Applied Economics Studies, Iran (AESI) **15**
Volume 9, Number 34, Summer 2020

Chaos theory and prediction of Future prices in the Oil Products

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Abstract
In this article, first, we discussed the concepts of oil and oil products. Then, the internal and external factors affecting the time series of the prices of these industries in the stock market were evaluated. Subsequently, the chaos theory and its formation and features were introduced. In addition, describing fractal time series, we investigated the feasibility of chaos in the time series structure of petroleum products prices in the stock market of Iran during a 10-year period. To this end, the Lyapunov exponent diagram, the correlation dimension and the Poincaré section map were used as chaotic tests. In order to obtain the Lyapunov exponent diagram and the Poincaré section map, the insert point was obtained through the false nearest neighbors and delayed time using the average mutual information algorithm. The results confirmed the chaos in this time series and showed the non-linearity of the daily price system of oil products. In the final section, an artificial neural network model was developed to predict the future prices of oil products. Based on the results, it can be concluded that this model has a relatively strong correlation coefficient for prediction.

Keywords: Time series prediction, Chaos theory, Lyapunov exponent, Poincaré section, Correlation dimension, Nonlinear models, Artificial neural networks.

JEL Classifications: E17, Q47, C45, C61, C53, C55.

1. Introduction
Financial and monetary markets are very good for the chaos theory, because, first and foremost, the existing and dominant theories in financial and monetary economics suggest that monetary variables such as exchange rates, are random and, as a result, their changes are unpredictable. Secondly, if the final order is discovered in the process of monetary variables, it will be possible to obtain huge profits. The price of energy industries in financial markets is one of the most important variables that, on the one hand, affect the economy of exporting and importing countries and, on the other hand, the process of managing and estimating the financial risk of portfolio stocks of investment companies (Akbari, 2020). Therefore, recognizing the price structure of this product and modeling it has always been the focus of economic research, and efforts have been made to investigate the cause of fluctuations and to predict them.

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Chaos theory can be tested in a system in two ways, either through the differential equations of that system or through its time series data (Strogatz, 2014). In this study, first, the definitions of chaos theory are given in the first step and, then, a review of the practical background of the research is provided. Then, in the next step, chaos tests are performed for the time series of petroleum products industries using the relevant software. Finally, the results and graphs obtained are interpreted and a solution is proposed to predict this industry. The tests applied in this industry were used for the time series of the price of petroleum products in the Tehran Stock Exchange market and also the designed neural network had a very good performance for forecasting.

2. Background

Lahmiri (2017) examined chaos in crude oil markets (Brent and WIT) before and after late 2008 when the international financial crisis occurred. After estimating the greatest Lyapunov's exponent for price, return, and chaos, the results showed that there was no chaotic system in both markets, before the international financial crisis, in price and return, but there was strong evidence that there is chaos in post-crisis volatility. This means that they saw chaos in the time series of prices and returns of both markets before the 2008 financial crisis, but after this crisis they found evidence for chaos. Thus, a dynamic international crisis affects crude oil fluctuations making them less predictable. In fact, due to the chaos in fluctuations after the international financial crisis, the behavior of fluctuations becomes irregular. They pointed out that these results should take into account the forecasts of the oil market, traders and risk managers. Dabbagh and Yousefi tested crude oil spot prices using computational tools of Lyapanov exponent, correlation dimension as well as phase space diagram. They found that the crude oil spot prices are, firstly, high dimension and, secondly, do not show a strong dependence on initial conditions. Therefore, they concluded that there are random and nonlinear rules in the dynamic market system of crude oil price points. They also showed that analysis of phase space reconstruction diagrams, clustering fluctuations is sufficient but not complete.

Using the chaos theory and its role in the implementation of national energy policy in a Brazilian state-owned company, Silvestre et al. (2018) showed that the recession in oil prices in 2015, along with the spread of corruption in the company, led to organizational chaos. They introduced strategic management policy and non-political interference in the level of organizational decision-making as a social and economic policy-making means of achieving their financial goals.

Cortez et al. (2018) pointed out that chaos theory and machine learning are used only to describe system behavior and not for prediction purposes. In fact, chaos theory can determine the dynamics of the system in the form of time delay and embedding dimension. They showed that these two methods are able to show the temporal relationships of variables and their evolution separately to better understand and provide a clearer picture of mineral markets.

Debnath and Mourshed (2018) systematically and critically reviewed the methods of predicting energy planning models. These methods were analyzed based on forecast accuracy, applicability for time and space forecasting, and relevance to planning and policy objectives. They called artificial neural network the most common method and used computational intelligence techniques to evaluate the accuracy of these methods. In fact, depending on the circumstances, they introduced a suitable method for forecasting.

