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# Markov Switching Artificial Neural Networks for Modelling and Forecasting Volatility: An Application to Gold Market

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**Abstract**

The study analyses the family of regime switching GARCH neural network models, which allow the generalization of MS type RS-GARCH models to MS-GARCH-NN models by incorporating with neural network architectures. Proposed models differ in terms of both the dynamics of the conditional volatility process and the forecasting capabilities compared to a family of GARCH models. Gray (1996) RS-GARCH model allows regime dependent heteroscedasticity structure following the markov switching methodology of Hamilton (1989). The MS-GARCH-NN model family differ in the sense that, they allow regime switching between GARCH-NN processes. Single regime GARCH-NN models are developed by Donaldson and Kamstra (1996) and further extended by Bildirici and Ersin (2009). Further, the proposed models incorporate a variety of neural network architectures. MS-GARCH-MLP and MS-GARCH-Hybrid-MLP models by Bildirici and Ersin(2014) are augmented with fractional integration (FI) and asymmetric power GARCH variants. And they developed models are MS-FIGARCH-Hybrid-MLP, MS-APGARCH-Hybrid-MLP and MS-FIAPGARCH-Hybrid-MLP models. In this paper, these models were used to test volatility of gold return. Tests are evaluated with MAE, MSE and RMSE criteria and equal forecast accuracy is tested with modified Diebold-Mariano tests. An empirical application is provided for forecasting daily returns in gold market. The results suggest that the proposed approach performs well in modeling and forecasting volatility in daily returns of international gold market.


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*Keywords*: Volatility, Gold, Neural Networks, Markov Switching- GARCH , MS-FIGARCH-Hybrid-MLP, MS-APGARCH-Hybrid-MLP, MS-FIAPGARCH- Hybrid-MLP

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## 1. Introduction

Some papers analyzed the volatility of price of gold. If the results obtained by the papers, which examined the relationship between oil and gold price in the literature, are investigated, it is observed that different results are obtained.

Pindyck and Rotemberg(1990) tested and confirmed the claim that the prices of raw commodities have a persistent tendency to move together. Melvin and Sultan (1990) searched the relation between oil and gold and they determined a strong positive correlation between oil and gold through the export revenue channel. Cashin et al.(1999) analyzed the correlations between seven commodities and they found that there exist significant correlation between oil and gold. Nakamura and Small(2007) determined that both daily gold price and oil price had essentially random walk, and their first differences were independently distributed random variables or time-varying random variables(Zhang and Wei:2010). Sari etal.(2007), examined the relation between commodity prices such as oil, gold, silver and copper and two financial variables such as exchange rate and interest rate. They determined that both gold and exchange rate can explain some of the movements in oil price. Beahm(2008) determined that relationship between oil price and gold price was one of the fundamentals that drive the prices of precious metals. Hammoudeh et al. (2008) pointed out that the price of gold was the forcing variable of the oil price. Liao and Chen (2008) analyzed the relationship between oil prices and gold prices in Taiwan by using TGARCH model and they found that fluctuations of return of oil price influence the returns of gold prices. Ewing et al.(2012) and Fattouh(2010a and b) examined the asymmetry in the adjustment process for oil and metal commodities.

Chiu et al. (2009) showed that there is a unidirectional causality running from WTI oil to gold (Le and Chang: 2011). Narayan et al.(2010) found co-integration relationship between spot prices of gold-oil and future prices of gold-oil. Zhang and Wei (2010) found out a consistent trend between crude oil and gold price during period of January 2000 and March 2008. Oil price linearly Granger causes the volatility of gold price but changes in gold price do not linearly cause oil price volatility. Wang et al. (2011) found bi-directional causal relationship between oil price and gold price. Hsiao et.al. (2013) tested the correlation among oil prices, gold prices and exchange rates over the period between 09.2007 and 12.2011.

Some papers used to non-li,near models to analyse the relation between variables. For example, Bildirici and Turkmen(2015) aims to analyze the cointegration and causality relationship among oil and precious metals of gold, silver and copper by using nonlinear ARDL and two popular nonlinear causality tests; Mackey Glass and non-linear casualty, for the period from 1973:1 through 2012:11 monthly. Some other papers used GARCH models.

Ewing and Malik (2012) employed univariate and bivariate GARCH models to examine the volatility of gold and oil incorporating structural breaks. They found strong evidence of significant transmission of volatility between returns of gold and oil when structural breaks in variance are accounted for in the model. Some of these studies explained the relationship between gold and oil prices through the inflation channel. Gencer and Kılıç(2014) tested the impact of oil and gold returns and their volatilities via multivariate CCC M-GARCH model. They analysed 28 different portfolio investments consisting equal investments in oil, gold and each sector index by turn and determined that oil GARCH effects are significant and close to unity in each model. According to their's results, Gold GARCH effects follow oil GARCH parameters in magnitude, implying that gold prices also have significant effects on portfolio volatility. Tiwari and Sahadudheen (2015), explored the relationship between real oil price and real gold price over a period of 1990 April to 2013 August. In order to check for the impact of real oil price on the real gold, return on real oil and return on real gold are used. The study employed types of GARCH models which suggested that an increase in real oil price has positive effects on gold. The EGARCH model provides the evidence that a 10% increase in the oil price returns leads to 4.7% increase of gold and shocks to gold price have an asymmetric effect, which means positive and negative shocks have different effect on gold price in terms of magnitude.

This study can be defined as complementary of the previous empirical papers. This paper is aim to investigate the volatility of return of gold price in Turkey. Since Turkey is the fourth largest gold-consuming country. Gold is