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Predicting oil price movements: A dynamic Artificial Neural Network approach

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HIGHLIGHTS

- Nonlinear Auto Regressive model with eXogenous (NARX) inputs is developed for predicting oil prices.
- The results of NARX model in oil price forecasting is more accurate than those of time series and Artificial Neural Network.
- The NARX model predicts the price shocks in the oil market.
- The NARX model is dynamic and accounts for the factor of time.

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ABSTRACT

Price of oil is important for the economies of oil exporting and oil importing countries alike. Therefore, insight into the likely future behaviour and patterns of oil prices can improve economic planning and reduce the impacts of oil market fluctuations. This paper aims to improve the application of Artificial Neural Network (ANN) techniques to prediction of oil price. We develop a dynamic Nonlinear Auto Regressive model with eXogenous input (NARX) as a form of ANN to account for the time factor. We estimate the model using macroeconomic data from OECD countries. In order to compare the results, we develop time series and ANN static models. We then use the output of time series model to develop a NARX model. The NARX model is trained with historical data from 1974 to 2004 and the results are verified with data from 2005 to 2009. The results show that NARX model is more accurate than time series and static ANN models in predicting oil prices in general as well as in predicting the occurrence of oil price shocks.

1. Introduction

Since 1970s, the oil markets have been subject to strong periodic fluctuations and shocks. Price of oil, as a globally traded commodity, is sensitive to changes in economic conditions and political events (Adrangi et al., 2001; Panas and Ninni, 2000). Oil prices also affect the economic prosperity of both oil exporting and oil importing countries. In addition, price of oil, directly and indirectly, impacts various markets including those of other energy carriers. Hence, a better understanding of the likely future behaviour of oil prices can reduce vulnerability of the economy from fluctuations and changing conditions in the oil market.

However, the inherent difficulty to predict the oil price shocks[1] is a major challenge and is reflected in the diversity of the previous studies on the subject. The literature has used several approaches to predicting oil price (Section 2). These have led to different price predictions and levels of accuracy. More precisely, due to the complex interactions between economic and other factors which affect oil price, the traditional approaches for prediction of oil prices have exhibited some shortcomings (Mirirani and Li, 2004; Tang and Hammoudeh, 2002).

The present study aims to improve the modelling and accuracy of predictions of oil prices and shocks. We address this issue mainly through using a time factor, which enables the model to be dynamic and better predict the prices and price shocks. We develop a dynamic Artificial Neural Network (ANN) approach known as Nonlinear Auto Regressive model with eXogenous input (NARX). To our knowledge, the present study is one of the few to use the Mackinnon–White–Davison (MWD) test to analyse and compare different models of oil price prediction. The model is optimised by identifying dummy variables which help the inclusion of qualitative factors[2] and time

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[1] Sudden fluctuations in oil price as a result of factors such as political crisis, disturbance in the oil supply, and unilateral decisions by oil exporters (see Appendix B).

[2] In this study, we consider the supply-side factors which affect oil price as qualitative factors. For more details see Section 4.1.2.

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Nomenclature

C	total consumption (US$)
COP	crude oil price (US$)
d_k	actual value of unit k
E	error
EP	energy production (kt of oil equivalent)
EU	energy use (kt of oil equivalent)
FC	final consumption expenditure (% annual)
GDP	gross domestic product (US$)
GG	GDP growth (%)
GP	gold price (US$)
OIR	oil rent (US$)
O_i	activation of unit i
P_t	number of delay input i
q	number of delay output unit
R^2	adjusted R-squared
r	GDP growth (%)
RSME	root square mean error
T	number of entire data
T	time
w_{ij}	weight from unit j to unit i
y_i	activation function of unit i

Subscripts

H	hidden unit
I	input unit
j	hidden unit
k	output unit

delays. Additionally, we use a three-step approach (time series, ANN static and NARX) that allows validating the results and assessing the improvement in the accuracy of the model after each stage. We show that the application of the NARX model enhances the dynamic performance of the model and improves the ability of the ANN methodology to predict oil price and in particular the occurrence of price shocks.

The next section provides a brief overview of the previous methods and studies for predicting the price of oil. Section 3 describes the general aspects of the methodology and the data used in this paper. Section 4 describes times Series, ANN and NARX models developed in this study and presents and compares the results obtained from them. Section 5 is the conclusions.

2. Previous studies

Previous studies of oil price prediction have used a range of approaches and techniques. Broadly, these approaches can be classified into (i) Auto-Regressive Conditional Heteroskedasticity (ARCH), (ii) simulation, (iii) value at risk, and (iv) mathematical modelling. Table 1 summarises a selection of these studies. As shown in the table, these have used different techniques and time spans and have achieved differing results and degrees of accuracy, thus leaving scope for further improvements.

In order to mitigate such deficiency, we use dynamic models to account for time dependency of oil price (Movagharnejad et al., 2011). ANN is a suitable technique for such a purpose (Kermanshahi, 1998) and has been applied to modelling and forecasting of the behaviour of nonlinear economic variables. For example, Nakamura (2005) has employed a Multi-Layer Perceptron (MLP) method for forecasting inflation and Zhang and Qi (2005) explore applicability of neural networks to forecast seasonal time series with a trend component.

To our knowledge, the literature on the application of the ANN method for forecasting the oil price is rather limited. Ghaffari and Zare (2009) forecast the West Texas Intermediate (WTI) crude oil spot prices using a combination of ANNs and Fuzzy Logic. Movagharnejad et al. (2011) used ANN and a time variable as a constant variable; thus the dynamic nature of the process was not accounted for. In order to account for time dependency of the variables Jammazi and Aloui (2012) applied mathematical models while Yu et al. (2008) used short periods of time for modelling.

3. Methodology and data

The methodology used in this paper consists of three distinct but complementary stages namely time series, ANN static, and ANN dynamic (NARX). While each stage (method) could be used to obtain some results (i.e., oil price prediction), applying the chain analysis (to improve the results of previous stage) makes it possible to increase the overall accuracy of the analysis. Details of the procedure applied in this paper are as follows:

- Stage 1: Time series: A time series model is used to identify the factors affecting oil price and to calculate the number of lags of independent and dependent variables (inputs for ANN static and NARX). The time series model itself will be further developed to obtain the final results (time series oil price prediction).
- Stage 2: ANN static: In order to validate the applicability of the result of the time series (inputs for the NARX model) we develop an ANN static model to verify the data and to prevent possible errors in the NARX model. The static ANN model is developed following the methodology described in Movagharnejad et al. (2011) and based on the results of time series analysis in Stage 1 (i.e., the factors with the biggest impacts on the oil price). The results of this stage are comparable to those previously reported in Movagharnejad et al. (2011).
- Stage 3: Using the time series results (i.e., main factors affecting oil price and the number of lags), the NARX model is used to include the time factor in the analysis.

In each of the stages above, the R-squared was compared to the previous stage to ensure improvement in the accuracy of the results. A description of alternative methodologies is presented in the following subsections. A detailed application of these methods for predicting the oil prices is discussed in Section 4.

3.1. Time series (TS)

A time series is a stretch of values (observations on the values) that a variable takes at successive points in time. Times series data is usually spaced at uniform time intervals (Brillinger, 2001; Greene, 2003; Gujarati and Madsen, 1998). Time series forecasts the future based on past data. In other words, time series analysis models use previously observed values in a trend to predict the future values (Greene, 2003). A critical step in time series