Available online at www.sciencedirect.com
ScienceDirect
Procedia Computer Science 55 (2015) 415 – 421
Procedia Computer Science

Information Technology and Quantitative Management (ITQM 2015)

An analysis on crude oil price mutation in view of Zeeman's catastrophe machine

Yanyu Jia[a],Kun Guo[b,c]*,Xiaohui Sun[d]

[a]University of political science and law, Beijing,102200, China
[b] University of Chinese Academy of Sciences, Beijing, 100190, China
[c] Research Center on Fictitious Economy and Data Science, Chinese Academy of Sciences, Beijing,100190, China
[d]China Foreign Affairs University, Beijing,102206, China

Abstract

With the acceleration of international market integration and the frequent outbreak of international political and economic events, the volatility of oil prices has continued to increase in recent years. As the main source of energy, crude oil plays an important role in the development of a country's economy. Therefore, it is meaningful to study the mutation of oil prices. Based on the Zeeman's catastrophe machine, USDX and excess demand are selected as two main factors to construct the catastrophe model, which helps to explain the structural relationship between USDX and excess demand when the crude oil price mutates.

© 2015 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Organizing Committee of ITQM 2015

Keywords: Zeeman's catastrophe machine; cusp catastrophe; oil price

1. Introduction

Crude oil is one of the most important bulk stocks in the world. The variation of its price has an important effect on the development of world economy. With the change of world economic condition, the oil prices present a feature of high volatility, making it harder to predict.

The existing study on oil prices maintains two main opinions: as for the first one, the oil price is mainly decided by speculation. The other is that oil, as a kind of bulk energy; its prices should be determined by measuring the demand and supply. But there is a weakness in both of the opinions: they cannot logically explain and practically forecast the mutation of oil prices. This shortcoming comes from their mathematical

* Corresponding author. Tel.: Tel.:+86-13810439286; fax: +86-10-82680697.
*E-mail address:*guokun@ucas.ac.cn.

1877-0509 © 2015 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the Organizing Committee of ITQM 2015
doi:10.1016/j.procs.2015.07.095

methods, for their methods only focus on the stable time series and the catastrophe ones are not included. Therefore we need a new method to study the mutation of oil prices.

At present, researches on mutation mainly focus on the prediction of financial crisis. The prediction methods are also divided into two categories. The first one is based on model pre-warning, such as FR model. The second is index early warning, such as KLP model. Both of them share the same idea, which is searching the samples, selecting the index, studying the variation of these indices and working out the critical value and finally using these indices as the early warning mechanism.

Concerning the above problems, this essay brings the catastrophe theory into the prediction of oil price mutation. Based on the Zeeman's catastrophe machine, firstly, this essay will explain the structural relationship between US dollar index and excess demand function when oil prices mutate and then construct the cusp mutation model among the three. Next, it will work out the potential function of oil prices by fitting the mutation data. Finally, an analysis on the condition of mutation will be made in view of the cusp model in order to predict the potential mutation. This is to provide a new method to study the mutation of crude oil prices.

In the second part of this essay, Zeeman's catastrophe machine and its basic theory will be introduced. In the third part, we are to construct the mutation model of oil prices. Then in the next part, we will fit this model and make some analysis. Finally, the conclusion will be presented.

2. Zeeman's catastrophe machine

The sketch map of Zeeman's catastrophe machine is as follows:

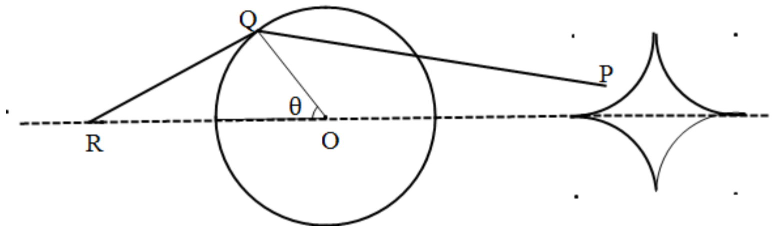

Fig.1 Zeeman's catastrophe machine

Zeeman's catastrophe machine is a kind of catastrophe model created by Zeeman. In this map, RQ and QP is the same rubber band which is one unit long. The round O is a disk whose diameter is also one unit long. What's more, Q is a fixed point on the round and can move around point O.

