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# Time Series and Neural Networks Comparison on Gold, Oil and the Euro

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***Abstract.*** **Gold, oil, and the euro are three very important economic markets that have been studied individually by numerous authors. But certain basic questions about their inter-relationships since the year 2000 remain unaddressed. Gold has been an important commodity for several centuries. Oil's importance grew during the 20th century, and the euro has become important during the 21st. Standard economic analysis allows us to hypothesize about a specific relationship and test for it, and a neural network gives us the ability to identify important variables in a forecast without forming a prior hypothesis about the relationship of each variable to the target.**

**This paper analyzes the inter-relationships among the price behavior of gold, oil and the euro using a standard time series methodology then employs neural networks to build a forecast for each of the three variables. We then compare the results of the neural network to those implied by the time series tests. The statistical evidence of time series analysis demonstrates that both short-term and long-term relationships exist between the three variables. Both the time series and neural network results indicate that the series move together though they identify slightly different relationships. The time series results imply that oil adjusts to gold, the euro and oil have equal affects on each other, and the weakest relationship is between gold and the euro. The neural network indicates that oil impacts gold more than gold impacts oil, oil's affect on the euro is greater than the euro's effect on oil and last, gold's impact on the euro is greater and faster than the euro's impact on gold.**

## I. Introduction

Numerous studies have analyzed the relationships between oil prices and the impact those prices have upon the U.S. economy. The traditional line of argument goes like this: crude oil prices influence several energy related products such as gasoline, heating oil and natural gas that in turn impact the producer price index, the consumer price index and other inflation indexes. Since inflation is a fundamental topic, economists have studied extensively not only how to control inflation via monetary and fiscal policies but also how to hedge against it. A long standing hypothesis claims that gold is a potential hedge against inflation.

The gold and oil markets each have a long history. Past evidence suggests that gold has played the longest and most influential economic role in history during the last 150 years since it anchored the British pound as a global currency. Oil emerged as a significant economic force in the early and mid-1970s and its influence remains substantial to date. In contrast to the significant economic roles that gold and oil have played for a long period, the euro was created on January 1, 1999 and, in a relatively short period of nine years since its creation, is challenging the US dollar for global currency leadership. The depreciation of the US dollar against the euro has generated fears of global inflation for countries that peg their currency to the dollar. In turn, the appreciation of oil, fueled increases in the price of gold. In this paper we consider the questions of whether increases in the prices of one of the three markets are related to the current or lagged appreciation of the other markets and whether the time series and neural network results yield complimentary information.

## II. Review of the Literature

Recently Bordo, Dittmar and Gavin [1] and several other authors earlier such as [2]-[9], among numerous others, have presented various aspects of the role of the gold standard as a global monetary system. These studies document the role of gold in preserving price stability. The main disadvantage of the gold standard was its cost in terms of constraining real economic growth.

Independent of anchoring the global monetary system on gold, after August 15, 1971, the metal ceased its association with global monetary matters but maintained its property as an indicator of inflation. Diba and Grossman [10] argued theoretically and investigated empirically whether the price of gold exhibits rational bubbles. They concluded that the empirical analysis finds a close correspondence between the time series properties of the relative price of gold and the time series properties of real interest rates. Theoretically, real interest rates are a proxy for the fundamental component of the relative price of gold. The authors conclude the evidence is consistent with the combined hypothesis that the relative price of gold corresponds to market fundamentals, that the process generating first differences of market fundamentals is stationary, and that actual price movements do not involve rational bubbles. From 1982 to 2005, the price of gold fluctuated between \$250 and \$500. During the past 3 years the price of gold has skyrocketed to over \$1,000.

With regard to oil, we can organize the large literature into microeconomic and macroeconomic studies. Representative of the first approach is the recent study [11] that develops a five-region model of the global economy and considers various scenarios to study the

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implications of different shocks driving oil prices worldwide. The model introduces significant real adjustment costs in the energy sector, making both the demand and supply for crude oil extremely inelastic in the short run, thus requiring large movements in crude oil prices to clear the energy market.

