Hindawi
Complexity
Volume 2022, Article ID 5367693, 12 pages
https://doi.org/10.1155/2022/5367693

Research Article

The Catastrophe Analysis of Shanghai Crude Oil Futures Price from the Perspective of Volatility Factors

Weifeng Gong[1,2] **Yahui Li**[3] **Chuanhui Wang**[1] **Haixia Zhang**[1] **and Zhengjie Zhai**[1]

[1]*School of Economics, Qufu Normal University, Rizhao 276826, China*
[2]*School of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing 211006, China*
[3]*Liaocheng Municipal Tax Service, State Taxation Administration, Liaocheng 252000, China*

Correspondence should be addressed to Chuanhui Wang; chhwang001@163.com

Received 15 August 2021; Revised 12 November 2021; Accepted 4 February 2022; Published 21 March 2022

Academic Editor: M. M. El-Dessoky

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The volatility of Shanghai crude oil futures prices is researched in this paper. The cusp catastrophe analysis of Shanghai crude oil futures price is based on the perspective of volatility influencing factors. Some important factors are selected based on commodity attributes and financial attributes, including certain China's macrofactors, such as producer price index and macroeconomic prosperity index. The principal component analysis is used to process the factors. The control variables of the cusp catastrophe model are extracted. The discriminant of the cusp catastrophe model and the principal component analysis are combined to determine the month of mutation. The three-dimensional renderings and plane projections of Shanghai crude oil futures price mutations in 2018 and 2019 are presented. The model is tested by comparing the time points of price sudden change nodes and emergencies. The results show that only nine factors can be used to roughly determine whether the Shanghai crude oil futures price has a sudden change. During the analysis period, the mutation months are May 2018, December 2018, February 2019, June 2019, and September 2019. It can be proved that the established model has certain feasibility and accuracy.

1. Introduction

Shanghai crude oil futures are currently China's first and only crude oil futures, and they are also the first product opened to the outside world in China's futures industry. The official listing of Shanghai crude oil futures marks the start of the internationalization of China's futures market, which means that an important step has been taken in the internationalization of the renminbi, and it also means that China has formally joined the competition for crude oil pricing power in the Asia-Pacific region. In recent years, oil prices have experienced roller coaster-like ups and downs, and some unexpected events have also caused shocks in crude oil prices, thereby affecting the trend of crude oil futures. Sudden changes in prices belong to the evolution of the economic and financial category, which is manifested in the economic and financial aspects, mainly due to the sharp rise and fall of some financial instruments such as stocks, futures, and foreign exchange or the impact of some "black swan events" on the economic and financial markets.

Since its inception, catastrophe theory has been well applied in the fields of physics and engineering, but its application in the fields of social and behavioral sciences is not very extensive, and there are relatively few studies on economics. In the existing literature, the research part adopts the method of structural mutation. For example, a structural mutation phenomenon could be verified using the volatility of the financial market [1, 2]. The mutation inflection point of the economic interval was clarified range using the structural mutation theory [3]. Ewing and Malik [4] introduced the GARCH model to study the volatility of financial markets. Zeng and Yin [5] combined Bayesian statistical methods to analyze the stock market. Zhang [6] tested the operability of structural mutations introduced in the time series model. Gong and Lin [7] combined the HAR model to study the crude oil futures market [7]. Some scholars also focus on method improvement. Wang [8] used latent state variables and the irreversible hidden Markov chain method. Zhang [9] used the PPM mutation point and Hurst index method.

There are some pieces of literature on economic issues using the cusp catastrophe model. Wang and Sun [10] combined the model with the supply chain financial ecosystem to evaluate the stability of the system. Wang et al. [11] focused on the early warning of sudden changes in the economic system. The former mainly integrates a variety of theories such as catastrophe theory, grey number theory, and grey prediction theory, while the latter researches the cusp catastrophe warning of generalized virtual assets with real estate as the representative. Qiu and Yang [12] and Li [13] combined the cusp catastrophe model with other theories. The former combines the dissipative structure theory to analyze the entropy change of the financial system, and the latter combines the random theory to establish a catastrophe model based on the Shanghai Stock Exchange Index and the Shenzhen Stock Exchange Index in China. Li and Shi [14] used the cusp catastrophe model to analyze the general characteristics of securities returns. In the paper, the cusp catastrophe model is used to study the abrupt changes in crude oil futures prices.

A study on the mutation of Shanghai crude oil futures prices is helpful to comprehensively understand and grasp the development status and inherent characteristics of the oil futures market and can make up for China's shortcomings in oil futures. Understanding the reasons for the changes in oil futures prices and grasping the laws of oil futures price fluctuations are conducive to the further development and improvement of China's oil futures market, further reflecting the price guiding role of oil futures and thus enhancing the voice and power of China's crude oil futures market in the international market. In the paper, the cusp catastrophe model would be adopted. Use influencing factors to reflect the mutation in price fluctuations so as to research the fluctuations of Shanghai crude oil futures prices.

2. Methodology

The catastrophe theory was founded by the French mathematician Rene Thom in 1972 in the book "Stable Structure and Morphogenesis." This book systematically expounds the catastrophe theory. For the discontinuous mutations that exist in nature and social life, various forms and structures have been studied in the catastrophe theory.

When dealing with the phenomenon of continuous gradual change, the classic calculus method is usually used. However, when encountering a sudden change, the state space of the system becomes nondifferentiable. We cannot use calculus. In this case, the catastrophe theory was born. Catastrophe theory is a mathematical theory specially used to deal with discontinuous and jumping phenomena. The volatility of Shanghai crude oil futures prices has seen skyrocketing and slumping phenomena, which is a sudden change in the economic and financial aspects. It has mutation characteristics and can be studied using mutation models.

2.1. Catastrophe Theory. The mathematical foundation of catastrophe theory mainly involves three aspects. One is the singularity theory of smooth mapping. The second is the bifurcation set theory of power system. The third is stability theory. Among the more basic concepts are potential, singularity, bifurcation, and stability.

