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Crude Oil Price Shocks and Stock Market Volatility: Evidence From China*

GAO Hui[1] & GAO Tian Chen[2]

[1] Shang Hai Futures Exchange, Shanghai ,China

[2] University of Sydney, Sydney, Australia

Correspondence: GAO Hui, Shang Hai Futures Exchange, Shanghai, China

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Abstract

As the first international futures variety in China, crude oil futures, its price influence and function play has attracted much attention at home and abroad, from the perspective of market performance, crude oil futures have had a greater impact on the capital market since its launch, and what needs to be further studied is the quantitative degree and complexity of the impact of crude oil futures price fluctuations on stock market fluctuations. The daily data from March 26, 2018 to July 5, 2022 were selected to study the influence of domestic crude oil futures prices on domestic Shanghai and Shenzhen stock index by Granger causality, cointegration test and smooth transition regression model. The study shows that the price yield of domestic crude oil futures have a one-way guiding effect on the domestic Shanghai and Shenzhen stock indexes yields, but their guiding effect on the Shenzhen component index is greater than that of the Shanghai Composite Index. Domestic crude oil futures prices and Shanghai and Shenzhen stock indexes have a long-term similar negative cointegration relationship. The positive and negative impact of the domestic crude oil futures price yield on Shanghai and Shenzhen stock index yields is non-linear and asymmetrical, but the mechanism of impact on the two stock markets is different, for the Shanghai stock market, the negative impact of the crude oil futures price yield is greater than the positive shock impact, for the Shenzhen stock market, the positive impact of the crude oil futures price yield is greater than the negative shock impact, and the impact on both stock markets was limited. Therefore, for domestic crude oil futures to become the global crude oil price benchmark, they also need to be continuously improved in terms of national policies, industry supervision, exchange rules and market system construction.

Keywords: Crude oil futures, Granger causal test, Cointegration test, Nonlinear, STR model

1. Introduction

Since the domestic crude oil futures were listed on the International Energy Center of the Shanghai Futures Exchange on March 26, 2018, as the first international futures variety in China, the launch is of great significance, and the launch of crude oil futures has an important milestone for the international development of China futures market. With the steady operation of the domestic crude oil futures market, the trading volume and position volume of domestic crude oil futures continue to enlarge, the participation of international investors has increased, and the international influence of crude oil futures has been further expanded. China crude oil futures market has become the world's third largest crude oil futures market after WTI crude oil and Brent crude oil.

In order to further enhance the discovery function of domestic crude oil futures prices and the international pricing power and influence, it is necessary to carry out research on the operation law and influence of the domestic crude oil futures market. Since the launch of the domestic crude oil futures market for more than four years, the impact of domestic crude oil futures prices has been expanding, and the fluctuations in crude oil futures prices have had a greater impact on the futures market and the domestic capital market. Therefore, this paper focuses on the study of the impact of the domestic crude oil futures market on the domestic stock market, through the use of Granger causality test, cointegration test, study the guiding relationship and long-term impact of domestic crude oil futures prices on the domestic stock market, through the use of nonlinear smooth transition regression model (referred to as STR) research, to reveal the nonlinear and asymmetric impact of the fluctuation of domestic crude oil futures price yield on the domestic stock market yield fluctuations. Through research, it provides new ideas for the construction of the crude oil market and the supervision of the capital market.

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2. Crude Oil Markets and China Stock Markets

After more than four years of market operation, the crude oil futures launched by Shanghai International Energy Trading Center have continuously improved the market operation mechanism and expanded their market influence. The following is a time series chart of domestic crude oil futures and the most influential international crude oil futures prices (Brent crude oil, WTI crude oil futures prices) (Figure 1, Source: wind. The following is the same).

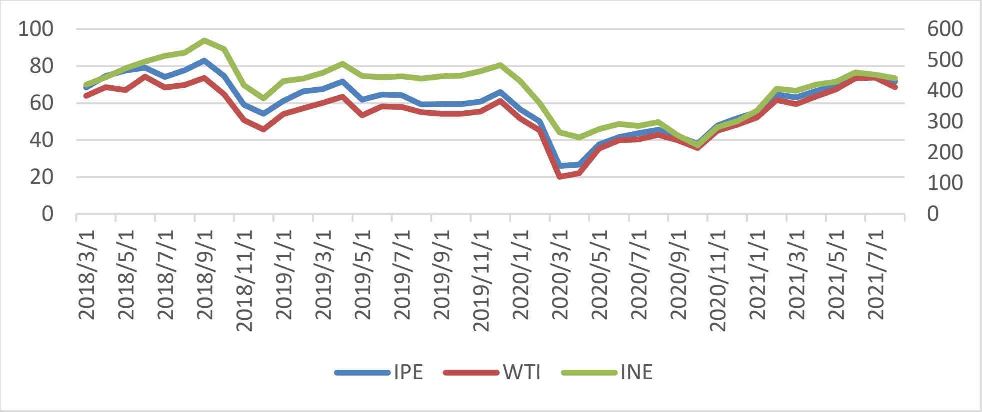

Figure 1. Domestic crude oil (INE) and international crude oil (IPE, WTI) futures prices chart

From the figure 1, it can be seen that the domestic crude oil futures prices have a good correlation with Brent crude oil and WTI crude oil futures prices.

After more than 30 years of development, the domestic stock market has been expanding, which has played a huge role in promoting the national economy, as of July 5, 2022, the total number of listed companies in China's stock market is 4,736 (including A shares and B shares), with a total market value of 78,085.806 billion yuan (see Figure 2).

Figure 2. The total market value and the total number of listed companies of China's stock market

From the perspective of the relationship between stock market value and GDP, as of December 2021, the domestic stock market value was 91,608.818 billion yuan, the total GDP value was 114,366.970 billion yuan (current price), and the stock market value accounted for 80.1% of GDP(see Figure 3).

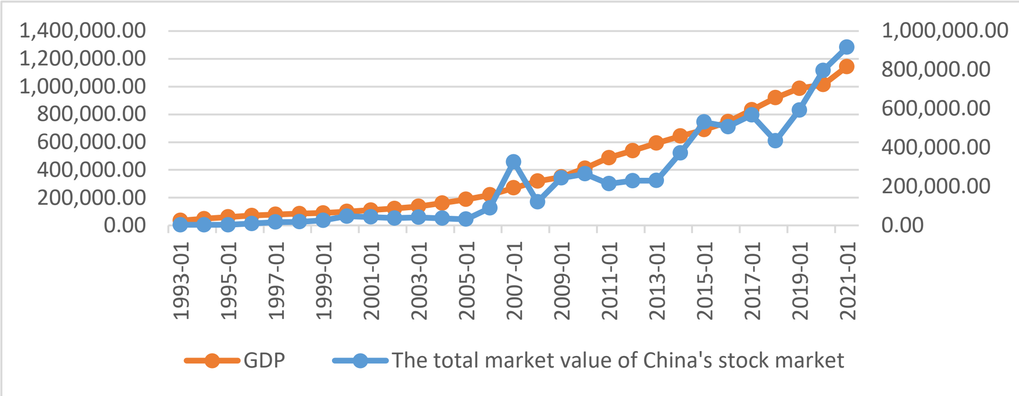

Figure 3. The total market value of China's stock market and China GDP

From the perspective of the impact mechanism of crude oil futures prices on the stock market, crude oil futures as the leading variety of commodities, its price fluctuations have a relatively large impact on the commodity market, the rise and fall of commodity prices affect the production costs of enterprises, thereby affecting the profits of listed companies, from the investment market, the valuation of listed companies changes with the profits of listed companies, thereby affecting the stock prices of listed companies, therefore, the price fluctuations of commodities affect the stock price fluctuations of listed companies, which affects the fluctuations of stock indexes. Below we make a time series chart of the domestic crude oil futures price and the stock index (see figure 4, figure 5).

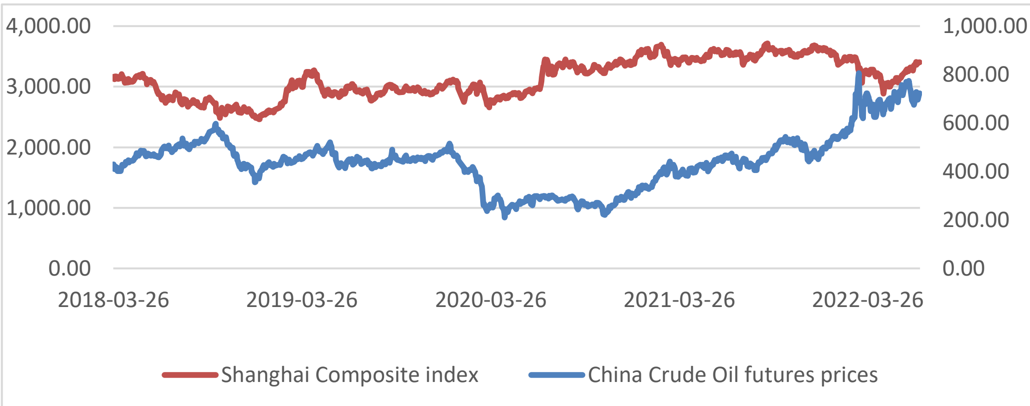

Figure 4. Domestic crude oil futures prices and Shanghai Composite Index time series chart

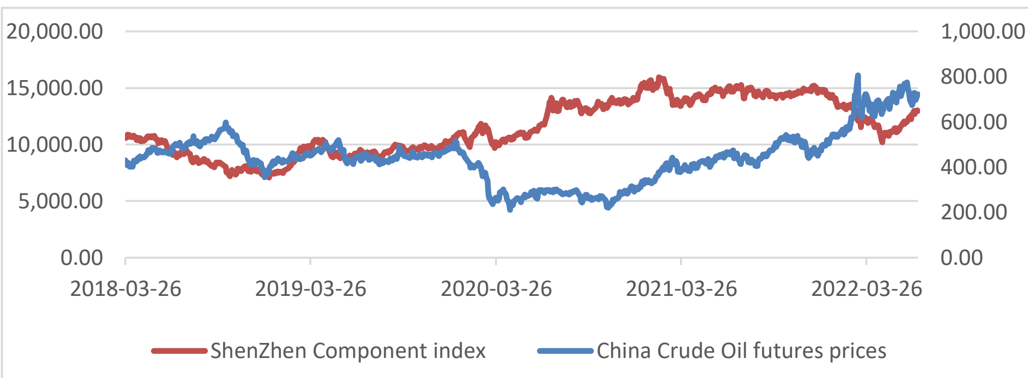

Figure 5. Domestic crude oil futures prices and Shenzhen component index time series chart

As can be seen from above Figures 4 and 5, the fluctuations in domestic crude oil futures prices have a strong correlation with the Shanghai and Shenzhen stock market indices, especially at the end of 2018, the domestic crude oil futures prices fell sharply, and the domestic Shanghai and Shenzhen stock market indices also fell sharply. In the first quarter of 2020, due to the impact of the COVID-19, the price of domestic crude oil futures plummeted, and the domestic Shanghai and

Shenzhen stock markets were affected to a certain extent.