Barunik and Malinska (2015) explained the structure of crude oil prices using the Nelson-Siegel dynamic model and introduced a general regression framework based on neural networks to predict oil prices. The proposed framework was experimentally tested over 24 years of crude oil prices, covering several recessions and periods of significant crisis. The 1-month, 3-month, 6-month and 12-month forecast strategies of this time-based neural network produced the lowest error of all time.

3. Method

The main and key concept in chaos theory is that there is order in every disorder. That is, order should not be sought on a single scale. A system is considered unpredictable when it is impossible to determine its next position and there is no possibility of predicting it. But, according to the theory of chaos, if such a system is monitored for a long time, by examining the state of the system at different times, it becomes clear that the system always displays its own inherent order. Even the most unpredictable (chaotic) systems always move within certain limits and never go beyond them. Also, a phenomenon that appears to be completely random and unpredictable on a local scale may be quite large, stable, and predictable on a larger scale.

In general, two perspectives are presented to examine the status of complex economic time series. In the first perspective, the question of whether a given time series is created by a specific or random process is examined. In the second view, an attempt is made to identify the chaotic or non-chaotic behavior of the time series. In this study, according to the concept of chaos, methods related to the second perspective are examined. These methods include the Lyapanov exponent diagram, Poincaré section map, and the correlation dimension calculation. In the following section, the methods of testing the existence of a turbulent process are examined.

Because the chaotic process of a particular nonlinear system is complex, linear models are not suitable for explaining the behavior of systems such as the petroleum industry. The success of neural networks in the analysis and prediction of nonlinear systems led to the use of neural networks to predict exchange rates, stock prices, economic planning, and various stock market indicators in the late 1980s. Out of 1989 data on the relevant time series, 80%

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are considered as training sets and the rest as test sets. In order to learn this neural network, after different experiments with different hidden neurons, a four-layer neural network was used in the first hidden layer of five neurons and in the second hidden layer of four neurons with tansig function in both layers.

4. Replication

One of the characteristics of chaotic systems is their sensitivity to changing the initial conditions. Lyapanov's exponent is one of the tools used for this purpose. If there is a small change in the initial condition of such a system, the effect of this change will become clearer over time, to the point that it creates a time path that is completely different from the previous one. This feature is known as the butterfly effect and can be estimated by looking at Lyapanov's exponent. Lyapanov’s exponents are the average convergence rate or divergence of adjacent paths in the phase space. Two phase parameters of time, latency, and circumferential dimension are required to obtain the phase space as well as the Liapanov diagram. In the present study, the time delay vector is obtained by means of the mean mutual information method (AMI) and the embedding dimension of the corresponding time series using the method of counting the nearest false neighbors (FNN). As shown in Fig 1, according to the results obtained, $\tau = 25$ and $m = 6$, respectively, show the results of time delay and embedding dimension. Liapanov's exponent is also positive, indicating that the time series is chaotic.

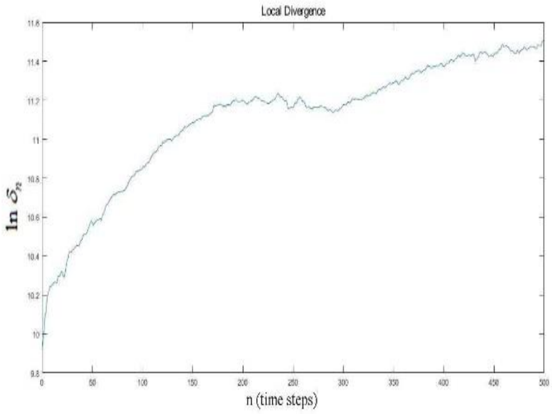

Fig. 1. Lyapunov exponent diagram for m = 6 and τ = 25

The Poincaré section is a means of testing the presence of chaos over a period of time. It is used for better display of the state space or phase space in a two-dimensional space. In other words, reducing the dimensional space mode provides a better understanding of the time phase space evaluation (see Fig 2).