Potential can express the state variables and external parameters of the system to describe the behavior of the system. The degenerate stationary point is a singularity. The stationary point is the point where the potential derivative of the smoothing function is zero. Stationary points are classified according to different conditions. Bifurcation is a change phenomenon in a parameter-containing system, which is mainly manifested in the sudden change of qualitative properties such as the equilibrium state of the system and the number and stability of periodic motion when the parameters in the system change or pass certain critical values. Stability mainly refers to the ability of things to resist interference. When the system continues to appear in a certain state, external interference may cause the system to deviate from this state and become unstable. But when the interference is eliminated, it returns to its original state and continues to remain stable. A set of parameters can be used to describe the state of a system. When the parameter takes a unique extreme value, the system is in a stable state. When the parameter changes within a certain range, it means that there is more than one extreme value. Then the system is in an unstable state.

The catastrophe theory is based on differential equations and functions to classify the singularities of the system. When the number of state variables does not exceed two and the number of control variables does not exceed four, there are at most seven types of elementary mutations. The type of each elementary mutation is determined by a potential energy function, where y and x are state variables and t, w, v, and u are control variables. The first derivative of the potential energy function is zero, or the set of all points where the first partial derivative is zero is called a balanced surface, which can be used to describe the whole process of a certain type of sudden change.

2.2. The Cusp Catastrophe Model. In mutation theory, the definition of the catastrophe model gives the potential function equation. The determination of the potential function equation is judged by the number of state variables and control variables, and different numbers determine different potential functions. According to the perspective of this study, the appropriate potential function and mutation model are selected.

The potential function equation of the cusp catastrophe model is shown as follows:

$$V(x) = x^4 + ux^2 + vx, \tag{1}$$

where x is the state variable and u and v are the control variables. This function presents the phase point in the three-dimensional space with (x, u, v) as the coordinate, which represents the state of the system. In addition, x also represents the influence factor of Shanghai crude oil futures price fluctuation. Through the data processing of the influence factors, two new variables representing the commodity attributes and financial attributes are extracted, namely, u and v. In this way, the potential function of the catastrophe model can be combined with the economic problem being studied.

When $V'(x)$ is equal to zero, equilibrium surface equation of potential function M is shown as follows:

$$4x^3 + 2ux + v = 0. \quad (2)$$

When $V''(x)$ is equal to zero, singularity set S of potential function is shown as follows:

$$12x^2 + 2u = 0. \quad (3)$$

The equilibrium surface equation M and the singularity set equation S are established jointly. The forked set B is obtained.

$$8u^3 + 27v^2. \quad (4)$$

According to the balance surface equation of the potential function, the balance surface is the set of all critical points of the potential function. From the singular point set equation of the potential function, it is known that the singular point set is the set of all points with vertical tangents on the balance surface. It can be seen from the bifurcation set equation that the bifurcation set is a projection on the plane of the control variable. It is a collection of points of the control variable and represents all the points that make the state variable jump.

As shown in Figure 1, the curved surface in the curved surface graph is the abrupt manifold of the cusp catastrophe model (in Figure 1), which represents the change of the potential function at different positions. The balance surface is composed of three layers, upper leaf, lower leaf, and middle leaf, which are three possible balance positions. The upper and lower leaves represent a stable balance and are smooth curved surfaces. The middle leaf represents an unstable balance and is the middle fold. The bifurcation set is the projection of the middle lobe on the plane where the control variable is located, which represents the critical position where the system changes suddenly. If the control variables u and v do not cross the bifurcation set, then the behavior of the system changes gradually from the initial state to the end state. If the control variable crosses the bifurcation set, it will cause nonstationary and discontinuous changes in the state variable, and it may fall from the upper leaf of the curved surface to the lower leaf or jump from the lower leaf to the upper leaf of the curved surface. The instability of this state can be considered a sudden change.

The balance surface equation of the cusp catastrophe model is a one-dimensional cubic equation about x, $4x^3 + 2ux + v = 0$ (i.e., formula (2)). According to the Kaldan formula, the number of real roots of the equation can be determined by the sign of the discriminant $\Delta = 8u^3 + 27v^2$ (i.e., formula (4)). When $\Delta = 0$, it means the projection on the control variable plane, that is, the bifurcation set. At the same time, the bifurcation set divides the plane of the control variable into two regions. As shown in Figure 2, the point above the bifurcation set curve indicates $\Delta > 0$, and the point below the bifurcation set curve indicates $\Delta < 0$. The point on the bifurcation set curve indicates $\Delta = 0$.

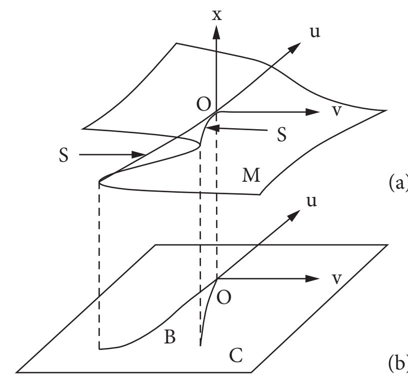

FIGURE 1: Cusp catastrophe model surface map.

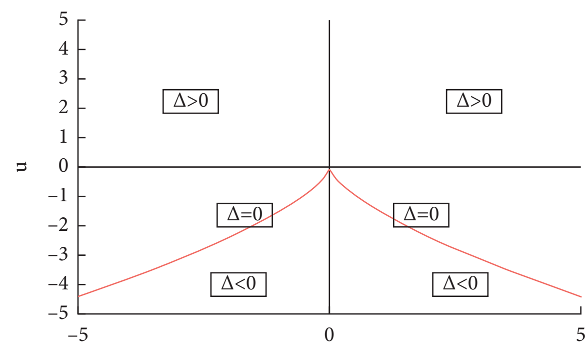

FIGURE 2: Bifurcation set curve.

3. Volatility Factors

The Shanghai crude oil futures price is essentially a CIF price, which is different from Brent crude oil futures and WTI crude oil futures. Therefore, the factors affecting the price fluctuation of Shanghai crude oil futures are slightly different from those of other crude oil markets. For obtaining a price that more closely matches the market, one of the meanings and functions of Shanghai crude oil futures is to reflect the changes in the supply and demand structure of China's crude oil market. Therefore, the prices generated by the market during trading will refer more to the current fundamentals of China's crude oil market.