3. Literature Review

In recent years, the domestic research on the relationship between the crude oil market and the stock market literature, from the perspective of quantitative research, mainly using time series related theory and a variety of econometric models, the research mainly focuses on the relationship between the international crude oil market and domestic and foreign stock markets. For example, Jiang & Tao (2013) using multi-factor models, empirically studied the impact of international crude oil price fluctuations on the differentiated yields of domestic stock markets based on industry and company size. Zhao et al. (2014) studied the relationship between international crude oil prices and yields in Chinese stock markets using the Bonferroni test of near-single full time series. Hu & Ding (2016) Using the VAR-Asymmetric-BEKK model to study the fluctuating spillover effect of international crude oil prices on stock prices in China's new energy industry. Ren et al. (2017) use the VAR-BEKK model, Granger causality testing to study the direction of volatility spillover and lag effect between the international energy market and the Chinese stock market. Li et al. (2017) apply non-parametric time-varying Copula methods to test the correlation between oil prices and global stock markets. Chen & Huang (2017) constructed a quantile regression model to study the linkage relationship between the international crude oil market and eight Asia-Pacific stock markets. Ding et al. (2017) established vector autoregressive model and vector error correction model to study the linkage effect between international oil prices and stock markets. Fang & Lu (2018) based on the variable coefficient quantile model, the impact of changes in international crude oil prices under different stock market trends and crude oil price impacts on China's A-share market is studied. Huang et al. (2018) used wavelet variation and vector autoregressive models to study the dynamic impact of different types of crude oil price changes on global composite stock indexes. Xu et al. (2019) based on the wavelet analysis method, the interaction between the stock market in China and the fluctuations in the price of oil and gold in the world is studied. Ren (2020) used the generalized correlation measure (GMC) method to make an empirical analysis of the non-linear and asymmetric dependence between international crude oil prices and the daily returns of major international stock market indices. Li (2020) uses the VAR model and the EGARCH(1,1) model to study the mean spillover effect and asymmetric effect of international crude oil price fluctuations on industry stock indices.

Due to the relatively short launch time of domestic crude oil futures, there are relatively few literature on the relationship between the domestic crude oil futures market and the stock market, only for example, Yu (2020) through the construction of the GARCH-Copula-CoVaR model, the risk spillover effect of Shanghai crude oil futures on stock indices in oil-related industries was studied. Chen & Yu (2021) used the VAR model to analyze the correlation between crude oil futures prices and stock price indices in China. Zhong et al. (2022) based on the time-varying POT model and spillover index model, the tail risk spillover effect between China's stock market and the macroeconomic system, including international crude oil prices, was studied.

From the perspective of foreign literature, in recent years, there have been many foreign literatures to study the relationship between crude oil prices and the stock market, and from the perspective of research methods, time series related theories and a variety of econometric models are also used, such as: Basher & Sadorsky (2006) used multi-factor models to study the impact of changes in international oil prices on stock returns in emerging markets. Arouri & Rault (2012) used panel cointegration methods to study the relationship between oil prices and the stock market in GCC. Broadstock & Filis (2014) based on the Scalar-BEKK model examine the dynamic correlation between different types of oil price shocks and U.S. and Chinese stock market returns. Caporale et al. (2015) based on the VAR-GARCH mean model, study the dynamic impact of uncertainty on international oil prices on Yields in Chinese stock markets. AlMaadid et al. (2016) GARCH–BEKK was used to study the relationship between international oil price volatility and stock market yields in GCC countries. Tchatoka et al. (2019) using the QQ method, the relationship between international oil price shocks and stock market yields in 15 countries was studied. Ji et al. (2020) used the CoVaR method to study the dynamic correlation between the impact of crude oil price changes and the stock yields of the BRICS countries and its risk spillover. Hashmi et al. (2021) using the quantile ARDL model, the stock markets of some oil importing and exporting countries were studied by short-term and long-term asymmetric influences of international oil prices in bull, bear and normal conditions. Ma et al. (2021) the impact of supply and demand impacts on the international crude oil market on the stock yields of 16 listed banks in China is studied using the panel vector autoregressive model

From the existing literature, most of the research findings are based on linear models, Balcilar et al. (2015) Argues that ignoring potential nonlinear relationships in the study of crude oil and stock markets may lead to erroneous conclusions. Therefore, some foreign literature has studied the asymmetric effects of international crude oil price fluctuations on the impact of stock market yields from a nonlinear perspective, such as Bittlingmayer (2005), Park & Ratti (2008), Mohanty et al. (2011), Sim & Zhou (2015), Reboredo & Ugolini (2016), et al.

Since Granger & Teräsvirta (1993) proposed the smooth transition regression model, and Teräsvirta (1994) further improved the STAR model, the model has received some effective applications in the economic and financial field, but there is relatively little research literature on the study of crude oil price fluctuations and stock markets, the only ones such as Nidhaleddine et al. (2018) studied the impact of international crude oil prices on the stock markets of GCC countries using a nonlinear smooth transition regression model.

Therefore, this paper uses STR model to study the nonlinear asymmetric effect of domestic crude oil futures prices on the stock market for the first time in China, and through the STR model, the asymmetry of the impact of oil price fluctuations on Chinese stock market is studied. In this paper, the STR model not only solves the problem that the linear regression model can only solve the linear relationship between domestic crude oil price changes and the stock market, but also overcomes the abruptness of the transition mechanism through the transition function, and solves the problem that the threshold regression model cannot smoothly describe the range transition of the impact of crude oil price changes on the stock market.

4. Method

4.1 Related Theory Models

In this paper, we use the smooth transition autoregressive model proposed by Granger & Teräsvirta (1993), also known as the nonlinear regime-switching model. The general expression for the STR model is as follows:

$$y_t = \theta_1 x_t + \theta_2 x_t G(s_t;\gamma,c) + u_t \tag{1}$$

Where θ_1 and θ_2 is coefficient, $G(s_t;\gamma,c)$ is a transition function that controls the nonlinear dynamics of the STR model. $G(s_t;\gamma,c)$ is a continuous function between 0 and 1, s_t is transition variable, γ is the speed of the regime-switching, c is threshold value, $u_t \sim$ iid(0, σ^2).When the transition function in model (1) is as follows:

$$G(s_t;\gamma,c) = \left[1+\exp\{-\gamma(s_t-c)\}\right]^{-1},\ \gamma > 0 \tag{2}$$

Then the model (1) is the LSTR1 model , if $s_t - c \to -\infty$, $G(s_t;\gamma,c) \to 0$, then the coefficient of the model is θ_1. if $s_t - c \to +\infty$, $G(s_t;\gamma,c) \to 1$, then the coefficient of the model is $\theta_1 + \theta_2$ .if $s_t = c$, $G(s_t;\gamma,c)$=0.5, then the coefficient of the model is $\theta_1 + \theta_2/2$.

When the transition function in model (1) is in exponential form as follows:

$$G(s_t;\gamma,c) = 1-\exp\{-\gamma(s_t-c)^2\}\ \gamma > 0 \tag{3}$$

Then the model (1) is the ESTR model. If $s_t - c \to \pm\infty$, $G(s_t;\gamma,c) \to 1$, then the coefficient of the model is $\theta_1 + \theta_2$. If $s_t = c$, $G(s_t;\gamma,c) \to 0$, then the coefficient of the model is θ_1 .

When the transition function in model (1) is in the form as follows:

$$G(s_t;\gamma,c) = \left[1+\exp\{-\gamma(s_t-c_1)(s_t-c_2)\}\right]^{-1},\quad \gamma > 0, c_1 \le c_2 \tag{4}$$

Then the model (1) is the LSTR2 model. where the transition function values are symmetrical about $(c_1+c_2)/2$, if $s_t \to \pm\infty$ then $G(s_t;\gamma,c) \to 1$ .If $c_1 \le s_t \le c_2$, $\gamma \to \infty$ then $G(s_t;\gamma,c) \to 0$. If s_t is other values , then $G(s_t;\gamma,c) \to 1$.

LSTR1 and ESTR models study different nonlinear situations. The LSTR1 model is used to calculate the asymmetric of the direction of change in crude oil prices (negative or positive oil price shocks), especially when the threshold value is close to zero. On the other hand, the ESTR model is used to study asymmetric of the impact of crude oil price changes extent.

4.2 Empirical Models

In this paper, the basic model of the impact of China crude oil futures prices on the Shanghai and Shenzhen stocks markets indices is assumed as follows:

$$D\ln shi_t = \alpha_1 + \sum_{j=1}^{n_1}\lambda_{1j} D\ln shi_{t-j} + \sum_{j=0}^{n_2}\varphi_{1j} D\ln msci_{t-j} + \sum_{j=0}^{n_3}\delta_{1j} D\ln i_{t-j} + \sum_{j=0}^{n_4}\beta_{1j} D\ln p_{t-j} + \varepsilon_{1t} \tag{5}$$

$$D\ln szi_t = \alpha_2 + \sum_{j=1}^{m_1}\lambda_{2j} D\ln szi_{t-j} + \sum_{j=0}^{m_2}\varphi_{2j} D\ln msci_{t-j} + \sum_{j=0}^{m_3}\delta_{2j} D\ln i_{t-j} + \sum_{j=0}^{m_4}\beta_{2j} D\ln p_{t-j} + \varepsilon_{2t} \tag{6}$$

where, n_1, m_1 indicates the lag order of the yield of the Shanghai and Shenzhen stock markets index respectively.

n_2, m_2 represents the lag order of the MSCI Index yield in two cases, respectively. n_3, m_3 represents the lag order of the CHIBR yield in both cases, respectively. n_4, m_4 represents the lag order of domestic crude oil futures price yield in both cases, respectively. λ、φ , δ , β are the model coefficients , respectively. $\varepsilon_{1t}, \varepsilon_{2t}$ represents a random perturbation term.