According to the Lyapunov second method and some related mathematical derivation, we get that, generally, the state variable θ of the mutation system will change continuously when we move point P. However, when P arrives at some special points, the state variable θ will change dramatically. All these special points make up the tetracuspid on the right side of the map. When P comes across the tetracuspid, this system is likely to mutate. In the similar way, oil prices will change continuously in general situation and change dramatically under some special circumstances.

Comparing the Zeeman's catastrophe machine and the determination mechanism of oil prices, we can see the oil price as the state variable of Zeeman's catastrophe machine. What's more, the influencing factors of oil prices can be seen as pull of RQ and QP.

3. The mutation model of oil price

3.1 Select influence factors

The influence factors of oil price can be divided into two:

(1) The US dollar index

Since the US and Saudi Arabia signed the contract to make sure that all these oil transaction should be settled by dollar. US dollar has been accepted gradually as the only currency using in the oil transaction. The negative correlation between dollar and the oil price become significant.

(2) The excess demand function

It is reasonable to study the oil price from its demand and supply, since oil is a kind of bulk energy.

Besides such two factors, unexpected events and geopolitics can also influence the volatility of oil price. But both of them influence the oil price through the factors as mentioned. In the short term, the unexpected event and geopolitics can influence the oil price by influencing the US dollar index. In the long term, the unexpected event and geopolitics can influence the production and consumption of oil. Then it influences the oil price.

Taking all these into consideration, it is reasonable to see the US dollar index and excess demand function as the main factors which can influence the oil price.

3.2 The cusp catastrophe model of oil price

3.2.1 Some definitions and assumptions

This essay applies Zeeman's catastrophe machine to the oil price mutation, which caused by US dollar index and excess demand. The influence of excess demand on oil prices can be seen as the pull of the rubber band QP. The index $Z_{t_0} = ac(3)_{t_0} = \sum_{t=t_0}^{t_0+2} \frac{D_t - P_t}{D_t}$ are assumed to indicate the sum of excess demand changing rates in every three months. Let us denote by D_t, the demand of oil at t, and P_t, the supply of oil at t, where $t \geq 0$.

In the same way, the pulling of rubber band of QR can be seen as the influence of US dollar index on oil prices. Assume the index $K_t = USDX_t$ to indicate the price of dollar at t.

Finally, we use θ, the angel between OQ and OR, to represent the oil price p.

All these assumptions can be shown as follows:

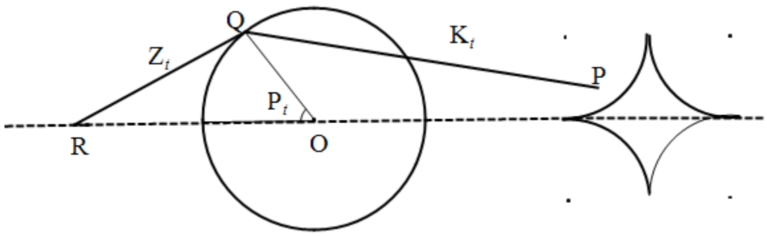

Fig 2 Oil price mutation model

3.2.2 Explanation of the model

At first, keep QR still and increase the tension of QP by pulling P. Then Q moves towards P and the angel θ also increases. Next, rubber band QR produces more tension to ease the influence caused by the change of QP.

In the real world, when the investors know that the excess demand of oil will increase at some time, setting the US dollar index to be fixed, they expect the oil price will increase in the near future. They will then buy more crude oil futures in the international market. As a result, the oil prices rise. However, with more and more money flooded in the crude oil future market, the expected rate of return is to drop. Then the rest investors will choose to invest in the alternative, US dollar, to avoid the risk. Later on, the price of dollar will increase to stop the originally continuous growth of oil prices induced by excess demand.

Vice versa, we can have a similar analysis by holding the P still and pulling the point R.

3.3.3 Cusp catastrophe model of oil prices

Before defining the potential function V, it should be noticed that the two factors (Z_t, K_t) have different degree of effects on the oil price. Therefore, we should assume that the two rubbers have different elastic coefficient μ. What's more, considering that degree of influence from the two factors have something to do with the current price, we insert the adjustment coefficient $\sin(p)$ and $\cos(p)$ into the potential function V. This method is common in vector difference. Next, according to the standard cusp catastrophe potential function, we introduce p^4 into the function. Finally, because the calculation of potential energy changes the sign of Z_t, we use the $\frac{Z_t}{|Z_t|}$ to restore its sign.