3.1. Selection of Impact Factors. Although crude oil futures are derivative financial instruments relying on crude oil prices, they are closely related to crude oil. The influencing factors involve not only the category of crude oil but also the characteristics of crude oil futures themselves. On the one hand, as an indispensable strategic resource for national survival and development, crude oil is endowed with dual attributes by the market, including its own commodity attributes and derivative financial attributes. Crude oil not only occupies a very important position in global trade but also is closely related to the political, financial, and economic aspects of countries around the world. On the other hand, both Shanghai crude oil futures and crude oil futures in other markets have commodity and financial attributes. Therefore, there will be some of the same influencing factors, such as fundamental factors, geopolitical factors, macro-factors, and capital factors. Therefore, this paper is mainly based on the commodity and financial attributes of crude oil futures to explore the factors affecting the price of Shanghai crude oil futures.

3.1.1. Commodity Attributes. The so-called commodity attributes are related to the microinfluencing factors of crude oil futures products, the most important of which is the supply and demand relationship of crude oil. Shanghai crude oil futures reflect the supply and demand of China's coastal crude oil market. On the one hand, it has maintained a good linkage with international oil prices for a long time. On the other hand, when emergencies occur in the region, they can respond more directly and quickly. Especially in the face of emergencies, the price of Shanghai crude oil futures can quickly rise or fall to meet market supply and demand requirements and support prices. Not only is it friendly to market participants in terms of hedging risks, but also in terms of optimizing resource allocation, the Shanghai crude oil futures market provides industrial customers with new resource allocation channels. Market participants commented that Shanghai crude oil futures prices are reasonable and meaningful not only to the buyers and sellers involved in the transaction but also to producers and end consumers. Therefore, in view of the crude oil commodity attributes reflected in Shanghai crude oil futures, China's crude oil production volume and crude oil import volume indicators are used as the supply of crude oil futures.

Since the Shanghai crude oil futures price is essentially a CIF price, it is relatively more able to reflect changes in refinery processing costs. In the case of large fluctuations in the freight market, changes in overseas crude oil prices, which represent the shipping port price, generally do not reflect this difference. However, the fluctuation of the Shanghai crude oil futures price, which represents the arrival price, includes freight fluctuations. In contrast, because it can better reflect the changes in refinery processing costs, it can attract more resource countries, producers, international oil companies, and traders to make quotations based on Shanghai crude oil futures. Considering this reason, crude oil futures demand uses crude oil processed volume and crude oil apparent consumption indicators.

3.1.2. Financial Attributes. Crude oil futures are traded with crude oil as the subject matter and play a role in providing risk management tools. The standardized contracts, margin systems, and settlement systems of futures all reveal the inherent financial attributes of futures. The financial attributes are mostly related to macroinfluencing factors, such as exchange rates, politics, and economics. Therefore, when studying the factors affecting the price of Shanghai crude oil futures, the trading volume and open interest indicators can be used.

International crude oil futures, such as Brent crude oil futures, WTI crude oil futures, and Dubai/Oman crude oil futures, are all priced and settled in US dollars. However, China's crude oil futures are priced and settled in RMB. Therefore, under normal circumstances, changes in China's monetary policy and the value of RMB will have an impact on the price and operation of China's crude oil futures. Although the RMB has not yet achieved internationalization, there are still many restrictions on cross-border flows. However, when studying the influencing factors of Shanghai crude oil futures, the RMB exchange rate is still indispensable.

According to the relevant announcement of the Shanghai International Energy Exchange, the subject of the Shanghai crude oil futures contract is intermediate sour crude oil. Deliverable oil types include UAE Dubai crude oil, Upper Zakum crude oil, Oman crude oil, Qatar offshore oil, Yemen Masira crude oil, Iraqi Basra light oil, and China Victory crude oil. Among the international crude oil futures, Dubai crude oil and Oman crude oil are sour intermediate crude oils. Brent crude oil can be used as a representative of the benchmark crude oil in the west region, while Dubai crude oil can be used as a representative of the benchmark crude oil in the East region. Among the three major crude oil futures, from the perspective of distance, the physical resources corresponding to WTI and Brent crude oil futures will arrive in China much longer than the actual delivery of Oman crude oil futures. In terms of oil quality, the quality of WTI, Brent crude oil, and Oman crude oil is also very different. Therefore, when it comes to cross-regional arbitrage, it is obvious that there is no need to set aside short distances and correlate Shanghai crude oil futures prices with WTI and Brent. Similarly, when studying influencing factors, the Oman crude oil price index can be used.

From a macroperspective, changes in China's economic data will be more intuitively reflected in changes in oil prices. The impact of this change on Shanghai crude oil futures prices is obvious to all. This paper uses the producer price index of the petroleum industry and the macroeconomic prosperity index to represent the impact of China's macrolevel on crude oil futures.

3.2. Impact Factor Index Construction. The factors affecting the price fluctuation of Shanghai crude oil futures are discussed from the perspective of commodity attributes and financial attributes. The construction of its indicators also starts from these two aspects. According to the analysis and selection of influencing factors, when considering the commodity attributes based on supply and demand, China's crude oil production and crude oil imports are used as the supply of crude oil futures. Since China's crude oil production is very small and basically depends on imports, the combined crude oil production and crude oil imports are two indicators of crude oil supply. The demand for crude oil futures uses crude oil processed volume and crude oil apparent consumption indicators. When considering financial attributes, it uses crude oil futures' own trading volume and open interest indicators, as well as the RMB exchange rate and Oman crude oil prices. In addition, the producer price index of the petroleum industry and the macroeconomic prosperity index represent the impact of China's macrolevel on crude oil futures. The influencing factors of Shanghai crude oil futures price fluctuation mentioned above are shown in (Table 1).

4. Empirical Analysis

4.1. Principal Component Analysis. Through the above analysis, nine indicators are selected from the influencing factors of Shanghai crude oil futures, and the principal components are extracted based on the principal component model. Since Shanghai crude oil futures were listed on March 26, 2018, the time period for selecting data began in April 2018. Due to the statistical delay of certain macro-indicators, the data are as of December 2019. The data come from the Central Economics database and the CSMAR database. The reported data were used to support this study and are available at https://www.cei.cn/ and https://www.gtafe.com/.