In order to study the nonlinear effect of crude oil price fluctuations on the impact of the Shanghai and Shenzhen stock markets, we use the nonlinear STR model for testing, introduce the transition function in the above basic model, and establish a nonlinear model of the yield of the Shanghai and Shenzhen stock markets indices as follows:

$$\begin{aligned} D\ln shi_t &= \alpha_1 + \sum_{j=1}^{n_1}\lambda_{1j} D\ln shi_{t-j} + \sum_{j=0}^{n_2}\varphi_{1j} D\ln msci_{t-j} + \sum_{j=0}^{n_3}\delta_{1j} D\ln i_{t-j} + \sum_{j=0}^{n_4}\beta_{1j} D\ln p_{t-j} \\ &+ \left(A_1 + \sum_{j=1}^{n_1} B_{1j} D\ln shi_{t-j} + \sum_{j=0}^{n_2} C_{1j} D\ln msci_{t-j} + \sum_{j=0}^{n_3} E_{1j} D\ln i_{t-j} + \sum_{j=0}^{n_4}\phi_{1j} D\ln p_{t-j} \right) G\left(s_{1t};\gamma_1, c_1\right) + \varepsilon_{1t} \end{aligned} \tag{7}$$

$$\begin{aligned} D\ln szi_t &= \alpha_2 + \sum_{j=1}^{m_1}\lambda_{2j} D\ln szi_{t-j} + \sum_{j=0}^{m_2}\varphi_{2j} D\ln msci_{t-j} + \sum_{j=0}^{m_3}\delta_{2j} D\ln i_{t-j} + \sum_{j=0}^{m_4}\beta_{2j} D\ln p_{t-j} \\ &+ \left(A_2 + \sum_{j=1}^{m_1} B_{2j} D\ln szi_{t-j} + \sum_{j=0}^{m_2} C_{2j} D\ln msci_{t-j} + \sum_{j=0}^{m_3} E_{2j} D\ln i_{t-j} + \sum_{j=0}^{m_4}\phi_{2j} D\ln p_{t-j} \right) G\left(s_{2t};\gamma_2, c_2\right) + \varepsilon_{2t} \end{aligned} \tag{8}$$

when the crude oil futures price yield is used as a transition variable, $s_t = D\ln p_{t-j}$. All of the above variables are series of yields, and the data are all stable with first-order differences.

According to equations (7) and (8), the long-term effects of crude oil futures price changes on the yields of Shanghai and Shenzhen stock markets indices are as follows:

$$\left[\sum_{j=0}^{n}\beta_{1j} + \sum_{j=0}^{n}\phi_{1j} G\left(s_{1t};\gamma_1, c_1\right)\right] \Big/ \left[1 - \sum_{j=1}^{n}\lambda_{1j}\right], \quad \left[\sum_{j=0}^{m}\beta_{2j} + \sum_{j=0}^{m}\phi_{2j} G\left(s_{2t};\gamma_2, c_2\right)\right] \Big/ \left[1 - \sum_{j=1}^{m}\lambda_{2j}\right]$$

The lag length of the variables in equations (7) and (8) is selected according to Van Dijk et al. (2002) proposed method of selecting the final order from general to special. We start with the maximum lag order N=8 and then gradually decrease the lag order until the absolute value of the corresponding parameter t statistic is less than 1.

For the LSTR1 model, the impact of crude oil futures prices on the yields of Shanghai and Shenzhen stock markets indices depends on whether the transition variable *c* is less than or greater than the threshold value $D\ln p_{t-j}$,if $\left(D\ln p_{t-j} - c_1\right) \to -\infty$ (Negative oil price shock), then the impact on the shanghai stock market price yield is $\sum_{j=0}^{n}\beta_{1j} \Big/ \left(1 - \sum_{j=1}^{n}\lambda_{1j}\right)$, if $\left(D\ln p_{t-j} - c_2\right) \to -\infty$ (Negative oil price shock), then the impact on the price yield of the Shenzhen stock market is $\sum_{j=0}^{m}\beta_{2j} \Big/ \left(1 - \sum_{j=1}^{m}\lambda_{2j}\right)$. If $\left(D\ln p_{t-j} - c_1\right) \to +\infty$ (Positive oil price shock), then the impact of crude oil futures prices on the price yield of the Shanghai stock market is $\left(\sum_{j=0}^{n}\beta_{1j} + \sum_{j=0}^{n}\phi_{1j}\right) \Big/ \left(1 - \sum_{j=1}^{n}\lambda_{1j}\right)$, if $\left(D\ln p_{t-j} - c_2\right) \to +\infty$ (Positive oil price shock), then the impact of crude oil futures prices on the price yield of Shenzhen stock market prices is $\left(\sum_{j=0}^{m}\beta_{2j} + \sum_{j=0}^{m}\phi_{2j}\right) \Big/ \left(1 - \sum_{j=1}^{m}\lambda_{2j}\right)$.

For the ESTR model, the impact of crude oil futures prices change depends on whether $D\ln p_{t-j}$ are close to or far from thresholds *c*, whether $\left(D\ln p_{t-j} - c\right)$ is positive or negative.

Therefore, if $\left(D\ln p_{t-j} - c_1\right) \to \pm\infty$ (Larger oil price shocks), then the impact on the shanghai stock market yield is $\left(\sum_{j=0}^{n}\beta_{1j} + \sum_{j=0}^{n}\phi_{1j}\right) \Big/ \left(1 - \sum_{j=1}^{n}\lambda_{1j}\right)$, if $\left(D\ln p_{t-j} - c_2\right) \to \pm\infty$ (Larger oil price shocks), then the impact on the yields of the Shenzhen stock market is $\left(\sum_{j=0}^{m}\beta_{2j}+\sum_{j=0}^{m}\phi_{2j}\right)\Big/\left(1-\sum_{j=1}^{m}\lambda_{2j}\right)$. If $D\ln p_{t-j}=c_1$ (Smaller oil price shocks), then the impact on the shanghai stock market yield is $\sum_{j=0}^{n}\beta_{1j}\Big/\left(1-\sum_{j=1}^{n}\lambda_{1j}\right)$, if $D\ln p_{t-j}=c_2$ (Smaller oil price shocks), then the impact on the yields of the Shenzhen stock market is $\sum_{j=0}^{m}\beta_{2j}\Big/\left(1-\sum_{j=1}^{m}\lambda_{2j}\right)$.

We use the STR model to test nonlinearity, which is used to select the appropriate lag order of the crude oil futures price yield variable as the threshold variable, as well as the most appropriate form of transition function. For lag crude oil price yields $D\ln p_{t-j}$, linear test is carried out. The parameters of STR equations (7) and (8) are then estimated using the nonlinear least squares (NLS).

5. Empirical Results

5.1 Variable Selection and Data Description

5.1.1 Variable Selection

We chose to make a model empirical study of the daily data from the launch time of domestic crude oil futures on March 26, 2018 to July 5, 2022 to study the impact of crude oil price fluctuations on China's stock market.

Domestic crude oil price variable selection as follows: We select the crude oil futures price of Shanghai International Energy Exchange Center as the domestic crude oil futures price variable. Domestic crude oil spot price selects the domestic influence of the South China Sea crude oil spot price and Shengli Oilfield crude oil spot price, through comparative analysis, select the domestic crude oil futures price as the crude oil price variable[1], the main contract closing price day data, the selection of data to take logarithmic processing, crude oil price yield using crude oil futures price logarithmic first-order difference as follows: $D\ln p_t=\ln p_t-\ln p_{t-1}$.

The selection of domestic stock market variables as follows: The securities market, as the main component of the financial market, plays an important role in the distribution process of social capitals, and the development of the securities market has a huge impact on the whole society. There are Shanghai Stock Exchange and Shenzhen Stock Exchange in China[2], and the two exchanges have launched a variety of stock price indices, because the Shanghai Composite Index launched by the Shanghai Stock Exchange represents the overall domestic main board listed companies, and the Shenzhen Component Index is a listed company listed on the Shenzhen Stock Exchange that extracts a large weight of listed companies, and the index obtained by weighted average represents the domestic ChiNext board and other listed companies. From the perspective of market impact, the Shanghai Composite Index and the Shenzhen Component Index have a large market influence, so we choose the Shanghai Composite Index and the Shenzhen Component Index as stock price index indicators. Using the daily data of the closing price of the index, the selected data is logarithmic processing, calculating the return rate of the stock index, and the first-order difference of the logarithm of the Shanghai Composite Index and the Shenzhen Component Index is used respectively, showed as follows: $D\ln shi_t$, $D\ln szi_t$.

Selection of control variables as follows: Refer to Nidhaleddine et al. (2018) To study the impact of U.S. crude oil price fluctuations on the stock markets of GCC countries, the MSCI International Index (MSCI) and the March Treasury yield were used as the selection method for controlling variables, so we chose the MSCI index yield and the domestic interest rate of marketing as the control variables for the relationship between crude oil futures prices and the stock market. Because the MSCI index and the domestic market interest rate are the main external factors affecting the domestic stock market. Because in developed market economies, the interest rate of treasury bonds is the basic interest rate of the financial market, and the overall scale of China's treasury bond market is still small, which is not enough to guide the market interest rate. With the development of the domestic interest rate marketization construction, because

[1] Through the correlation and causal relationship between the domestic crude oil futures price and the domestic Daqing crude oil and the spot price of Shengli crude oil, it can be known that the domestic crude oil futures price has a high correlation with the spot price and the futures price has a strong guiding relationship with the spot price. The specific test results are omitted, Email:gao_hui1018@163.com.

[2] Since the Beijing Stock Exchange was established on September 3, 2021, the time was relatively short and it was not included in the scope of the study.

the deposit and loan interest rate has not been fully liberalized, and the rapid development of the interbank lending market can reflect the supply and demand of funds in the money market, we select the 7-day period interest rate as the market interest rate variable from the weighted average China inter-bank offered rates (1 day, 7 days, 14 days, 21 days, January, February, March, April, June, September, 1 year)[3], showed as i_t.The MSCI index uses the data of the closing price of the index, the selected data is logarithmic, and the yield of the MSCI index adopts its logarithmic first-order difference, showed as $D\ln msci_t$.

5.1.2 Data Processing and Description

For futures prices, each futures contract will expire at a certain time, for example, domestic crude oil futures contracts are 12 months old, so 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 continuous time series data. Finally, we selected a total of 1039 data on domestic crude oil futures prices, Shanghai Composite Index(SHCI), Shenzhen Component Index(SZCI), China inter-bank offered rates of 7-day(CHIBOR), and MSCI Global Index(MSCI) Continuous Price Daily Data[4]. Period: 2018.3.26-2022.7.5.

