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Analysis and Bayes statistical probability inference of crude oil price change point

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ABSTRACT

This paper introduces the Poisson distribution, power-law distribution, and logarithmic-normal distribution as the prior distributions to construct Bayes statistical probability inference model for the simulation of the monthly crude oil price change point trends. Based on basic statistical cognition and product partition model (PPM), the historical change points are defined, identified, and analyzed. The PPM-KM integration model is established by combining PPM model and K-means method to measure, cluster, and identify the posterior probability of change points. The appearance probabilities of change points under different scenarios are calculated and compared for single recursive probabilistic predictions. The results showed there were 37 significant change points during 1986–2015. In different time points, unbalance of market supply-demand structure, sudden geopolitical event, the US dollar index, and global economic development situation have become the main reasons for oil price catastrophes. The monthly crude oil price change point complied with the power-law distribution hypothesis. It provides a new analytical perspective and is beneficial to governments, enterprises and investors to understand the market trends, avoid investment risks and make the right investment decisions.

1. Introduction

As an important strategic material, oil is one of goods which are most fluctuated (Regnier, 2007; Plourde and Watkins, 1998; Wang et al., 2016) and most active in transaction. In recent years, scholars have made all kinds of researches on the price fluctuation in crude oil price which have provided a lot of materials to establish effective pricing mechanism, risk management and energy policy. The research can be generally divided into two types, the first of which analyzes the volatility of oil prices based on econometric techniques using oil price data (Askari and Krichene, 2008; Gong et al., 2017; Kilian, 2009; Kilian, 2014; Hamilton, 2012; Hamilton and Wu, 2014; Hou and Suardi, 2012; Mohammadi and Su, 2010). In recent years, with the development of econometrics, many computational intelligence algorithms have been applied to oil price analysis and forecasting (Baruník and Malinska, 2016; Chiroma et al., 2015; Chiroma et al., 2013; Chiroma et al., 2016; Fan et al., 2016; Tang et al., 2017) and qualitative analyses of oil price volatility based on economic theory are another important method to understand the essential characteristics in the crude oil price fluctuations (Chai et al., 2011a, 2011b; Kilian, 2009; Ji and Fan, 2012, Wang et al., 2015; Wu and Zhang, 2014). Since 1973, the oil crisis has started another new round of researches on change points of commodity price. The international crude oil price has successively witnessed several drastic fluctuations, so a great many of scholars start to pay attention to the influence caused by the soaring oil price, especially the change point and structure break issue of drastic fluctuation in oil price which has drawn much attention from every aspect. In general, structural break is divided into three types, the change point is known, the change point is unknown, and the structural break occurs in the unit root test at a certain interval (Arouri et al., 2012; Chen et al., 2014; Chu and Morrison, 1984; Ewing and Malik, 2017; Popkin, 19274; Salisu and Fasanya, 2013; Leybourne et al., 1998). In 2015, the international crude oil price presented a wave-like decline, and the global crude oil supply was excess. Analyzing the tendency of international crude oil price and identifying the change point in the tendency of crude oil price are beneficial for the country, the enterprises, and the investors to understand market tendency, avoid investment risk, and make correct investment decision. Therefore, in the analysis on crude oil price tendency, the identification of price change points is of great importance, and the prediction of the time when the next change point of crude oil price appears has become a scientific issue with important theoretical and practical significance.

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The significant change of continuous rise or fall of crude oil price can be regarded as the transition from one mechanism to another mechanism in the inner generative mechanism of price time sequences, and that is to say the rise/fall state transfers to fall/rise. In fact, it is also a state catastrophe. The catastrophe theory has been widely verified in the field of natural science, but the interaction of different factors in the social field is more to provide an understanding, because in the social field, the systematic equation is unknown, and in addition with the time-dependent nature of system structure, the statistical methods are at most applied to verify the existence of some characteristics (Perron 1993; Labys and Maizels 1993; Labys et al. 1995). In fact, the change point issue has been a hot topic since put forward by Canova in 1970s (Canova, 1994). In recent several decades, no matter in the aspect of theory or application, the research on change point has been rapidly developed. The methods used to identify and handle change point issue include Choy inspection, Bayes method, maximum likelihood ratio method, Schwarz information criterion method, and product partition model (PPM) etc. On specific assumed conditions, all these methods can effectively judge and identify mean change point value, probable change point, and model change point. On the same assumptions, Chin Choy and Broemeling (1980) handled the change point issue of regression coefficient in generalized linear model. Due to the wide application, in mathematical statistics, the statistical inference of change point issue has become a research branch with great theoretical significance. Based Bayes method, Dey et al. (1997) handled the change point issue in uni-parameter exponential family of distributions of the number of known change points, and with this method, it is easy to obtain the marginal posteriori distribution of change point. Inclan (1993) applied Bayes method to research the multiple change points analysis of yield rate of shock price. Inclan and Tiao (1994) applied accumulative quadratic sum method to research the multiple change points issue of variance, and gave the IT test. This method features small calculated amount, but while detecting multiple change points, please separate the whole time sequence sample, so it is hard to guarantee that the change points obtained are of significance in an overall situation. Based on the assumption of knowing the number of change points, Ferreira (1975) made analysis on the change point of equation coefficient in simple linear regression model. Perron (1994) developed a recursive and sequential unit root and tendency breaking point assumption test, and Zivot and Andrews (1990) and Andrews (2003) took the breaking point as an unknown prior to give an asymptotic distribution of the statistical amount of predicted breaking points to test the structural breaking points of commodity price.

