that there is a mutual impact on the volatility transmission of domestic and foreign crude oil futures markets. The above shows that although the crude oil futures trading of China Shanghai International

Energy Trading Center is still relatively short, However, its yield level and volatility have already played a certain exemplary role in the global market, and the international pricing power and influence of domestic crude oil futures have been further improved..

5. Conclusion

Through empirical analysis and the establishment of different models, we have obtained many important conclusions about the relationship between domestic and foreign crude oil markets and the law of market operation. The study shows that there is a two-way Granger causal relationship and cointegration relationship between domestic crude oil futures prices and Brent crude oil, WTI crude oil and Oman crude oil futures prices. Domestic crude oil futures and the three foreign crude oil markets futures price yield there is an interaction, but their short-term fluctuation process there is a different fluctuation pattern, domestic crude oil futures prices are greatly affected by international crude oil futures prices, pricing power exceeds the influence of Omani crude oil, but weaker than Brent crude oil and WTI crude oil. There are obvious nonlinearities and asymmetries in the futures price yields and volatility of the four crude oil futures markets at home and abroad, and the leverage effect of the three foreign crude oil futures markets is stronger than that of the domestic crude oil futures markets. The spillover effect of domestic and foreign crude oil markets is asymmetrical, and the spillover effect of the domestic crude oil futures market on the foreign crude oil futures market is stronger than that of the foreign crude oil futures market on the domestic crude oil futures market.

In short, although the launch time of domestic crude oil futures trading is still relatively short, its yield level and volatility transmission have a strong influence in the global market, and the international pricing ability and influence of domestic crude oil have been further improved. Due to the interaction between the futures price yield and market volatility in the domestic and foreign crude oil futures markets and the long-term cointegration relationship, leverage effect, fluctuation spillover effect and asymmetry of risk transmission between domestic and foreign crude oil futures prices, therefore, there are theoretical speculative arbitrage opportunities in the domestic and foreign crude oil markets, due to the asymmetry of the volatility transmission of the crude oil markets at home and abroad, foreign crude oil market investors have a stronger risk appetite than domestic crude oil market investors. Speculative arbitrage through domestic and foreign crude oil markets can create significant market risks. In order to promote the healthy development of Chinese futures market and promote the internationalization of the Chinese futures market, today, when the Futures Law is launched, we should give full play to the "five-in-one" market supervision under the legal framework to reduce market risks as much as possible. Futures exchanges should further enrich the varieties of international futures investment, continuously improve the market operation rules of existing international futures varieties, and continuously enhance the international pricing influence of international futures varieties. In the process of opening up the futures market to the outside world, we will actively promote "going out" and "bringing in", continuously optimize the investor structure, attract more international investors to enter the domestic market, and promote the healthy and orderly development of China's futures market.

The research in this paper has certain limitations, due to the relatively short listing time of domestic crude oil futures, the study is based on daily data, and in the future, with the domestic crude oil futures running for a period of time, the research time period can be expanded to a longer range, and the conclusions of the study may be different. In addition, from the perspective of research methods, more quantitative model research methods can be explored in the future, the operation rules of domestic crude oil futures can be studied more accurately, and the construction of the domestic futures market can be better served.

References

- Allen, D. E., & Cruickshank, S. N. (2002). *Empirical Testing of the Samuelson Hypothesis: An Application to Futures Markets in Australia, Singapore and the UK*. Working Paper, School of Finance and Business Economics. <https://doi.org/10.2139/ssrn.315300>
- Baille, R. T., & Myers, R. J. (1991). Bivariate GARCH Estimation of the Optimal Commodity Futures Hedge. *Journal of Applied Econometrics*, 6, 109-124. <https://doi.org/10.1002/jae.3950060202>
- Balciyar, M., Demirel, R., & Ulussever, T. (2017). Does Speculation in the Oil Market Drive Investor Herding emerging Stock Markets? *Energy Economics*, 65, 50-63. <https://doi.org/10.1016/j.eneco.2017.04.031>
- Boubaker, H., & Raza, S. A. A. (2017). Wavelet Analysis of Mean and Volatility Spillovers between Oil and BRICS Stock Market. *Energy Economics*, 64, 105-117. <https://doi.org/10.1016/j.eneco.2017.01.026>
- Broadstock, D. C., & Filis, G. (2014). Oil Price Shocks and Stock Market Returns: New Evidence from the United States and China. *Journal of International Financial Markets Institutions & Money*, 33, 417-433. <https://doi.org/10.1016/j.intfin.2014.09.007>
- Brunetti, C., Gilbert, & Christopher, L. (2000). Bivariate FIGARCH and Fractional Cointegration. *Journal of*