Compared to existing studies such as Mohanty et al., Arouri et al. (2012)、Nidhaleddine et al. (2018) and other studies on the relationship between foreign crude oil and foreign stock markets, the time span is relatively long, although the domestic crude oil futures launch time is relatively short, but domestic and foreign crude oil price fluctuations have a certain impact on the domestic stock market after the domestic crude oil futures launch, especially in the past two years, foreign crude oil futures plunged and soared to have a greater impact on the stock market, It is of good practical significance to study the latest impact situation.

The descriptive statistics of the individual variables and the variables yields are given below (see Table 1, Table 2), and the correlation coefficients between the variables and the yields of each variable are given (see Table 3, Table 4).

Table 1. Descriptive statistics for individual Logarithmic variables

	LNP	LNSHI	LNSZI	LNI	LNMSCI
Mean	6.055	8.047	9.330	0.999	6.514
Median	6.099	8.044	9.310	0.987	6.465
Maximum	6.693	8.220	9.678	1.537	6.787
Minimum	5.350	7.810	8.866	0.500	6.132
Std. Dev.	0.267	0.103	0.217	0.185	0.153
Skewness	-0.355	-0.211	-0.221	-0.158	0.297
Kurtosis	2.913	1.9570	1.845	2.695	1.794
Jarque-Bera	22.206	54.772	66.185	8.350	78.257
Probability	0.000	0.000	0.000	0.015	0.000
Sum	6291.459	8360.581	9693.467	1038.991	6767.664
Sum Sq. Dev.	73.861	10.932	48.710	35.545	24.392
Observations	1039	1039	1039	1039	1039

Note: P represents the price of domestic crude oil futures, SHI represents the Shanghai Composite Index, SZI represents the Shenzhen Component Index, I represents China interbank offered weighted 7-day interest rate, MSCI represents the MSCI international index of Morgan Stanley Capital, LN represents the logarithm, and the following is similar. Data: wind.

Table 2. Descriptive statistics of variables yields

	DLNP	DLNSHI	DLNSZI	DLNI	DLNMSCI
Mean	0.001	7.97E-05	1.98-04	-0.001	2.22-04
Median	0.001	2.84-04	2.75-04	0.003	0.001
Maximum	0.097	0.056	0.054	0.382	0.078
Minimum	-0.141	-0.080	-0.088	-0.450	-0.096
Std. Dev.	0.024	0.012	0.015	0.095	0.011

[3] The correlation and causality test of the CHIBR of all periods and the Shanghai Composite Index and the Shenzhen Component Index were used, and the result was that the 7-day interest rate and the stock index were more correlated and had a more significant causal relationship.

[4] Source: Wind Database, Shanghai International Energy Exchange Center website. The data processing and model research was carried out using Eviews10.0 software and JMulTi software.

Skewness	-0.275	-0.625	-0.541	-0.166	-1.270
Kurtosis	5.804	7.762	5.713	3.950	20.461
Jarque-Bera	353.068	1048.271	369.030	43.793	13466.22
Probability	0.000	0.000	0.000	0.000	0.000
Sum	0.520	0.083	0.205	-0.583	0.230
Sum Sq. Dev.	0.619	0.143	0.241	9.276	0.124
Observations	1038	1038	1038	1038	1038

Note: D represents a first-order difference, and the following are similar. Data Source: wind.

Table 3. Correlation coefficients between individual variables

variables	LNP	LNSHI	LNSZI	LNI	LNMSCI
LNP	1				
LNSHI	-0.009	1			
LNSZI	-0.183	0.957	1		
LNI	0.092	-0.416	-0.551	1	
LNMSCI	0.291	0.854	0.828	-0.480	1

Table 4. Correlation coefficients between individual variables yields

variables	DLNP	DLNSHI	DLNSZI	DLNI	DLNMSCI
DLNP	1				
DLNSHI	0.233	1			
DLNSZI	0.171	0.932	1		
DLNI	-0.012	-0.026	-0.044	1	
DLNMSCI	0.190	0.318	0.305	-0.063	1

5.2 Related Test Results

5.2.1 Unit-Root Test

We perform data stationarity tests on the logarithm of selected variables, stationarity tests are commonly used in unit root test methods. This article uses the most commonly used Engle & 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 that the lag order when both values are the minimum is the optimal lag order. The specific test results are as follows:

Table 5. ADF unit root test results for the logarithm of each variable

Variable	Augmented Dickey-Fuller test statistic	Test type (c,t,n)	1% level	5% level	10% level	Durbin-Watson stat	whether or not stable
LNP	-0.973	(c,0,2)	-3.436	-2.864	-2.568	1.999	No
LNSHI	-3.071	(c,t,0)	-3.967	-3.414	-3.129	2.008	No
LNSZI	-2.113	(c,t,0)	-3.967	-3.414	-3.129	1.975	No
LNI	-1.610	(c,0,19)	-3.437	-2.864	-2.568	2.000	No
LNMSCI	-2.201	(c,t,10)	-3.967	-3.414	-3.129	2.001	No
ΔLNP	-21.296	(0,0,1)	-2.567	-1.941	-1.616	1.999	Yes
ΔLNSHI	-32.567	(0,0,0)	-2.567	-1.941	-1.616	1.996	Yes
ΔLNSZI	-31.944	(0,0,0)	-2.567	-1.941	-1.616	1.997	Yes
ΔLNI	-11.694	(0,0,18)	-2.567	-1.941	-1.616	2.000	Yes
ΔLNMSCI	-9.724	(0,0,9)	-2.567	-1.941	-1.616	2.002	Yes

Note: Δ represents the first-order difference, (c, t, n) in c represents the intercept, t represents the time trend, and n represents the order of lag.

The results of the unit root test show that the logarithmic series of the variable time series data selected by us are non-stationary series at the critical values of 1%, 5%, and 10%. The first-order differential series of the time series data for each variable are stationary series at the 1%, 5%, and 10% critical values, so the variable series we select are all stationary series with a unit root.

5.2.2 Granger Causality Test

We perform Granger causality test on the selected variables, because the causality test is more sensitive to the lag order, in the actual test, according to the AIC, SC criterion, when the value of the two is the smallest is the best lag order. The specific test results are as follows:

Table 6. Causal relationship test between variables

Null Hypothesis	Sample	F-Statistic	Prob.
LNSHI does not Granger Cause LNP	1035	1.746	0.138
LNP does not Granger Cause LNSHI		2.218	0.065
LNSZI does not Granger Cause LNP	1035	1.047	0.382
LNP does not Granger Cause LNSZI		3.394	0.009
LNI does not Granger Cause LNSHI	1038	13.338	0.0003
LNSHI does not Granger Cause LNI		3.158	0.076
LNMSCI does not Granger Cause LNSHI	1035	8.542	9.E-07
LNSHI does not Granger Cause LNMSCI		2.863	0.022
LNI does not Granger Cause LNSZI	1036	4.481	0.004
LNSZI does not Granger Cause LNI		2.187	0.088
LNMSCI does not Granger Cause LNSZI	1035	4.502	0.001
LNSZI does not Granger Cause LNMSCI		2.162	0.071

From the above Table 6 causality test results, it can be seen that at the significance level of 10%, the domestic crude oil futures price has a one-way guiding effect on the domestic Shanghai and Shenzhen stock indexes, and the guiding effect on the Shenzhen Component Index is greater than that of the Shanghai Composite Index. The CHIBOR has a strong two-way guiding effect with the Shanghai and Shenzhen stock index at a significant level of 10%, of which the guiding effect on the Shanghai Composite Index is greater than that of the Shenzhen Component Index. The MSCI Index has a two-way guiding role with the domestic Shanghai and Shenzhen stock index at a significance level of 10%, of which the guiding effect of the MSCI on the Shanghai and Shenzhen stock index is greater than that of the Shanghai and Shenzhen stock index.

Table 7. Causal relationship test between the various differential variables

Null Hypothesis	Sample	F-Statistic	Prob.
DLNP does not Granger Cause DLNSHI	1034	1.673	0.154
DLNSHI does not Granger Cause DLNP		1.507	0.198
DLNI does not Granger Cause DLNSHI	1034	0.360	0.837
DLNSHI does not Granger Cause DLNI		0.837	0.502
DLNMSCI does not Granger Cause DLNSHI	1034	6.858	2.E-05
DLNSHI does not Granger Cause DLNMSCI		2.214	0.066
DLNP does not Granger Cause DLNSZI	1034	2.451	0.045
DLNSZI does not Granger Cause DLNP		1.128	0.342
DLNI does not Granger Cause DLNSZI	1034	0.803	0.523
DLNSZI does not Granger Cause DLNI		1.119	0.346
DLNMSCI does not Granger Cause DLNSZI	1034	4.502	0.001
DLNSZI does not Granger Cause DLNMSCI		1.154	0.330

From the above Table 7 test results, it can be seen that at the significance level of 10%, the domestic crude oil futures price yield has a strong one-way guiding effect on the Shenzhen component index yield, and the guiding effect on the Shanghai Composite Index yield is weak. The MSCI yield and the Shanghai Composite Index yield have a two-way guiding effect, and have a one-way guiding effect on the Shenzhen Component Index yield. The CHIBR yield does not play a guiding role between the two domestic stock indexes yield at a significant level of 10%.

5.2.3 Cointegration Relaition Test

From the above Granger causality test, we can see that the domestic crude oil futures price, the CHIBOR and the MSCI index are all Granger reasons for the Shanghai and Shenzhen stock indexes, which we regard as endogenous variables, so we select the domestic crude oil futures price, CHIBOR and MSCI index and the Shanghai and Shenzhen stock indexes to test long-term cointegration relationship.

First, we use Johansen (1988) based on the MLE Test to test the cointegration relationship between the Shanghai Composite Index and the domestic crude oil futures price, CHIBOR and the MSCI Index, and select the lag order from 1 to 2 by testing, and determine whether there is a cointegration relationship based on the Johansen feature root maximum statistic and trace statistic (see Table 8 for the specific test results).

Table 8. Cointegration relationship test between the Shanghai Composite Index and other variables

Cointegration Trace testing					Cointegration Maximum Eigenvalue test			
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**	Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value
None *	0.030	46.503	40.175	0.010	0.030	32.089	24.159	0.003
At most 1	0.010	14.414	24.276	0.503	0.010	10.238	17.780	0.461
At most 2	0.004	4.176	12.321	0.685	0.004	4.145	11.225	0.605
At most 3	2.96E-05	0.031	4.130	0.886	2.96E-05	0.031	4.1299	0.886

Note: Test indicates 1 cointegrating eqn(s) at the 0.05 level. * denotes rejection of the hypothesis at the 0.05 level,**MacKinnon-Haug-Michelis (1999) p-values.