This paper uses SPSS software for principal component analysis. Standardize the original indicators to eliminate the influence of variables on the level and dimension. Then KMO and Bartlett sphericity tests were performed, and the test passed. The method of determining the number of principal components is based on the number of eigenvalues greater than 1. As shown in Table 2, all variables have extracted 70% or more of the information; that is, most of the information of all variables can be explained by the principal components, and the variable information is less lost. Therefore, it is determined that there are two principal components in this principal component extraction, and the overall effect is relatively ideal.

As shown in Table 3, the score coefficient matrix of the principal components after normalization is obtained. $F_i = k_1 X_1 + k_2 X_2 + \cdots + k_8 X_8,\ i = 1, 2.$ The coefficients in the formula are shown in Table 3.

4.2. Application of Cusp Mutation Model. The catastrophe model type can be judged according to the number of state variables and the number of control variables. The two extracted principal components can be used as control variables of the catastrophe model. The price of Shanghai crude oil futures can be used as the state variable of the mutation model. Therefore, the cusp catastrophe model was used according to two control variables and one state variable. A three-dimensional image of the equilibrium surface equation of the cusp catastrophe model can be made. As shown in Figure 3, the projection on the control variable plane is the bifurcation set. The red line is the left bifurcation set, and the blue line is the right bifurcation set.

Through the results of principal component analysis, the two extracted principal components are used as the control variables $u(t)$ and $v(t)$ of the mutation model. The mutation model is established as follows:

$$\begin{aligned} u(t) &= 0.282x_1(t) + 0.270x_2(t) - 0.016x_3(t) + 0.257x_4(t) - 0.031x_5(t) \\ &\quad - 0.107x_6(t) - 0.312x_7(t) - 0.252x_8(t) - 0.139x_9(t), \\ v(t) &= -0.125x_1(t) - 0.104x_2(t) + 0.270x_3(t) - 0.493x_4(t) + 0.281x_5(t) \\ &\quad + 0.357x_6(t) + 0.193x_7(t) + 0.095x_8(t) - 0.074x_9(t). \end{aligned} \tag{5}$$

Two principal components can be calculated by combining the historical data of nine indicators, including crude oil supply, crude oil apparent consumption, crude oil processing volume, trading volume, position, RMB exchange rate, Oman crude oil price, producer price index, and macroeconomic climate index. Since the equilibrium surface equation of the cusp mutation model is $4x^3 + 2ux + v = 0$, $4x^3(t)$ can also be calculated based on the actual historical data. The nonlinear regression is transformed into multiple linear regression, and the equilibrium surface equation of the abrupt transition model is fitted. The regression model is expressed as follows:

$$4x^3(t) + 11.838u(t)x(t) - 2.815v(t) + 2.434 = 0. \tag{6}$$

Therefore, the standard cusp catastrophe model balance surface equation is constructed as follows: $4X^3(t) + 2U(t)X(t) + V(t) = 0$.

Then, $X(t) = x(t)$, $U(t) = 5.919u(t)$, and $V(t) = -2.815v(t) + 2.434$.

According to the equilibrium surface equation of the cusp mutation model, it can be seen that $\Delta = 8u^3(t) + 27v^2(t)$.

When $\triangle > 0$, the balance surface equation of the cusp catastrophe model has only one real root, so the corresponding potential function curve has only one minimum value. In this case, the smooth change of (u, v) makes x change smoothly, indicating that the system is stable.

When $\triangle < 0$, the balance surface equation of the cusp catastrophe model will have three different real roots. Therefore, the corresponding potential function curve will have two minimum values. In this case, the system has three balance points. One is in an unstable state, and two are in a stable state. The system changes smoothly between states, a process of slow change. A sudden change occurs only when the system passes or reaches the boundary of the equilibrium state, at which time the system is in an unstable state.

When $\triangle = 0$, the equilibrium surface equation of the cusp catastrophe model has three real roots. When u and v are not zero, two of the three real roots are the same. In this

Table 1: Influencing factors of Shanghai crude oil futures price changes.

Dependent variable	Main type	Influencing factors
Shanghai crude oil futures prices	Commodity attributes	Crude oil supply X_1
		Apparent crude oil consumption X_2
		Crude oil processing volume X_3
	Financial attributes	Trading volume X_4
		Open interest X_5
		RMB exchange rate X_6
		Oman crude oil prices X_7
		Producer price index X_8
		Macroeconomic sentiment index X_9

Table 2: Explanation of total variance.

Ingredient	Initial eigenvalue			Rotating load sum of squares		
	Total	Percentage of variance	Accumulation %	Total	Percentage of variance	Accumulation %
1	5.657	62.851	62.851	4.065	45.169	45.169
2	1.198	13.314	76.165	2.790	30.996	76.165
3	0.756	8.400	84.565			
4	0.641	7.123	91.688			
5	0.426	4.735	96.424			
6	0.175	1.942	98.365			

Table 3: Component score coefficient matrix.

Influencing factors	The coefficient of component 1	The coefficient of component 2
Crude oil supply X_1	0.282	−0.125
Apparent crude oil consumption X_2	0.270	−0.104
Crude oil processing volume X_3	−0.016	0.270
Trading volume X_4	0.257	−0.493
Open interest X_5	−0.031	0.281
RMB exchange rate X_6	−0.107	0.357
Oman crude oil prices X_7	−0.312	0.193
Producer price index X_8	−0.252	0.095
Macroeconomic sentiment index X_9	−0.139	−0.074

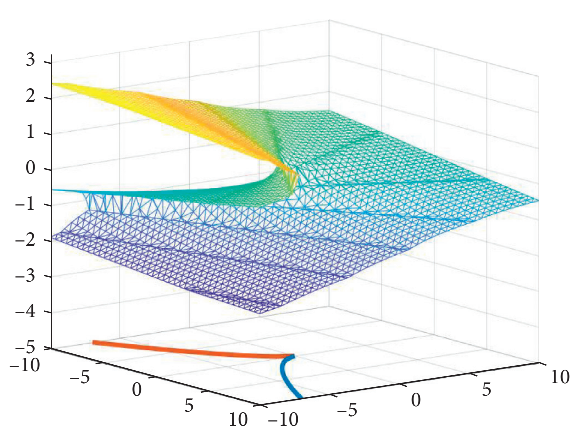

Figure 3: Cusp catastrophe model balance surface equation 3D diagram.

case, the system is in two critically stable states. If a slight disturbance occurs, the system will jump from a critical state to a stable equilibrium state, that is, a sudden change. If $u = v = 0$, there are three equal real roots, all at the zero point, and there is only one minimum value for the corresponding potential function curve. Although the system jumps over the state of zero point, because the state before and after the jump is the same, there is no sudden change.