- Empirical Finance, Elsevier*, 7(5), 509-553. [https://doi.org/10.1016/S0927-5398\(00\)00021-9](https://doi.org/10.1016/S0927-5398(00)00021-9)
- Bu, L., Li, X. Y., & Zhu, M. H. (2020). Price Discovery Function of Shanghai Crude Oil Futures and Its International Comparative Study. *International Trade Issues*, 9, 160-174.
- CAO, J. T. (2019). Study on the Conduction Effect of Price Change of Crude Oil Futures in Shanghai. *Price Theory and Practice*, 6, 107-111.
- Cecchetti, S. R., Cumby, & S, Figlewski. (1988). Estimation of the Optimal Futures Hedge. *Review of Economics and Statistics*, 70, 623-630. <https://doi.org/10.2307/1935825>
- Cheng, F. Z. (2018). *Research on oil price prediction method*(Unpublished doctoral dissertation). East China University of Science and Technology, Shanghai, China.
- CUI, L. M. (2017). *Research on the Influence of VAR Model on Chinese Crude Oil Price under the Background of Internationalization*(Unpublished master's thesis). Jinan University, Guangdong, China.
- DONG, X. L., & ZHANG, Y. S. (2006). Multivariate analysis of the spillover effect of crude oil market fluctuations at home and abroad. *China Soft Science*, 12, 120-125.
- Engle, R. F., & Granger, C. W. J. (1987). Cointegration and Error Correction Representation Estimation and Testing. *Econometrica*, 55, 251-276. <https://doi.org/10.2307/1913236>
- Engle, R. F. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica*, 50, 987-1007. <https://doi.org/10.2307/1912773>
- Fang, S., & Egan, P. (2018). Measuring Contagion Effects Between Crude Oil and Chinese Stock Market Sectors. *Quarterly Review of Economics & Finance*, 68, 31-38. <https://doi.org/10.1016/j.qref.2017.11.010>
- Fayyad, A., & Daly, K. (2011). The Impact of Oil Price Shocks on Stock Market Returns: Comparing GCC Countries with the UK and USA. *Emerging markets Review*, 12(1), 61-78. <https://doi.org/10.1016/j.ememar.2010.12.001>
- GAO, H., & GAO, T. C. (2022). Domestic crude oil futures promote the internationalization of the renminbi? Empirical research on cointegration model based on monthly data from 2018 to 2021. *China Securities & Futures*, 1, 23-43.
- Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the Relation Between the Expected Value and the Volatility of the Nominal Excess Return on Stocks. *Journal of Finance*, 48, 1779-1801. <https://doi.org/10.1111/j.1540-6261.1993.tb05128.x>
- Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Econometrica*, 37, 424-438. <https://doi.org/10.2307/1912791>
- Harmo, Y., & Masulis, R. W. (1990). Correlations in Prices Changes and Volatility Across International Stock Markets. *Reviews of Financial Studies*, 3, 281-307. <https://doi.org/10.1093/rfs/3.2.281>
- Hotelling, H. (1931). The Economics of Exhaustible Resources. *Journal of Political Economy*, 39(4), 137-175. <https://doi.org/10.1086/254195>
- Ivanovski, K., Hailemariam, & Abebe. (2021). Forecasting the dynamic relationship between crude oil and stock prices since the 19th century. *Journal of Commodity Markets, Elsevier*, 24(C). Handle: RePEc:eee:jocoma:v:24:y:2021:i:c:s2405851321000039. <https://doi.org/10.1016/j.jcomm.2021.100169>
- Jia, X. L. (2016). *Research on the linkage relationship of crude oil market based on time series correlation network model* (Unpublished doctoral dissertation). China University of Geosciences, Beijing, China.
- Johansen, S. (1988). Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control*, 2, 231-254. [https://doi.org/10.1016/0165-1889\(88\)90041-3](https://doi.org/10.1016/0165-1889(88)90041-3)
- Jouini, J., & Harrathi, N. (2014). Revisiting the shock and volatility transmissions among GCC stock and oil markets: A further investigation. *Economic Modelling*, 38, 486-494. <https://doi.org/10.1016/j.econmod.2014.02.001>
- Kaufmann, R. K., & Ullman, B. (2009). Oil Prices, Speculation, and Fundamentals: Interpreting Causal Relations among Spot and Futures Prices. *Energy Economics, Elsevier*, 31(4), 550-558. <https://doi.org/10.1016/j.eneco.2009.01.013>
- Khalifa, A. A. A., Hammoudeh, S., & Otranto, E. (2014). Patterns of Volatility Transmissions within Regime Switching across GCC and Global Markets. *International Review of Economics and Finance*, 29, 512-524. <https://doi.org/10.1016/j.iref.2013.08.002>
- LI, J. F., Lu, X. S., & JIANG, W. (2018). Empirical analysis of the relationship between monetary policy, RMB exchange rate and international crude oil market. *Statistics and Decision*, 34(18), 154-157.