Both test results show that at the 5% significance level, there is a cointegration relationship between the Shanghai Composite Index and domestic crude oil futures prices, CHIBOR and the MSCI Index.

According to the SC and AIC criteria to determine the equation form of the optimal lag order, the cointegration equation corresponding to the maximum feature root is selected as follows (no trend, no intercept, standard deviation in parentheses):

$$LNSHI=-0.260\ LNP+1.003\ LNI+\ 1.324\ LNMSCI \tag{9}$$

$$(0.105)\qquad (0.146)\qquad\qquad (0.092)$$

From the above cointegration equation (9), it can be concluded that in the long run, when the domestic crude oil futures price, CHIBOR and the MSCI index rose by 1 percentage point, the Shanghai Composite Index fell by 0.260 percentage points, rose by 1.003 percentage points and rose by 1.324 percentage points, respectively.

Secondly, we also use Johansen's (1988) MLE Test to test the cointegration relationship between the Shenzhen Component index and the domestic crude oil futures price, CHIBOR and the MSCI index, select the lag order from 1 to 3 by testing, and judge whether there is a cointegration relationship according to the Johansen feature root maximum statistic and trace statistic (see Table 9 for the specific test results).

Table 9. Cointegration relationship test between the Shenzhen component index and other variables

Cointegration Trace testing					Cointegration Maximum Eigenvalue test			
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**	Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value
None *	0.030	55.016	54.079	0.041	0.030	31.821	28.588	0.019
At most 1	0.012	23.195	35.193	0.515	0.012	12.267	22.300	0.629
At most 2	0.008	10.928	20.262	0.549	0.008	8.325	15.892	0.509
At most 3	0.003	2.603	9.165	0.657	0.003	2.603	9.165	0.657

Note: Test indicates 1 cointegrating eqn(s) at the 0.05 level. * denotes rejection of the hypothesis at the 0.05 level, **MacKinnon-Haug-Michelis (1999) p-values .

The above two test results show that at the 5% significance level, there is a cointegration relationship between the Shenzhen Component index and the domestic crude oil futures price, the CHIBOR and the MSCI index.

According to the SC and AIC criteria, the equation form of the optimal lag order is determined, and the cointegration equation corresponding to the maximized feature root is selected as follows (the intercept is included in no trend, and the standard deviation is represented in parentheses):

$$LNSZI=\ -0.270LNP-0.999\ LNI+0.678\ LNMSCI+7.537 \tag{10}$$

$$(0.111)\qquad (0.189)\qquad (0.221)\qquad (1.420)$$

From the above cointegration equation(10), it can be concluded that in the long run, when the domestic crude oil futures price, the CHIBOR and the MSCI index rose by 1 percentage point, the Shenzhen component index fell by 0.270 percentage points, fell by 0.999 percentage points, and rose by 0.678 percentage points, respectively.

5.3 Empirical STR Model Results

5.3.1 Nonlinearity Test and Determination of Transition Functions

STR model nonlinear test involves the selection of lag order, we use the linear model in the VAR model lag order selection method, starting from the maximum lag order 8th order, according to AIC, SC and other criteria, the final selection of Shanghai and Shenzhen stock market yield model the best lag order is 3rd order, 4th order, respectively

According to the research method of Teräsvirita (1998) the form of the selection of nonlinear equations was determined. By performing a recursive Lagrang multiplier test on the STR model to determine the form of the transition function, the nonlinear specific test results of the shanghai and shenzhen stock market yield models are as follows[5]:

Table 9. Nonlinear test results of the yield model of the Shanghai and Shenzhen stock markets

	Transition variable	F	F4	F3	F2	model suggested
shanghai stock market yield	dlnp(t)	2.8200e-07	2.5201e-02	2.2056e-01	6.0400e-08	LSTR1
	dlnp(t-1)	9.7017e-03	1.3615e-02	3.1476e-02	5.5395e-01	LSTR1
	dlnp(t-2)	3.9957e-04	2.7515e-01	4.4375e-04	3.7329e-02	LSTR2
	dlnp(t-3)*	9.5688e-08	6.1551e-02	1.4985e-04	5.7213e-05	LSTR1
shenzhen stock market yield	dlnp(t)*	2.0339e-13	2.0788e-05	5.9640e-09	1.6675e-02	LSTR2
	dlnp(t-1)	1.1118e-03	8.4983e-02	4.8445e-03	7.0960e-02	LSTR2
	dlnp(t-2)	6.2574e-02	7.6738e-02	2.0288e-01	2.8980e-01	Linear
	dlnp(t-3)	5.1866e-01	2.0285e-01	7.9621e-01	5.1460e-01	Linear
	dlnp(t-4)	2.5734e-01	4.7696e-01	5.0111e-01	1.1248e-01	Linear

Note: F, F4, F3, and F2 represent statistics under the H0, H4, H3, and H2 assumptions, respectively (H0 is the linear hypothesis: $\beta_1=\beta_2=\beta_3=0$；H2：$\beta_3=0$；H3：$\beta_2=0|\beta_3=0$；H4：$\beta_1|\beta_2=\beta_3=0$， If the test for H3 is P-value compared to the strongest rejection, the LSTR2 model is selected, and if the strongest rejection H4 is selected, the LSTR model is selected), and the corresponding number in each column is the probability p-value of the F statistic, * indicating that the test results are significant.

For the Shanghai Composite index yield model, the test results show that the third-order lag dlnp(t-3) of the logarithmic difference of domestic crude oil futures prices has a nonlinear effect, and the model suggests LSTR1, and the original series does not have a nonlinear effect.

For the Shenzhen Component index yield model, the test results show that the domestic crude oil futures price has a nonlinear effect in the logarithmic difference dlnp(t) in the current period, and the model recommends LSTR2, and the original series does not have a nonlinear effect.

5.3.2 Shanghai Composite Index Yield STR Model Estimation

In order to further characterize the change trend and specific path of the impact mechanism of domestic crude oil futures price fluctuations on the Shanghai stock market, the above model is further estimated. After determining the transition variables and the model form, the smoothing parameters γ and threshold c in the transition function are estimated. The smoothing parameters γ and the initial values of threshold c in the Shanghai stock index yield model transition function are determined by using the two-dimensional lattice point search method, and the smoothing parameters γ interval is [0.50, 10.0], and the interval of position parameter c is [-0.088,0.054] to obtain the smoothing parameters γ and the initial values of threshold c are 1.915 and -0.024, respectively (see Figure 6 and Figure 7 below), using these two initial values, using the Newton-Raphson iterative method, maximizing the likelihood function. Calculate the parameter estimates for the model (see Table 10).

5 The nonlinear test is completed by Jmulti software, first the processed data is stored into xls form file, the required data is extracted through the import data function in the software, the date format of the data is set after the data extraction is successful, the variables are renamed according to the needs of the study through the rename function, and the relevant tests are carried out according to subsequent requirements after completion.

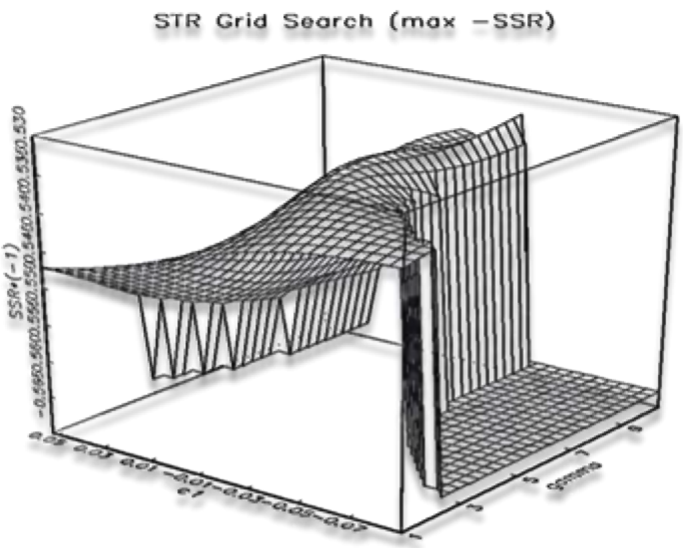

Figure 6. Shanghai Composite index yelds STR model grid point search graph

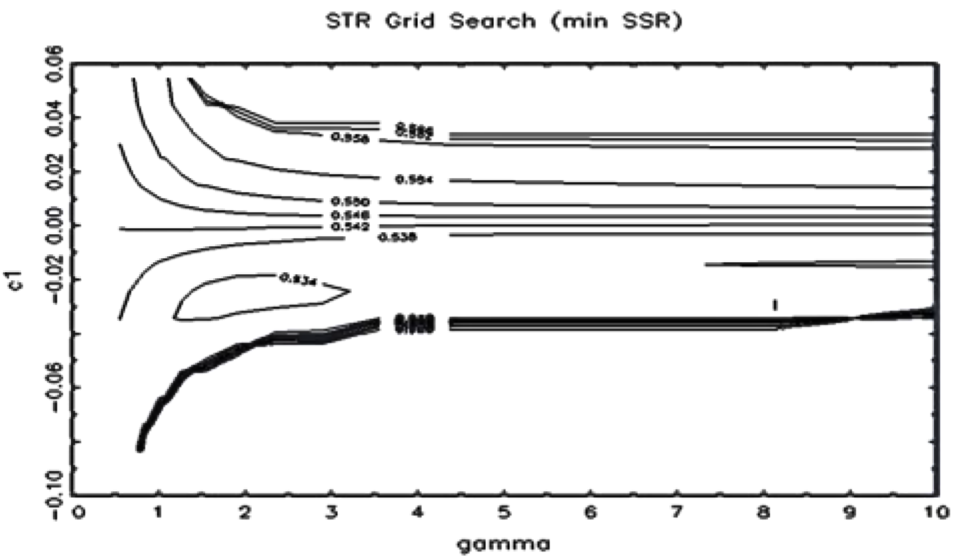

Figure7. Shanghai Composite index yelds STR model grid point search contour chart