The selected data are from 2018 to 2019 in this paper. Therefore, the monthly data frequency is used to divide the time according to the year, and the annual Shanghai crude oil futures price fluctuations are analyzed. The first time period is from April 2018 to December 2018, and the second time period is from January 2019 to December 2019. The 2018 data has nine months, and the 2019 data has twelve months. Therefore, first conduct a static analysis with three months as a partial range to determine the situation of $\Delta = 8u^3(t) + 27v^2(t)$, and then perform an integrated full-range analysis and judgment, which can more accurately represent the sudden change of crude oil futures.

4.2.1. Empirical Analysis in 2018. The analysis is divided into three months, which are from April to June, July to September, and October to December. First, according to the monthly distribution, the principal component analysis is performed in turn, and the number of principal component analyses is determined to be three times. Then calculate the control variables $u(t)$ and $v(t)$ of the catastrophe model. Finally, the judgment result of $\triangle$ is output according to the formula $\Delta = 8u^3(t) + 27v^2(t)$. The results are integrated as shown in Table 4, which is the analysis result table in 2018.

It can be seen from Table 4 that the months with $\triangle < 0$ are May and December. They are −0.32709 and −7.09259. Three-dimensional renderings of sudden changes in Shanghai crude oil futures prices in 2018 are shown in Figure 4.

When a three-dimensional map is presented in a two-dimensional state, some months cannot be fully displayed. Therefore, the U-V coordinates in the three-dimensional image are projected into a plane. The bifurcation curve to judge the sudden price change of Shanghai crude oil futures in 2018 is shown in Figure 5.

It can be seen from Figure 5 that the months in the $\triangle < 0$ area are May and December. It shows that the price of Shanghai crude oil futures fluctuated greatly from April to May, May to June, and November to December 2018 and was in an unstable situation. In Figure 5, the coordinates in May are $(u, v) = (-1.097, -0.3591)$. At this time, the system passes through the boundary of the equilibrium state and is in an unstable state, indicating that a sudden change will occur. The coordinates in December are $(u, v) = (-1.017, 0.5472)$. The system reaches the boundary of the equilibrium state and is also in an unstable state, and there is also the possibility of sudden changes.

4.2.2. Empirical Analysis in 2019. The analysis is based on a partial range of three months, which can be divided into January to March, April to June, July to September, and October to December. First, the principal component analysis is carried out based on the distribution of the month. The results determine that the number of principal component analyses is four. Then, the control variables $u(t)$ and $v(t)$ of the catastrophe model are calculated. Finally, the judgment result of $\triangle$ is output according to the formula and graphically through Matlab software. Because of the original data from October to December, there is a variable with zero variance. Therefore, the principal component analysis cannot be performed in these three months, so the time is combined and analyzed; that is, the principal component analysis is performed from July to December 2019. The analysis results are shown in Table 5.

It can be seen from Table 5 that the months with $\triangle < 0$ are February, June, and September. They are −0.09986, −12.31665, and −8.28.517. The three-dimensional graph is drawn, and the results from January to December 2019 in the graph are marked in Figure 6.

Table 4: The principal component analysis in 2018.

	$u(t)$	$v(t)$	$\triangle$	Judge symbol
April	0.98227	0.60702	17.53076	$\triangle > 0$
May	−1.01683	0.54717	−0.32709	$\triangle < 0$
June	0.03456	−1.15418	35.96788	$\triangle > 0$
July	−0.879	−0.74879	9.70532	$\triangle > 0$
August	−0.20897	1.13563	34.74769	$\triangle > 0$
September	1.08797	−0.38684	14.34288	$\triangle > 0$
October	0.23774	1.12996	34.58136	$\triangle > 0$
November	0.8597	−0.77087	21.12762	$\triangle > 0$
December	−1.09745	−0.35909	−7.09259	$\triangle < 0$

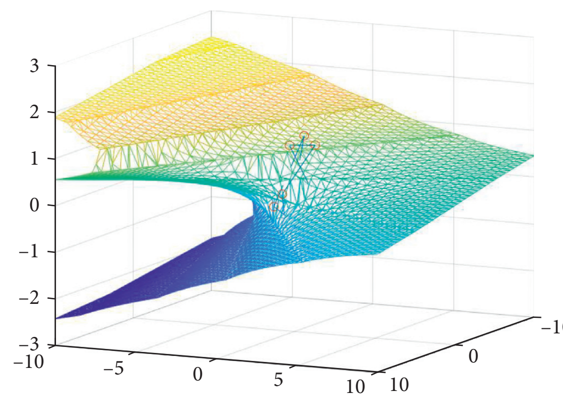

Figure 4: Three-dimensional renderings of sudden changes in Shanghai crude oil futures prices in 2018.

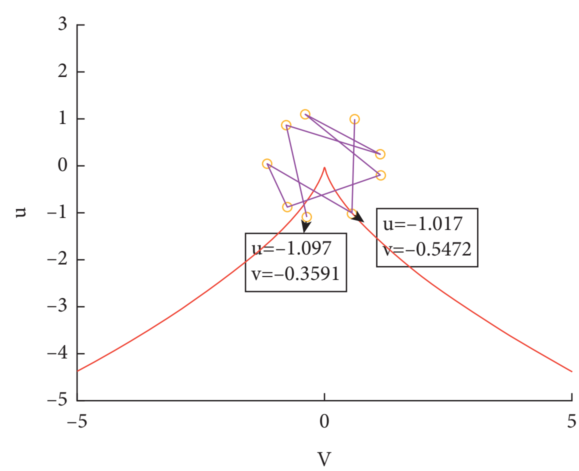

Figure 5: Plane projection chart of Shanghai crude oil futures price sudden change in 2018.

Table 5: The principal component analysis in 2019.