Taking all these into consideration, we can draw the potential function as follows:

$$V(p) = \frac{1}{2}\mu_1 Z_t^2 \sin(p)\frac{Z_t}{|Z_t|} + \frac{1}{2}\mu_2 K_t^2 \cos(p) + p^4 \tag{1}$$

We can then eliminate the trigonometric function by using Taylor expansion:

$$V(p) = \frac{1}{2}\mu_1 Z_t^2 \frac{Z_t}{|Z_t|} p + \frac{1}{2}\mu_2 K_t^2 (1 - \frac{1}{2} p^2) + p^4 \tag{2}$$

In order to predict the future mutation of crude oil price, we should determine the parameters by fitting this model with empirical data. Then we can draw its critical point and bifurcation set to make an analysis of the mutation of oil prices.

4. Fitting of the model

4.1 Selecting data

In this essay, we use monthly data of WTI (collected from US Energy Information Administration) and US dollar index (from the New York Mercantile Exchange) during January 1999 to December 2013. The excess demand function is calculated by supply and demand monthly data collected from United States Department of Energy.

4.2 Definition of mutation point

Before fitting the model, we should select the mutation point of oil price. Then it comes to the definition of price mutation. In this essay, the mutation of price should meet two conditions: (1) the changing rate of price dp should be large ;(2) the difference of changing rate ddp should also be large.

First, we pick out the calculated data dp which range out of the interval 3% to 97%. These data are likely to be mutation points.

Then, considering the economic man hypothesis, we remove the data whose $ddp < 5\%$. The remained data are thought to be the mutation points.

4.3 The fitting of model

In the fitting process, we introduce a penalty coefficient to make sure that all these mutation points are on the bifurcation set. Then using the least square method, we can determine the coefficient.

4.4 The result and checking of model

Based on the above preconditions, we can figure out the unknown parameters $(\mu_1, \mu_2) = (23.68, 13.50)$.
And then, we can draw the potential function:

$$V(p) = 11.84 Z_t^2 \frac{Z_t}{|Z_t|} p + 6.75 K_t^2 (1 - \frac{1}{2} p^2) + p^4 \quad (3)$$

And the boundary function:

$$V'(\text{p}) = 11.84 Z_t^2 \frac{Z_t}{|Z_t|} p - 6.75 K_t^2 + 4 p^3 \quad (4)$$

The boundary image is shown in the figure below:

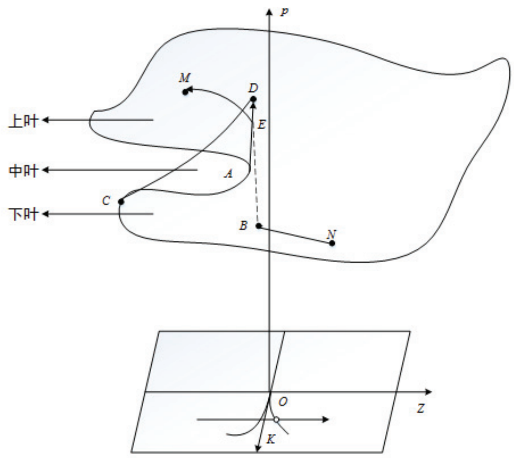

Fig 3 The boundary picture

The image is consisted of three leaves: the high leaf, the medium leaf and the low leaf. There are two types of price increase (1) with the continuous changes of US dollar index and excess demand, the price of oil change continually. There is no mutation in this process. (2) When the route of (Z_t, K_t) cross the branches of the cusp mutation model, the price of oil will jump beyond the expectation of investors. Then we have the dramatic change in prices.

Finally, we draw the mutation points on the cusp catastrophe image as below:

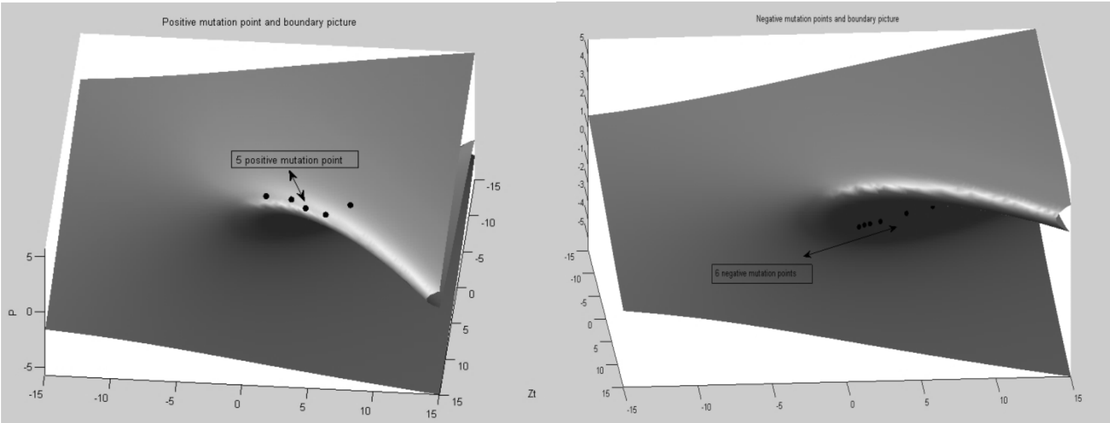

Fig 4 (a)5 positive mutation points on boundary picture,(b)6 negative mutation points on boundary picture

In the picture, the positive mutation points fall on the right bifurcation set, while the negative mutation points fall on the left bifurcation set. This fact is consistent with our assumption that the mutation of oil price is cusp catastrophe. As a result, it is reasonable to apply the cusp catastrophe model to analyse the oil price

Taking all these into consideration, we can draw the conclusion that the price mutation would occur only if the relationship of USDX and excess demand function crossed the branch of cusp catastrophe, or the prices will change continuously.

Finally, to test the effectiveness of prediction of this cusp catastrophe model, we introduced the data from January 2014 to December 2014 into the model. It is easy to find that the data of November is close to the left bifurcation set. Therefore, according to the model, the oil price mutates in November 2014. In practice, the oil price falls sharply from \$107 to \$50 in 2014. According to the definition of mutation point, we can recognize the negative mutation point in November 2014, which is consistent with the output of the model. In this way, the correctness of this model is proved.

5. Main conclusion

Targeted at the high volatility of oil prices in the Global Oil Market, this essay introduces the catastrophe theory into the prediction of oil price mutation. According to Zeeman's catastrophe machine, this essay builds the oil price cusp catastrophe model by analysing the related factors, USDX and excess demand function. At last, conclusion is drawn that there are two types of price changes (1) change continuously (2) change dramatically. What's more, it is also proved that price mutation would occur only if the USDX and excess demand reached certain structural relationship, and either of them could bring about the mutation alone.

Acknowledgements

This work is supported by China Postdoctoral Science Foundation funded project NO. 2013T60157 and Generalized Virtual Economy Research Fund NO. GX2011-1001(Z)).

References

[1] Subarna K.S,Ali H.M.Z. Co-movements of Oil,Gold,the U.S.Dollar,and Stocks[J]. Modern Economy,2012; 111-117.

[2] Chai J;Guo J E;Meng L Exploring the Core Factors and Its Dynamic Effects on Oil Price:An Application on Path Analysis and BVAR-TVP Model.Energy police,2011(12).
[3]Oscha Beckmann,Robert Czudaj, Oil prices and effective dollar exchange rates, International Review of Economics \& Finance June 2013;27(6): 621-636
[4] Juan Carlos Reboredo, Miguel A. Rivera-Castro, Gilney F. Zebende, Oil and US dollar exchange rate dependence: A detrended cross-correlation approach, Energy Economics March 2014;42(3): 132-139.
[5] Lingyu Y. Analysis of the International Oil Price Fluctuations and Its Influencing Factors. American Journal of Industrial and Business Management, 2012. An example appendix
[6] Hamilton, J. Understanding, Crude Oil Price. Energy Policy and Economics 023,2008.
[7] Krichene, N. World Crude Oil and Natural Gas: A Demand and Supply Mode. Energy Economics 2002;24: 557-576.
[8] Jeffrey A, Frankel and Andrew K.Rose. Currency Crashes in Emerging Markets: An Empirical Treatment [J].Journal of International Economics 1996(41): 351–366.
[9] Graciela L.Kaminsky, Saul Lizondo, and Carmen M.Reinhart.Leading Indicators of Currency Crises.IMF Staff Papers 1998(45):1-48.
[10] José Noguera, Oil prices: Breaks and trends, Energy Economics 2013;37(5): 60-67.
[11] Afees A. Salisu, Ismail O. Fasanya, Modelling oil price volatility with structural breaks, Energy Policy 2013;52(1): 554-562.
[12] En-Hsien Lee, Hsu-Ning Hu, Jer-Shiou Chiou, Jump dynamics with structural breaks for crude oil prices, Energy Economics 2010;32(2): 343-350