Although there has been significant research conducted on the changing oil price prediction trends and its influential effects, there have been few studies examining the identification and analysis of oil price saltation, and changes in the balanced oil price system structure. Moreover, most of the structural break research is related to unit root tests, there have been few articles on definition and identification of oil price change points. Zhang et al. (2009) analyzed the impact of the Iranian revolution, the Gulf War and the Iraq war on crude oil prices based on EMD model, and found that these three incidents all had a significant influence on crude oil prices, citing the Iranian revolution and the Iraq war, both of which had led to a structural break in oil prices. The impact models of these wars on oil prices all met the crisis model. Chai et al. (2014) used a product partition model (PPM) to identify and analyze the saltation of international oil prices and related influential variables. The results show eight significant breaking points of oil price. In the second quarter of 1999, breaking point of oil price was directly caused by the Asian financial crisis, the root cause is that the imbalanced structure of oil supply and demand. Specifically, the oil suppliers underestimated the oil demand of the market and China's net imports increased, as a result, a rapid decline the market underestimated of oil supply appeared in oil prices and a dramatic rebound in the short term. In the next seven breaking points of oil price, the US dollar index was one of the main direct causes. And geopolitical events and the anticipated changes or demand changes driven by economic conditions became the foundation of breaking point of oil price. At the same time, demand growth from emerging economies is also becoming a new factor for the breaking point of oil price. However, there is room for improvement in the price tolerance threshold.

In summary, research has been done on all aspects of crude oil market price volatility in recent years all of which has provided valuable information for oil market risk management and development. However, from current research, there have been few studies on the identification of oil price fluctuation status changes or comparative analyses on the impact of oil price fluctuations on the economy in different states, and, in particular, there have been very few articles on the analysis and prediction of the oil price change point. Moreover, in the modeling, whether it is for a study of system dynamics or a forecasting model, the key issue is to simulate the event probability distribution, especially in the tail of the distribution. Research has often simplified human behavior as a stationary random process which can be described by a Poisson process. Most research has assumed that the timing of oil price change points conforms to a Poisson distribution (D'Agostino and Stephens, 1986). However, with the continuous development of science and technology, there is now a great deal of data that can be recorded and analyzed. In 2006, a seminal article was published in Nature, which clearly revealed the deviation between human behavior and activities and the Poisson distribution (Barabási, 2005). Further studies into the effect of human activities have examined urban population distributions, internet information, market trading, finance, communications, natural disasters and a series of other issues, and have found that many human activities are not simply in a Poisson distribution, but in the power-law distribution with heavy tail characteristics. Power-law distribution allows for the frequent occurrence of events within a short time, with long periods of static activity after that. There are heavy characteristics in the time interval distributions of two adjacent events, which meet the inverse proportional function (Vázquez et al., 2006). In particular, many studies have shown that there is a significant correlation between the international crude oil price trends and that of the stock market (Cunado and Gracia, 2014; Masih et al., 2011; Chang and Yu, 2013; Kilian and Park, 2009). At the same time, many studies have also shown that the time interval distribution characteristics of stock trading obey the power-law distribution (Xavier et al., 2003; Zhou, 2007; Mayya and Santhanam, 2006; Haas and Pigorsch, 2009). Therefore, we plan to examine whether the crude oil price change point time interval complies with the power law distribution.

In this paper, the monthly international crude oil prices were taken as the study object and a model established based on monthly oil characteristics. The model establishment process took into account the internal complexities of oil price market fluctuations, introduced power-law distribution, Poisson distribution and logarithmic-normal distribution to study the crude oil price change point. First, based on the two thoughts of basic statistical cognition (statistical description) and PPM model (intelligence algorithm), the historical change points of crude oil price were defined, identified, and analyzed. During the analysis and identification of change point, the PPM-KM integration model was establish by extending PPM model to adapt to measure, cluster, and identify the posterior probability of change points of international crude oil price. We measure and calculate the posterior probability of sequential catastrophes of international crude oil price by PPM, and give the identification threshold value of posterior probability by combining K-Means method. Second, the appearance probabilities of the crude oil price change points in the two definitions and the three prior distribution models were calculated and compared. Finally, through a comparative analysis of the appearance probability in these three distribution models, the probability of the next crude oil price change point under different scenarios was predicted. The special schematic diagram of research is as follows Fig. 1.