	$u(t)$	$v(t)$	$\triangle$	Judge symbol
January	0.98542	−0.6019	17.43681	$\triangle > 0$
February	−1.01397	−0.55244	−0.09986	$\triangle < 0$
March	0.02856	1.15435	35.97833	$\triangle > 0$
April	0.57539	1.00113	28.58503	$\triangle > 0$
May	0.57931	−0.99886	28.49381	$\triangle > 0$
June	−1.1547	−0.00227	−12.31665	$\triangle < 0$
July	1.04845	−1.43844	65.08601	$\triangle > 0$
August	−0.67867	−0.8712	17.99199	$\triangle > 0$
September	−1.05655	−0.2064	−8.28517	$\triangle < 0$
October	−0.75572	0.83452	15.35063	$\triangle > 0$
November	0.12442	0.743	14.92073	$\triangle > 0$
December	1.31806	0.93852	42.10087	$\triangle > 0$

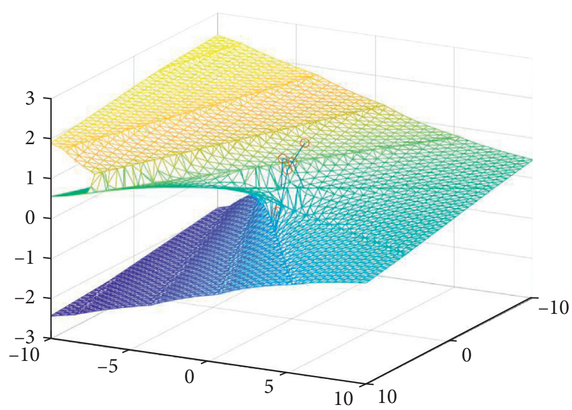

Figure 6: Three-dimensional renderings of sudden changes in Shanghai crude oil futures prices in 2019.

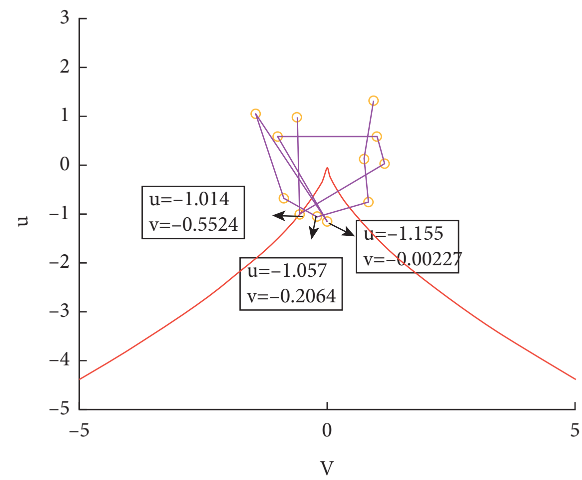

Figure 7: Plane projection of sudden changes in Shanghai crude oil futures prices in 2019.

When a three-dimensional map is presented in a two-dimensional state, some months cannot be fully displayed. Therefore, the U-V coordinates in the three-dimensional image are projected into a plane. The bifurcation curve to judge the sudden price change of Shanghai crude oil futures in 2019 is shown in Figure 7.

It can be seen from Figure 7 that the months in the $\triangle < 0$ area are February, June, and September. It shows that Shanghai crude oil futures prices fluctuated greatly around February, June, and September and were in an unstable situation. According to Figure 7, the coordinates in June are $(u, v) = (-1.155, -0.00227)$, and the coordinates in September are $(u, v) = (-1.057, -0.2064)$. At this time, the system passes through the boundary of the equilibrium state and is in an unstable state, indicating that a sudden change will occur. The coordinates in February are $(u, v) = (-1.014, -0.5524)$. The system reaches the boundary of the equilibrium state and is also in an unstable state, and there is also the possibility of sudden changes.

4.3. Model Test. Utilizing the cusp catastrophe model, the volatility and sudden change of Shanghai crude oil futures prices from April 2018 to December 2019 are applied and analyzed. The months of sudden change were May and December 2018 and February, June, and September 2019. In order to verify the feasibility and accuracy of the cusp catastrophe model, it can be compared with the real situation of Shanghai crude oil futures prices, and it can also be analyzed in conjunction with the actual international or domestic geopolitical events and emergencies. In this way, the cusp catastrophe model was tested.

In Figure 8, the real price curve of Shanghai crude oil futures trading from April 2018 to December 2019 is obtained. The daily price limit of Shanghai crude oil futures is 8%, but as the contract settlement day approaches, on the third to last trading day, the price limit will be adjusted to 10%. The Shanghai crude oil futures price standard line is set to 500, and the maximum fluctuation range is selected. Combined with the changing law of the graph, fluctuations in which the price difference is greater than or equal to 50 points can be regarded as a sudden change. The several obvious mutation months, namely, May and December 2018 and June 2019, can be directly observed.

Since March 2018, the Sino-US trade war has had a certain impact on crude oil futures prices, which intensified price fluctuations. On May 7, the Ministry of Ecology and Environment of our country passed the “Environmental Pollution Compulsory Liability Insurance Management Measures (Draft),” which included oil and natural gas exploitation, basic chemical raw material manufacturing, synthetic material manufacturing, and chemical raw material drug manufacturing into the scope of compulsory insurance. The price of crude oil futures was negatively affected. Therefore, Shanghai crude oil futures prices showed a sudden downward trend in May. In December 2018, the US’s crude oil and fuel exports exceeded imports for the first time in history, and it became a net oil exporter for the first time, demonstrating the influence of US shale oil on the global energy landscape. As American oil continuously enters the world oil market, the rebalancing of global oil is a long way off. On December 7, OPEC and its allies finally decided to reduce production by 1.2 million barrels per day. OPEC member states pledged to reduce their production by 800,000 barrels from January for a period of 6 months. At the same time, Russia and other partners also pledged to reduce

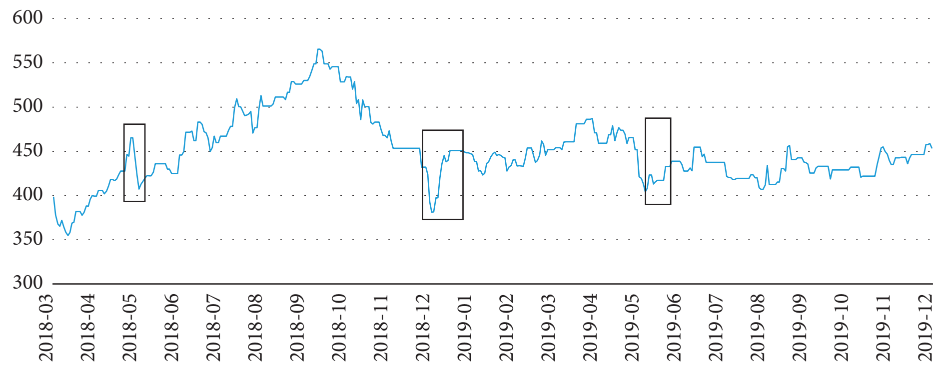

Figure 8: Shanghai crude oil futures real price chart.