Table 10. Shanghai Composite index yelds STR model Estimation

variable	start	estimate	SD	t-stat	p-value
		----- linear part ------			
CONST	0.019	0.022	0.017	1.255	0.210
dlnshi(t-3)	-0.470	-0.516	0.214	-2.410	0.016
dlnp(t)	0.831	0.893	0.331	2.702	0.007
dlni(t)	-0.061	-0.069	0.058	-1.195	0.232
dlnmsci(t-1)	-1.135	-1.248	0.582	-2.144	0.032
dlni(t-1)	-0.050	-0.054	0.059	-0.907	0.365
dlnp(t-2)	0.357	0.375	0.250	1.504	0.133
dlnmsci(t-2)	0.356	0.374	0.305	1.228	0.220
dlni(t-2)	-0.073	-0.084	0.069	-1.260	0.208

dlnp(t-3)	0.379	0.444	0.411	1.081	0.280
dlnmsci(t-3)	1.556	1.659	0.515	3.225	0.001
	---- nonlinear part ----				
CONST	-0.020	-0.023	0.019	-1.213	0.225
dlnshi(t-1)	-0.003	-0.003	0.035	-0.089	0.929
dlnshi(t-2)	0.022	0.022	0.034	0.645	0.519
dlnshi(t-3)	0.518	0.566	0.232	2.443	0.015
dlnp(t)	-0.767	-0.832	0.357	-2.330	0.020
dlnmsci(t)	0.382	0.383	0.085	4.481	0.000
dlni(t)	0.068	0.076	0.063	1.202	0.230
dlnp(t-1)	-0.049	-0.048	0.058	-0.837	0.403
dlnmsci(t-1)	1.645	1.761	0.614	2.866	0.004
dlni(t-1)	0.053	0.057	0.065	0.874	0.382
dlnp(t-2)	-0.343	-0.362	0.279	-1.297	0.195
dlnmsci(t-2)	-0.232	-0.253	0.350	-0.723	0.470
dlni(t-2)	0.084	0.096	0.072	1.330	0.184
dlnp(t-3)	-0.329	-0.388	0.371	-1.047	0.295
dlnmsci(t-3)	-1.693	-1.800	0.541	-3.324	0.001
dlni(t-3)	0.015	0.015	0.010	1.630	0.103
γ	1.915	1.764	0.640	2.757	0.006
C1	-0.024	-0.026	0.006	-4.190	0.000
AIC			-7.514e+00		
SC			-7.375e+00		
HQ			-7.461e+00		
R2			1.358e-01		
adjusted R2			0.137		
variance of transition variable			0.0002		
SD of transition variable			0.015		
variance of residuals			0.001		
SD of residuals			0.023		

As can be seen from the estimation results of Table 10, 93.1% of the p-values estimated by the parameters are less than 0. 5, the model estimation effect is good, from the above table results can determine the specific model equations as follows:

$$\begin{aligned} d\ln shi_t &= 0.022 - 0.516 d\ln shi_{t-3} + 0.893 d\ln p_t + 0.375 d\ln p_{t-2} + 0.444 d\ln p_{t-3} - 0.069 d\ln i_t - 0.054 d\ln i_{t-1} - 0.084 d\ln i_{t-2} \\ & -1.248 d\ln msci_{t-1} + 0.374 d\ln msci_{t-2} + 1.659 d\ln msci_{t-3} + (-0.023 - 0.003 d\ln shi_{t-1} + 0.022 d\ln shi_{t-2} + 0.566 d\ln shi_{t-3} - \\ & 0.832 d\ln p_t - 0.048 d\ln p_{t-1} - 0.362 d\ln p_{t-2} - 0.388 d\ln p_{t-3} + 0.076 d\ln i + 0.057 d\ln i_{t-1} + 0.096 d\ln i_{t-2} + 0.015 d\ln i_{t-3} + \\ & 0.383 d\ln msci_t + 1.761 d\ln msci_{t-1} - 0.253 d\ln msci_{t-2} - 1.800 d\ln msci_{t-3}) G\left(d\ln p_{t-1}, \gamma, c\right) + \varepsilon_t \end{aligned} \tag{11}$$

where the transition function is as follows:

$$G\left(d\ln p_{t-3}; \gamma, c\right) = \left[1 + \exp\left\{-1.764\left(d\ln p_{t-3} + 0.026\right)\right\}\right]^{-1} \tag{12}$$

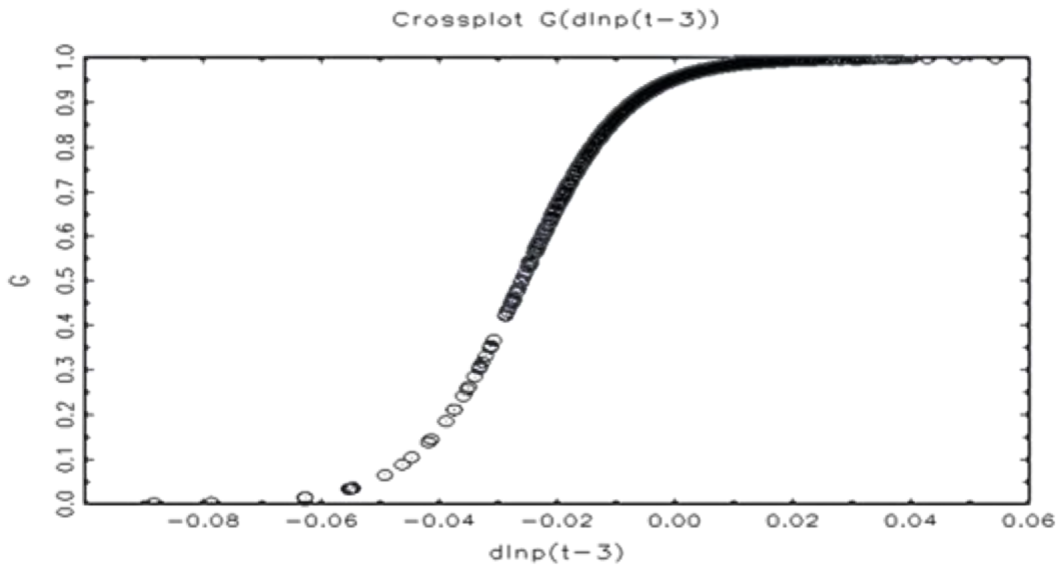

Figure 8. Scatter plot of the G function of the Shanghai Composite index yelds STR model

As can be seen from the above estimate results, the C1 estimate in the model is -0.026, indicating that when the transition variable dlnp(t-3) is less than the threshold value of -0.026, the transition function value is close to 0, and the nonlinear influence in the model disappears, at this time, there is only a linear relationship between the domestic crude oil futures price yield and the Shanghai Composite index yield, and the volatility of the stock index yield is greatly affected by the current and lagging phases II and III of the domestic crude oil futures prices yield and the yield lag of the MSCI index in the first and third phases. The current and lag phases of the domestic crude oil futures price yield have a positive pulling effect on the current stock index yield fluctuations, and the cumulative pull effect of each unit on the stock index yield is about 1.712 units. The three lag periods of the MSCI Index yield have a greater impact on the stock index yield, but the cumulative impact is smaller, and the cumulative pull effect of each unit on the stock index yield is about 0.785 units. The impact of the CHIBR yield on the Shanghai Composite index yield is relatively small, and the cumulative pull effect of each unit on the Shanghai Composite index yield is about -0.207 units. When the transition variable dlnp(t-3) is greater than the threshold value of -0.026, the nonlinear influence in the model begins to appear, and the impact of the nonlinear part on the domestic Shanghai Composite index yield increases with the increase of the transition variable value, which shows that the domestic crude oil futures price yield bigger fluctuation intensified the impact of the non-linear part on the Shanghai market yield fluctuations. The γ value of the model smoothing transition coefficient in the table is 1.764, which is a small value, indicating that the two mechanisms in the model are less faster.

It can be calculated from the model that the long-term positive impact of the crude oil futures price yield on the Shanghai Composite index yield is as follows:

$$\left(\sum_{j=0}^{n}\beta_{1j}+\sum_{j=0}^{n}\phi_{1j}\right)\Big/\left(1-\sum_{j=1}^{n}\lambda_{1j}\right)=（0.893+0.375+0.444-0.832-0.048-0.362-0.388/（1+0.516）=0.054 \quad (13)$$

It can be calculated from the model that the long-term negative impact of crude oil price yield on Shanghai Composite index yield is as follows:

$$\sum_{j=0}^{n}\beta_{1j}\Big/\left(1-\sum_{j=1}^{n}\lambda_{1j}\right)=（0.893+0.375+0.444）/（1+0.516）=1.130 \quad (14)$$

It can be seen that the positive and negative impact of the crude oil futures price yield on the Shanghai Composite index yield is asymmetrical, and the negative impact of the crude oil futures price yield is greater than the positive impact, and in general, the negative impact on the domestic Shanghai market is larger.

The above LSTR1 model can better reflect the non-linear asymmetric relationship between the domestic crude oil futures price yield and the Shanghai Composite index yield fluctuations, and the actual value and the fitted value have a goodness of fit, and the following gives the model actual value and the fitted value graph (see figure 9)

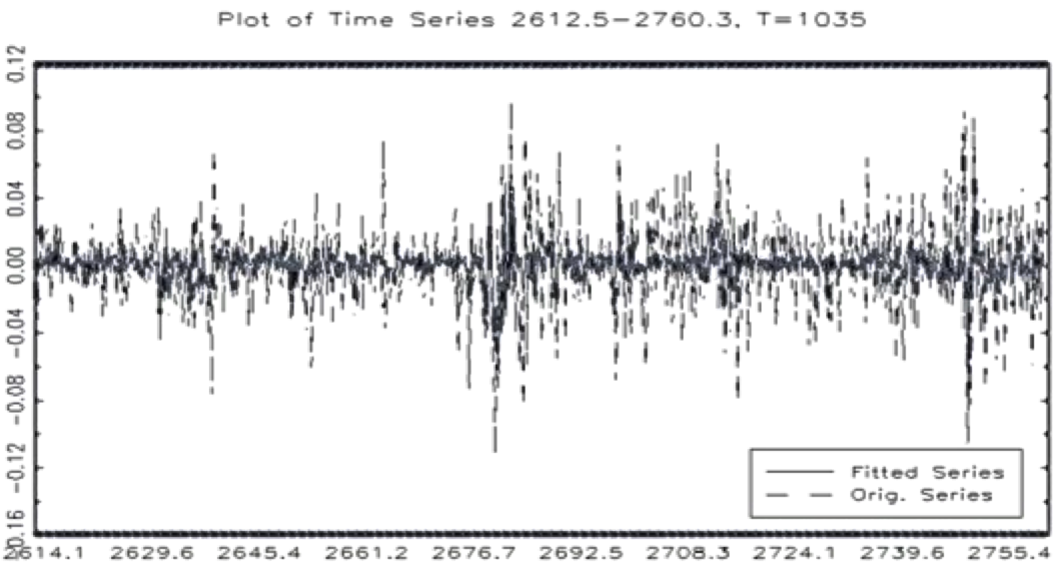

Figure 9. Shanghai Composite index yield actual value and fitted value chart

5.3.3 Shenzhen Component Index STR Model Estimation

In order to further characterize the change trend and specific path of the impact mechanism of domestic crude oil futures price fluctuations on the domestic Shenzhen stock market, the above model is further estimated. After determining the transition variables and the model form, the smoothing parameters γ and threshold c in the transition function are estimated. The smoothing parameters γ and the initial values of the thresholds c1 and c2 are determined by using the two-dimensional lattice point search method, and the smoothing parameters γ intervals are [0.500, 10.000], and the interval of position parameter c is [-0.088,0.054], the smoothing parameters γ and the initial values of the thresholds c1 and c2 are 10.000, -0.029, 0.040, respectively (see Figure 10 and Figure 11 below), using these two initial values. Using the Newton-Raphson iterative method, the maximum likelihood function of the model is calculated, and the estimated parameters of the model are calculated (see Table 11).