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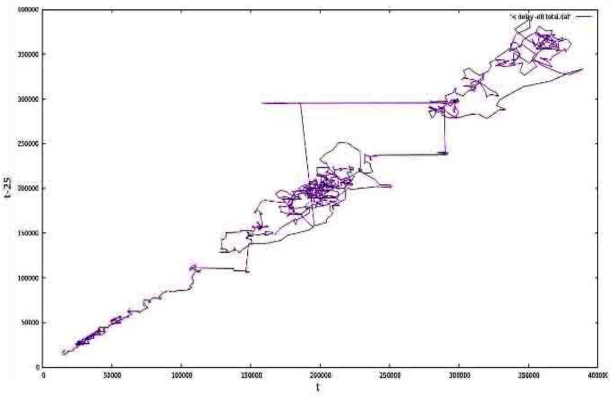

Fig. 2. Poincaré section diagram with delay time τ = 25

If the value of the correlation dimension of the number is correct, the geometric shape of our time series will be regular, and if this value is incorrect, then the system is considered as chaotic. As shown in Fig 1, the correlation dimension of the time series of oil products industry prices indicates that this series has a chaotic process because for chaotic systems, the correlation dimension is an incorrect number.

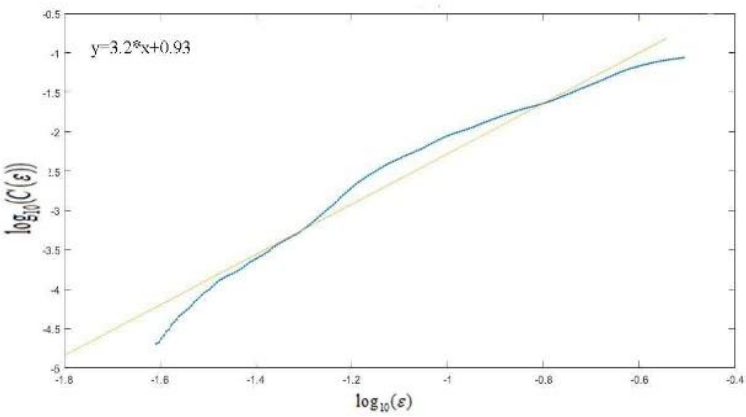

Fig. 3. Slope of correlation dimension test chart

According to the results obtained from different types of MLP neural network, the number of layers 2 as well as the number of neurons 4 and 5 and the stimulation functions of both tansigs have a correlation coefficient of 0.99831, which has the highest correlation coefficient and is selected as the desired neural network.

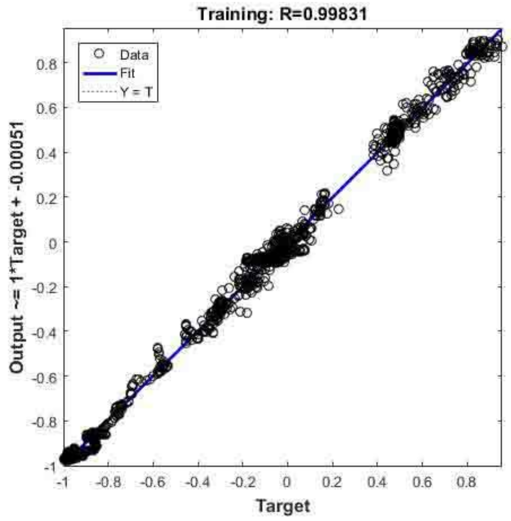

Fig. 4. Designed neural network correlation coefficient

5. Conclusion

Due to the large fluctuations, the time series price process of oil products is often considered random. Chaos theory seeks order in the seemingly random behavior of certain nonlinear dynamic systems. This theory in financial markets indicates that the prices of these markets follow a certain nonlinear relationship and can be predicted if they are fully aware of the initial conditions. In this study, chaos tests were conducted for the daily time series of oil products prices in the Tehran Stock Exchange over a period of 10 years and it was determined that the reason for price fluctuations in oil markets in this market is the internal mechanism of its generating system and foreign shocks and, coincidentally, they have no role in creating such seemingly erratic behaviors.

Since only time series data are derived from complex nonlinear dynamic systems, it is very important to estimate the appropriate embedding dimension and delay time to reconstruct the phase space and use them to estimate Lyapanov exponent to determine whether the desired dynamic system is chaotic or not in order to identify and predict the future. In the present article, Lyapanov exponent tests and Poincare section tests were used to investigate the chaotic time series of stock prices in the petroleum products industry. According to the tests conducted in this study, it can be concluded that due to the non-linearity of the time series price system of petroleum products, the use of linear models for estimating and forecasting will not be accurate and it is expected that forecasting with nonlinear models will be more accurate because artificial neural network models, due to their nonlinear and flexible structure, are able to learn, estimate, and predict any type of data-driven pattern. Therefore, in this paper, using artificial neural networks, an attempt was made to predict the future stock prices of petroleum products industries and use a four-layer progressive neural network with "tansig" nonlinear activation function as they have less error than other models. The price of petroleum products has been used to train the network. With this trained network, the future prices of these industries can be predicted with a very small error, and based on this prediction, strategic decisions can be made to achieve the goals.

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