production by an additional 400,000 barrels of oil a day. On December 12, the number of high-yield oil wells was born with the frequent success of China's oil exploration front. China National Petroleum Corporation announced that it would strongly promote China's continental shale oil revolution. Therefore, in December 2018, the Shanghai crude oil futures price experienced a sudden drop followed by a sudden rise.

On June 13, 2019, the Oman Sea was maliciously attacked, and a tanker explosion occurred. On June 20, 2019, Basra, an important oil production base in southern Iraq, was attacked by rockets. On September 14, 2019, two oil facilities of the Saudi Arabian National Petroleum Corporation (Aramco) were attacked by drones. Therefore, crude oil futures prices fluctuate due to geopolitical emergencies.

From what has been discussed above, the sudden change month of Shanghai crude oil futures price obtained by the cusp catastrophe model is basically consistent with the actual situation, which has certain significance for the study of its price fluctuation.

5. Predictive Analysis

5.1. Principal Component Variable Prediction. Through principal component analysis, it can be known that the variables of the first principal component, namely, the demand-oriented principal component, include crude oil supply, apparent crude oil consumption, Oman crude oil price, producer ex-factory price index, and macroeconomic prosperity index. The variables of the second principal component, namely, the transactional principal component, include crude oil processing volume, transaction volume, open interest, and RMB exchange rate. Discrete variables can be predicted using the grey GM (1, 1) model. Continuous variables can be predicted using the ARIMA model.

Taking crude oil supply as an example, the forecasting process of discrete variables is illustrated. Firstly, the original sequence is processed as follows.

Then, the grey model development coefficient a and grey action volume b need to be calculated.

$$\begin{aligned} a &= -0.007, \\ b &= 5255.312. \end{aligned} \tag{7}$$

Finally, the average simulation relative error is calculated.

The average simulated relative error is 3.331%. From the above steps, the forecast data for the next period in the future can be obtained, and the forecast value is 6107.806.

Taking Oman crude oil price as an example, the prediction process of continuous variables is shown as follows:

The unit root test of the Oman crude oil price is a nonstationary time series. Differential processing on it is performed, as shown in Table 7. After two differences, the t-statistic is −6.062284, which is less than the significance level of 1% (−3.857386), 5% (−3.040391), and 10% (−2.660551). Therefore, it can be determined that $d = 2$ in the ARIMA (p, d, q) model (Table 7).

By processing the indicator of Oman crude oil price, the nonstationary time series is differentiated into a stationary time series. Using ACF and PACF functions to draw autocorrelation graphs and partial autocorrelation graphs, the p and q values of the ARIMA (p, d, q) model can be determined. As shown in Figure 9, it can be roughly judged that the model established for the indicator of Oman crude oil price is ARIMA (1, 2, 0).

The forecast function can be used to forecast the Oman crude oil price in the next period. That is to predict January 2020. The result is 65.41127. The predicted values of all variables in the next period are shown in Table 8.

The forecasted value with the data of the last quarter of 2019 for principal component analysis is combined. Then, the control variables $u(t)$ and $v(t)$ of the catastrophe model are calculated. Finally, the judgment result of $\triangle$ according to the formula $\Delta = 8u^3(t) + 27v^2(t)$ is shown in Table 9. The sudden change in the price of Shanghai crude oil futures in the next period can be predicted.

The U-V coordinates of the three-dimensional image into a plane are projected. It can be seen from Figure 10 that the month in the $\triangle < 0$ area is January 2020. The coordinates are $(u, v) = (-1.28446, -0.63602)$. The forecast results show that the status has changed from December 2019 to January 2020 and from January 2020 to February 2020. The price of Shanghai crude oil futures fluctuates greatly and is in an unstable situation. Sudden changes will occur.

In order to verify the feasibility and accuracy of the forecast model, an empirical comparison and analysis of the real situation of Shanghai crude oil futures prices can be

Table 6: Crude oil supply original sequence processing.

	Original sequence	1-AGO sequence	Immediate mean value
1	5497.1	5497.1	8248.1
2	5502	10999.1	13508.7
3	5019.2	16018.3	18612.0
4	5187.4	21205.7	23924.55
5	5437.7	26643.4	29262.85
6	5238.9	31882.3	34726.7
7	5688.8	37571.1	40491.4
8	5840.6	43411.7	46417.45
9	6011.5	49423.2	52320.35
10	5794.3	55217.5	57946.45
11	5457.9	60675.4	63469.45
12	5588.1	66263.5	69235.55
13	5944.1	72207.6	75030.5
14	5645.8	77853.4	80637.35
15	5567.9	83421.3	86287.4
16	5732.2	89153.5	92071.3
17	5835.6	94989.1	97833.3
18	5688.4	100677.5	103758.7
19	6162.4	106839.9	109899.95,
20	6120.1	112960.0	116037.4
21	6154.8	119114.8	

Table 7: ADF inspection of Oman crude oil prices.

		t-statistic	Prob.*
Augmented dickey-fuller test statistic		−6.062284	0.0001
	1% level	−3.857386	
Test critical values	5% level	−3.040391	
	10% level	−2.660551	

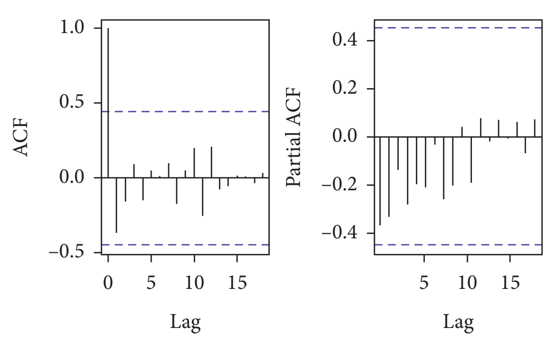

Figure 9: Autocorrelation graph and partial autocorrelation graph of Oman crude oil price difference series.