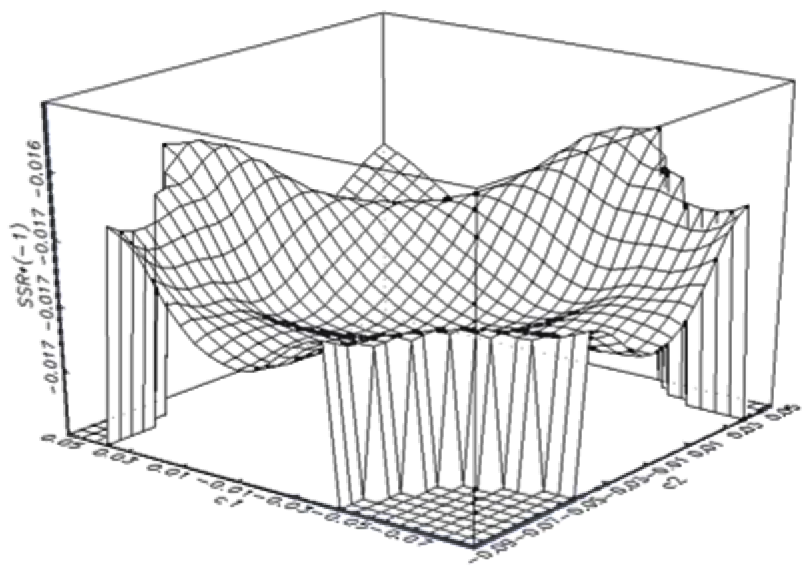

Figure 10. Shenzhen Component index yield STR model Grid point Search graph

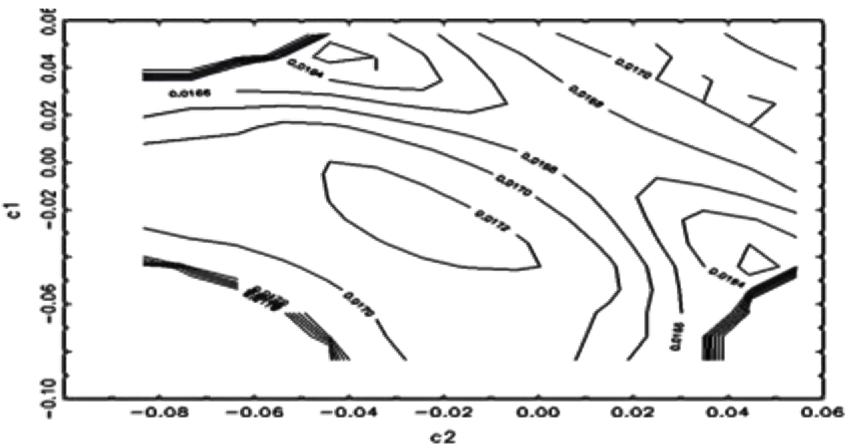

Figure 11. Shenzhen Component index yield STR model grid point search contour plot

Table 11. Shenzhen Component index yield STR model Estimation

variable	start	estimate	SD	t-stat	p-value
		----- linear part ------			
dlnszi(t-2)	0.060	0.063	0.030	2.096	0.036
dlnszi(t-3)	-0.021	-0.020	0.030	-0.660	0.510
dlnszi(t-4)	0.020	0.021	0.030	0.676	0.499
dlnp(t)	0.677	0.676	0.010	65.668	0.000
dlnmsci(t)	0.049	0.048	0.013	3.698	0.000
dlni(t-1)	-0.002	-0.002	0.002	-1.251	0.211
dlnmsci(t-1)	0.034	0.034	0.012	2.852	0.004
dlnp(t-2)	-0.030	-0.031	0.023	-1.344	0.179
dlni(t-2)	-0.003	-0.003	0.002	-2.244	0.025
dlnmsci(t-2)	0.011	0.012	0.013	0.879	0.380
dlnp(t-3)	0.021	0.020	0.023	0.846	0.398
dlnmsci(t-3)	0.014	0.014	0.013	1.070	0.285
dlnp(t-4)	-0.031	-0.030	0.023	-1.294	0.196
dlnmsci(t-4)	-0.015	-0.015	0.013	-1.218	0.224
		---- nonlinear part ----			
CONST	0.001	0.001	0.001	0.782	0.434
dlnszi(t-1)	-0.432	-0.505	0.194	-2.606	0.009
dlnszi(t-3)	0.603	0.551	0.197	2.794	0.005
dlnszi(t-4)	-0.440	-0.339	0.167	-2.026	0.043
dlnp(t)	0.120	0.118	0.034	3.455	0.001
dlni(t)	0.046	0.051	0.016	3.245	0.001
dlnmsci(t)	0.132	0.119	0.071	1.683	0.093
dlnp(t-1)	0.602	0.656	0.198	3.320	0.001
dlni(t-1)	-0.021	-0.019	0.009	-2.181	0.029
dlnp(t-2)	0.028	0.018	0.047	0.393	0.695
dlni(t-2)	-0.014	-0.015	0.013	-1.208	0.228
dlnmsci(t-2)	-0.087	-0.084	0.072	-1.169	0.243
dlnp(t-3)	-0.576	-0.515	0.145	-3.565	0.001
dlni(t-3)	-0.013	-0.011	0.010	-1.106	0.269
dlnp(t-4)	0.496	0.368	0.129	2.853	0.004
dlni(t-4)	-0.018	-0.016	0.011	-1.456	0.146
γ	10.000	51.952	272.583	0.191	0.849
C1	-0.029	-0.028	0.001	-43.433	0.000
C2	0.040	0.039	0.001	32.131	0.000
AIC	-1.103e+01				
SC	-1.087e+01				
HQ	-1.097e+01				
R2	8.898e-01				
adjusted R2	0.890				
variance of transition variable	0.0002				
SD of transition variable	0.015				
variance of residuals	0.000				
SD of residuals	0.004				

From the estimation results of Table 11 above, it can be seen that 91.0% of the p-values estimated by the parameters are less than 0. 5, the model estimate effect is good. The results from the above table can determine the specific model equations as follows:

$$
\begin{aligned}
d\ln szi_t &= 0.063d\ln szi_{t-2} - 0.020d\ln szi_{t-3} + 0.020d\ln szi_{t-4} + 0.676d\ln p_t - 0.031d\ln p_{t-2} + 0.020d\ln p_{t-3} \\
&-0.030d\ln p_{t-4} - 0.002d\ln i_{t-1} - 0.003d\ln i_{t-2} + 0.048d\ln msci_t + 0.034d\ln msci_{t-1} + 0.012d\ln msci_{t-2} + 0.014d\ln msci_{t-3} \\
&-0.015d\ln msci_{t-4} + (0.001 - 0.505d\ln szi_{t-1} + 0.551d\ln szi_{t-3} - 0.339d\ln szi_{t-4} + 0.118d\ln p_t + 0.656d\ln p_{t-1} + 0.018d\ln p_{t-2} \\
&-0.515d\ln p_{t-3} + 0.368d\ln p_{t-4} + 0.051d\ln i_t - 0.019d\ln i_{t-1} - 0.015d\ln i_{t-2} - 0.011d\ln i_{t-3} - 0.016d\ln i_{t-4} + 0.119d\ln msci_t \\
&-0.084d\ln msci_{t-2})G\left(d\ln p_{t-1}, \gamma, c\right) + \varepsilon_t
\end{aligned}
\quad (15)
$$

The transition functions is as follows:

$$
G\left(d\ln p_t, \gamma, c\right) = \left[1 + \exp\left\{-272.583\left(d\ln p_t + 0.028\right)\left(d\ln p_t - 0.039\right)\right\}\right]^{-1} \quad (16)
$$

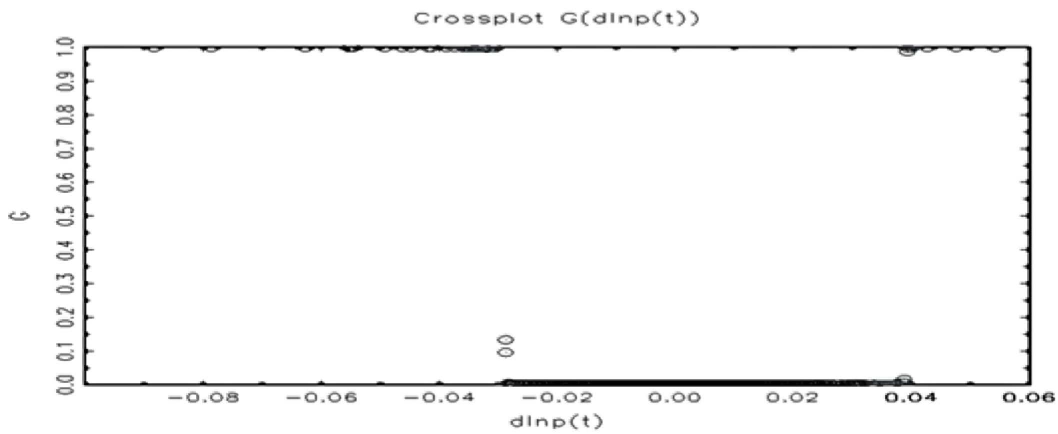

Figure 12. Shenzhen Component index yield STR model G function Scatter plot

From the above model estimation results, we can see that the parameter of the γ is 272.583, indicating that the transition speed of the model system is relatively large, when the current period of crude oil futures price yield is selected as the transition variable, there are two positional parameters, the model has three transition mechanisms (see Figure 12), when dlnp(t) = 0.005, the transition function G = 0, the nonlinear part of the model disappears, showing a linear form, you can see, crude oil futures price current period and lag 2, 3, 4-period yield has different effects on the Shenzhen Component index yield, with a cumulative effect of 0.691.The impact of CHIBR yield and MSCI index yield on the Shenzhen Component index yield is relatively small, and the cumulative impact is -0.005 and 0.078 respectively, so the yield on crude oil futures prices shows a strong positive correlation with the yield on the Shenzhen Component index yield. When the transition variable dlnp(t) is in the range [-0.028, 0.039], the transition function G=0.5, the crude oil futures price yield has a nonlinear effect on the Shenzhen Component index yield, when the transition variable dlnp(t) is less than -0.028 or greater than 0.039, the transition function is converted to 1, and the nonlinear impact in the model gradually increases.