- Lin, S. Xiao, W., & Tamvakis, M. N. (2001). Spillover Effects in Energy Futures Markets. *Energy Economics, Elsevier*, 23(1), 43-56. [https://doi.org/10.1016/S0140-9883\(00\)00051-7](https://doi.org/10.1016/S0140-9883(00)00051-7)
- MA, Z. W., ZHANG, J. W., & CAO, G. H. (2019). Research on International Crude Oil Futures Price Fluctuations and Their Influencing Factors. *Price Theory and Practice*, 4, 87-91.
- Michael, D., Mackenzie, & Heather, M. (2001). Power ARCH Modeling of Commodity Futures Data on the London Metal Exchange. *The European Journal of Finance*. Rout ledge, part of the Taylor & Francis Group, 7, 22-38. <https://doi.org/10.1080/13518470123011>
- Mukherjee, K. N., & Mishra, R. K. (2006). *Information Leadership and Volatility Spillover Across the Countries: A Case of Indian and Other Asian Equity Markets*. Social Science Electronic Publishing. <https://doi.org/10.2139/ssrn.874916>
- Mutawakil, M. Z., & Chris, S. (2020). Measuring the volatility spill-over effects of crude oil prices on the exchange rate and stock market in Ghana. *The Journal of International Trade & Economic Development, Taylor & Francis Journals*, 29(4), 420-439, May. Handle: RePEc:taf:jitecd:v:29:y:2020:i:4:p:420-439. <https://doi.org/10.1080/09638199.2019.1692895>
- Nelson, D. B. (1991). Conditional Heteroscedasticity in Asset Returns: A New Approach. *Econometrica*, 59, 347-370. <https://doi.org/10.2307/2938260>
- OChia, C., & Chenxu Yang. (2022). Identifying the Determinants of Crude Oil Market Volatility by the Multivariate GARCH-MIDAS Model. *Energies*, 15(8), 1-14. <https://doi.org/10.3390/en15082945>
- PAN, H. F., & ZHANG, J. S. (2007). Extreme risk spillover test in domestic and foreign oil markets. *Chinese Journal of Management Science*, 3, 25-30.
- Rita, M. A. (2003). *Maturity Effects in Futures Markets: Evidence from Eleven Financial Futures Markets*. Santa Cruz Center for International Economics, Working Paper Series.
- Stelios, D., Bekiros, C., & G. H. Diks. (2008). The Relationship Between Crude Oil Spot and Futures Prices: Cointegration, Linear and Nonlinear Causality. *Energy Economics*, 30(5), 2673-2685. <https://doi.org/10.1016/j.eneco.2008.03.006>
- Theodossiou, P., & Lee, U. (1993). Mean and Volatility Spillovers Across Major National Stock Markets: Further Empirical Evidence. *Journal of Financial Research*, 16(4), 337-350. <https://doi.org/10.1111/j.1475-6803.1993.tb00152.x>
- Tian, H. Z. (2016). A study on the in-depth factors of the decline in international crude oil prices: Based on the comparison of two international oil price declines in 2008-2019 and 2014-2015. *Price Theory and Practice*, 1, 112-115.
- Vasiliki, D., Skintzi, A., & N. Refenes. (2006). Volatility Spillovers and Dynamic Correlation in European Bond Markets. *Journal of International Financial Markets, Institutions and Money*, 16, 23-40. <https://doi.org/10.1016/j.intfin.2004.12.003>