Table 8: Index prediction value.

Index	Crude oil supply	Apparent crude oil consumption	Crude oil processing volume
Predictive value	6107.806	6115.305	5691.642
Index	Producer price index	Macroeconomic sentiment index	Trading volume
Predictive value	87.603	95.304	1.063356
Index	Open interest	RMB exchange rate	Oman crude oil prices
Predictive value	40.94751	7.007294	65.41127

Table 9: Predictive analysis result table.

$u(t)$	$v(t)$	$\triangle$	Judge symbol
1.09003	−0.34749	13.62131856	$\triangle > 0$
0.3647	−0.50602	7.301577059	$\triangle > 0$
−0.17027	1.48952	59.86459385	$\triangle > 0$
−1.28446	−0.63602	−6.031123225	$\triangle < 0$

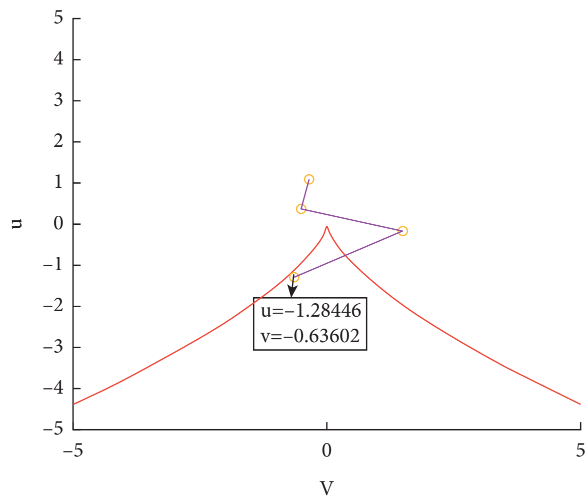

FIGURE 10: Plane projection chart of Shanghai crude oil futures price sudden change forecast.

FIGURE 11: Shanghai crude oil futures real price trend chart.

carried out. It can also be analyzed in conjunction with geopolitical events and emergencies which have occurred internationally or domestically. As shown in Figure 11, the real prices of Shanghai crude oil futures in January and February 2020 are compared and analyzed.

The US-Iran dispute in early January 2020 triggered market concerns about crude oil supply. Crude oil prices were strongly supported. During the continuous fermentation of the event, crude oil prices quickly rushed to the highest point since September 2019. However, as the event subsided and the global economy did not fully improve, crude oil prices fell rapidly.

During the Spring Festival, an epidemic in China occurred, and many provinces initiated the first-level response to major public health emergencies, especially Hubei Province, which was completely closed at the end of January. The market is expected to have a certain impact on China and the global economy, suppressing the rise of crude oil. China's crude oil demand accounts for 14%-15% of the world's total. The decline in China's demand for crude oil is also one of the reasons why crude oil prices have hit a new low. The results predicted in the paper are consistent with actual price trends and real sudden events.

6. Conclusions

Taking the factors related to domestic crude oil into account in the price fluctuations of China's market and expanding to foreign markets through the futures trading mechanism will help strengthen China's position in the international futures market pricing. In the paper, nine influencing factors are selected as the entry point (including China's crude oil supply, China's apparent crude oil consumption, China's crude oil processing volume, Shanghai crude oil futures trading volume, open interest, RMB exchange rate, Oman crude oil price, China's oil industry producer price index, and China's macroeconomic prosperity index). A principal component analysis to process factors is used. Then, two principal components as the control variables of the cusp catastrophe model are extracted. A standard cusp catastrophe model balance surface equation is constructed to analyze the Shanghai crude oil futures price catastrophe. Judging the sudden change in the price of crude oil futures is conducive to locking in the fluctuation range of crude oil prices and giving greater play to the hedging function of futures, thereby reducing the market risk of China's oil companies and avoiding China's passive position in international competition. Judging the sudden change based on the data factor and the sign of the discriminant can greatly simplify the calculation and make it more specific. Combining with the visualization of Matlab software is more conducive to China's oil companies and other market participants to obtain the volatility of futures market prices, thereby avoiding risks.

Through analyzing actual price fluctuations and actual sudden changes, it can be concluded that May and December 2018 and June 2019 are the sudden change months. The comparative analysis shows that the cusp catastrophe model has certain feasibility and accuracy. The model predicts a sudden change in January 2020 and compares the actual price trend with the real sudden change event to test the forecast results. It is found that the predicted results are more accurate and consistent with the facts. The research on the sudden change and forecast of Shanghai crude oil futures prices will help to fully understand and grasp the development status and inherent characteristics of the oil futures market and can make up for China's shortcomings in oil futures.

Many macrovariables in China are involved in the volatility factors. Limited by the statistics of macrovariables, the smallest scope of this paper can only be months. Therefore, the analysis of price changes in the Shanghai crude oil futures market can only be limited to months. The future research direction can shorten the research period from one month to one day and analyze the mutation in more detail.

Data Availability

Previously reported data were used to support this study and are available at https://www.cei.cn/, https://www.gtafe.com/.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Weifeng Gong conceptualized the study, developed methodology, wrote the original paper, and responsible for funding acquisition. Yahui Li investigated the study and was responsible for project administration. Chuanhui Wang contributed to formal analysis and reviewed and edited the paper. Haixia Zhang and Zhengjie Zhai contributed to formal analysis and edited the paper.

Acknowledgments

This paper benefited from years of thinking about these issues and the discussion with many colleagues related to economics at that time. This research was supported by the National Natural Science Foundation of China under grant number 71804089, Humanities and Social Sciences Youth Foundation of Ministry of Education of China under grant numbers 18YJCZH034 and 19YJC790128, and Jiangsu Postdoctoral Research Funding Plan under grant number 2018K195C. This research was also supported by the Graduate Education Quality Improvement Project of Shandong Province, China, under grant numbers SDYKC19180 and SDYAL19180, "the Quality Course in Financial Statistics" (Project no. SDYKC19180), and the "Financial literacy Oriented Teaching Case Library of Derivative Financial Instruments" (Project no. SDYAL19180).

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