It can be calculated from the model that the long-term positive impact of the crude oil futures price yield on the Shenzhen Component index yield is as follows:

$$
\left(\sum_{j=0}^{m}\beta_{2j} + \sum_{j=0}^{m}\phi_{2j}\right)\Big/\left(1 - \sum_{j=1}^{m}\lambda_{2j}\right) =
$$

（0.676-0.031+0.020-0.030+0.118+0.656+0.018-0.515+0.368）/（1-0.063+0.020-0.021）=1.368 (17)

It can be calculated from the model that the long-term negative impact of the crude oil futures price yield on the shenzhen Component index yield is as follows:

$\sum_{j=0}^{m}\beta_{2j}\Big/\left(1 - \sum_{j=1}^{m}\lambda_{2j}\right) =$（0.676-0.031+0.020）/（1-0.063+0.020-0.021）=0.710 (18)

It can be seen that the impact of crude oil futures price yield on the yield of Shenzhen Component index yield is non-linear asymmetric, and there is nonlinear asymmetry in the positive and negative impact of crude oil futures price yield, and the long-term positive impact is greater than the long-term negative shock impact, and the difference between the two is nearly twice.

The above LSTR2 model can better reflect the non-linear asymmetric relationship between the domestic crude oil futures price yield and the Shenzhen Component index yield fluctuations, and the actual value and the fitted value have a better goodness of fit, and the following gives the model actual value and the fitted value graph as follows(see figure 13).

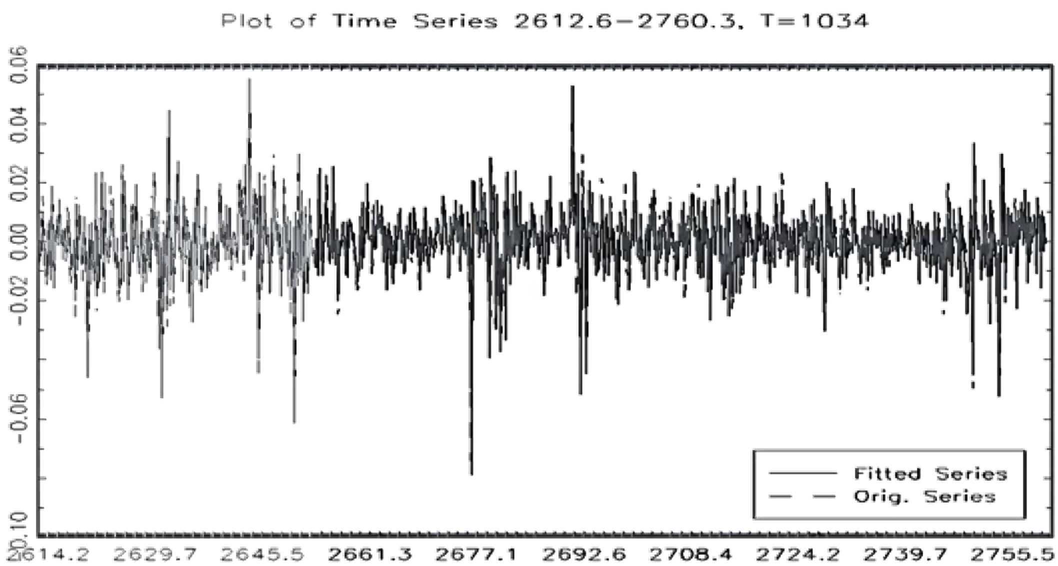

Figure 13. Shenzhen Component Index Yield Actual and Fitted Value Chart

6. Conclusion

Based on the daily data from March 2018 to July 2022, this paper studies the influence of domestic crude oil futures prices on domestic Shanghai and Shenzhen stock markets through Granger causality, cointegration test and STR model. The results of the causality test show that the domestic crude oil futures price has a one-way guiding effect on the domestic Shanghai and Shenzhen stock index, and the guiding effect on the Shenzhen Composite Index is greater than that of the Shanghai Composite Index. From the perspective of yield, the domestic crude oil futures price yield has a strong one-way guiding effect on the Shenzhen Component Index, and the guiding effect on the Shanghai Composite Index is weak. The CHIBR, the MSCI Index and the domestic Shanghai and Shenzhen stock indexes have a two-way guiding role. From the perspective of yield, the yield of the MSCI Index and the yield of the domestic Shanghai Composite Index have a two-way guiding effect, and have a one-way guiding effect on the Shenzhen Component Index yield. There is no guiding role between the CHIBR yield and the domestic two stock indexes yield.

The results of the cointegration test show that there is a long-term cointegration relationship between the domestic crude oil futures price and the domestic Shanghai and Shenzhen stock indexes, in the long run, when the domestic crude oil futures price, the CHIBR and the MSCI index rose by 1 percentage point, the Shanghai Composite Index fell by 0.260 percentage points, rose by 1.003 percentage points and rose by 1.324 percentage points respectively. In the long run, when the domestic crude oil futures price, the CHIBR and the MSCI index rose by 1 percentage point, the Shenzhen Component Index fell by 0.270 percentage points, fell 0.999 percentage points and rose by 0.678 percentage points respectively. Therefore, in the long run, crude oil futures prices have a similar negative impact on the Shanghai and Shenzhen stock markets indexes.

STR model constructed by the Shanghai and Shenzhen stock market indexes yield empirically analyzes the mechanism of the domestic crude oil futures price yield on the domestic stock index yield, and concludes that the crude oil futures price yield has a nonlinear effect on the Shanghai and Shenzhen stock market indexes yields, but the mechanism of the impact is different, for the Shanghai Composite index yield, the third-order lag in the domestic crude oil futures price yield has a nonlinear effect, and for the Shenzhen component index yield, the domestic crude oil futures price yield has a nonlinear effect in the current period. The two have different forms of transition functions.

The nonlinear influence of the crude oil futures price yield on the domestic Shanghai Composite index yield as follows: when the transition variable is less than the threshold value, the nonlinear effect in the model disappears, at this time there is only a linear relationship between the domestic crude oil futures price yield and the domestic Shanghai Composite index yield, the stock index yield fluctuation is greatly affected by the current period and the lag of the domestic crude oil price yield phase II and III, and the domestic crude oil futures price yield current period and lag phase II and phase III have a positive pulling effect on the current stock index yield fluctuations. The cumulative pull effect of each unit on the stock index yield is about 1.712 units. When the transition variable is greater than the threshold value, the nonlinear influence in the model begins to appear, and the impact of the nonlinear part on the domestic Shanghai Composite index yield increases with the increase of the transition variable value, which shows that the domestic crude oil futures price yield fluctuation intensified the impact of the non-linear part on the Shanghai market yield fluctuations, and the transition speed of the two mechanisms was small.

Nonlinear influence of crude oil futures price yield on domestic Shenzhen Component index yield as follows: There are three transition mechanisms, when the transition variable is the average of high and low threshold values, it shows a linear form, and the yield of crude oil futures prices in the current period and lag 2, 3 and 4 has different effects on the yield of Shenzhen Component index yield, the cumulative impact is 0.691, and the yield on crude oil futures prices shows a strong positive relationship with the yield of Shenzhen Component index. When the transition variable is in the high and low threshold range, the crude oil futures price yield has a nonlinear impact on the Shenzhen Component index yield, when the transition variable is outside the high and low threshold range, the nonlinear impact gradually increases, of which the model system transition speed is relatively large,

Therefore, the non-linear asymmetric impact of crude oil futures price yield on Shanghai and Shenzhen stock market index yields is different, the positive and negative impact of crude oil futures price yield on Shanghai Composite index yield is nonlinear asymmetrical, the negative impact of crude oil futures price yield is greater than the positive shock impact, and overall, the negative impact on the Shanghai Composite index yield is greater. The positive and negative impact of the crude oil futures price yield on the Shenzhen Component index yield is also non-linear and asymmetrical, however, the positive shock impact of the crude oil futures price yield is greater than the negative shock impact, and in general, the positive impact on the Shenzhen Component index yield is larger, and the difference between the two is nearly twice.

In short, the nonlinear impact of the yield of domestic crude oil futures prices has a certain impact on the domestic stock market, but the risk of oil price fluctuation impact faced by the domestic stock market mainly comes from the international crude oil market. Although the domestic crude oil futures market has become the third largest crude oil futures market in the world from the perspective of trading volume and position volume, it is still lagging behind WTI and Brent crude oil futures markets from the perspective of international pricing power and influence. For domestic crude oil futures prices to become the global crude oil price benchmark, it is necessary to continuously improve the institutional mechanism. First of all, under the regulation of laws and regulations such as the Futures Law, the continuous regulation of the operation of the futures market is conducive to attracting more mature international investors to enter the domestic crude oil futures market. Secondly, give full play to the "five-in-one" market supervision, reduce market risks as much as possible, and help the internationalization of the domestic crude oil futures market. Third, from the perspective of the exchanges, the futures exchanges should continuously optimize the market operation rules of international futures varieties, actively promote "going out" and "bringing in" in the process of opening up the futures market, continuously optimize the investor structure, promote the rational layout of the global delivery library of domestic crude oil futures, and attract more international institutions to enter the domestic market. Finally, from the perspective of market system construction, the establishment of a crude oil market system integrating spot and forward, on-site and off-site, enhances the pricing power and influence of domestic crude oil futures, better mitigates the impact of crude oil price fluctuations on the domestic stock market, and brings a positive impact on the healthy development of the domestic securities and futures market and the steady operation of the national economy.

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