- WANG, J. C. (2019). *Research on international pricing power of crude oil futures in China* (Unpublished master's thesis). Southwestern University of Finance and Economics, Chengdu, China.
- Wen, S. B. (2019). *Research on the Relationship between Crude Oil Market Fundamentals and Crude Oil Price Conduction Based on Price Difference* (Unpublished doctoral dissertation). China University of Geosciences, Beijing, China.
- Xu, X. E., & Fung, H. G. (2005). Cross-Markets Linkages Between U.S. and Japanese Precious Metals Futures Trading. *Journal of International Financial Markets, Institutions and Money*, 15(2), 107-124. <https://doi.org/10.1016/j.intfin.2004.03.002>
- YAO, X. J., & HU, W. X. (2011). Empirical Test of Spillover Effects in International Financial Market and International Crude Oil Futures Market: An Analysis Based on VAR-BEKK Model. *Journal of Financial Education and Research*, 24(3), 28-35.
- Yu, T. J. (2015). *Research on the impact of international oil price fluctuations on China's foreign trade* (Unpublished master's thesis). Harbin University of Commerce, Heilongjiang, China.
- Zakoian, J. M. (1994). Threshold Heteroscedasticity Models. *Journal of Economic Dynamics and Control*, 15, 931-955. [https://doi.org/10.1016/0165-1889\(94\)90039-6](https://doi.org/10.1016/0165-1889(94)90039-6)
- Zang, Z. N. (2017). *Research on the influence of financial market factors on global oil price fluctuations* (Unpublished doctoral dissertation). Huazhong University of Science and Technology, Hubei, China.

- Zhan, X. (2016). *Analysis of the causes of international crude oil price fluctuations and suggestions for countermeasures* (Unpublished master's thesis). Lanzhou University of Finance and Economics, Gansu, China.
- Zhang, Q. H. (2016). *Research on the influencing factors on crude oil price fluctuations under the background of commodity financialization* (Unpublished master's thesis). Guangdong University of Finance and Economics, Guangdong, China.
- ZHANG, D., & JI Q. (2018). Research on dynamic risk spillover of Crude Oil Futures in China. *CMS*, 26(11), 42-49.
- Zhang, Z. M., & Zou, G. (2016). Study on the Impact Effect of Monetary Policy on Energy Price Fluctuations in China. *Modern Management Science*, 3, 12-14.
- Zhu, H. M., Guo, Y. W., You, W. H., & Xu, Y. Q. (2016). The Heterogeneity Dependence Between Crude Oil Price Changes and Industry Stock Market Returns in China: Evidence from a quantile Regression Approach. *Energy Economics*, 55, 30-41. <https://doi.org/10.1016/j.eneco.2015.12.027>

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the [Creative Commons Attribution license](#) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.