To answer the question about the underlying causes of the oil price run-up since 2003, the authors offer a story based on stronger productivity growth in oil importing regions coupled with shifts in oil intensity in production (emerging Asia), and (to a much lesser extent) pure price increases by oil producers. Oil price shocks stemming from higher growth in the oil-importing regions are accompanied by wealth transfers through terms-of-trade movements, leading consumption to grow slower than output in the oil-importing regions. In the medium term, high investment rates in the high-growth regions crowd out investment in the oil-exporting regions. These results need not hold if higher oil prices bring about expectations of a larger availability of oil reserves in the future. Moreover, the positive effects of higher oil prices on consumption need not translate into reduced current account surpluses in the oil-exporting regions, to the extent that they are accompanied by an upward shift in the desired net foreign asset positions. The conclusions about the role of increased productivity in the oil-importing regions can be reinforced by considering emerging Asia in particular, with its increased intensive use of oil in the production of tradable goods.

The second approach assesses the macroeconomic impact of the oil sector on the economy. Numerous authors [12] – [22] have studied various implications of the price of oil on the U.S. economy, inflation and monetary policy. Some broad conclusions come from these studies. First, the effects of oil price shocks must have coincided in time with large shocks of a different nature. Second, the effects of oil price shocks have changed over time, with steadily smaller effects on prices and wages, as well as on output and employment. Third, one plausible cause for these changes is a decrease in real wage rigidities since such rigidities are needed to generate the type of large stagflation in response to adverse supply shocks such as those that took place in the 1970s. Fourth, another plausible cause for these changes is the increased credibility of monetary policy. Fifth, these changes may have simply been caused by the decrease in the share of oil in consumption and in production. The decline is large enough to have quantitatively significant implications.

With respect to the euro, in a matter of a few years, a very large bibliography has emerged that describes the creation of this new global currency and its relative success. Portes and Rey [23] offer a comprehensive background of the monetary history of the emergence of the euro while others [24] – [26] speculate on euro's future emergence as a competitor to the U.S. dollar. The euro initially weakened from 1999 to 2001, but since 2003 has strengthened considerably against the U.S. dollar.

Neural networks and other non-linear techniques have been used for various studies related to the gold, oil and euro markets. Grudnitski and Osburn [27], for example, forecast gold futures prices and Shambora and Rossiter [28] use neural networks for the oil futures market. Binner [29] builds neural networks to forecast euro inflation using measures of inflation and monetary aggregates. They find the neural networks superior to linear models. Jamaleh [30] finds that forecasting the euro/dollar exchange rate using interest rates, GDP and inflation with non-linear models provides reliable forecasts. Belaire-Franch and Opong [31] find that the behavior of the euro exchange rates are consistent with random walk behavior. Dunis and Williams [32] also find that neural network models have an advantage over traditional techniques in forecasting the euro/dollar exchange rate.

## III. Problem Statement

This rapid review of the literature illustrates that gold and oil have played important roles and have been studied essentially independent of one another. Gold has served as the anchor of the Global Monetary System known as the Gold Standard. Since the introduction of the euro and in particular during the past few years, the euro, gold and oil appear to be interrelated.

We argue that oil, gold and the euro as assets follow random walks and are cointegrated. Furthermore we claim that these time series properties that have emerged between these three markets the last few years allow one to develop forecasting models using neural networks to predict one market using past information from the same and the other two markets.

## IV. Data and Methodology

We use daily futures settlement prices measured in dollars for gold, oil, and the euro. The data sample covers the time period from January 4, 2000 through December 31, 2007 and was downloaded from BarChart. There are a total of 1,991 observations for prices for each of the three daily closing prices. All numbers are converted to logarithms and, for the forecasting model, the target variable is the natural logarithm of each of the specified variables. The inputs are the lagged natural logs for 5 days of the euro, gold, and oil. Input variable names were designed as follows: L indicates the natural log, the variable names occurs next, last M followed by a number indicates the number of lags. Thus, LGoldM2 indicates the natural log of gold two days ago. Figure 1 shows the natural logarithm of the three data series from 2000 through 2007 with the left y-axis for LnGold and the right y-axis for LnOil and LnEuro.

Several time series tests were run on the data set. The augmented Dickey and Fuller tests of stationarity and tests of cointegration are used first. If the variables are stationary, designated as I(0), then the distribution does not change when shifted in time and has limited memory of its past behavior. If they are cointegrated, then a linear combination of the variables is stationary.

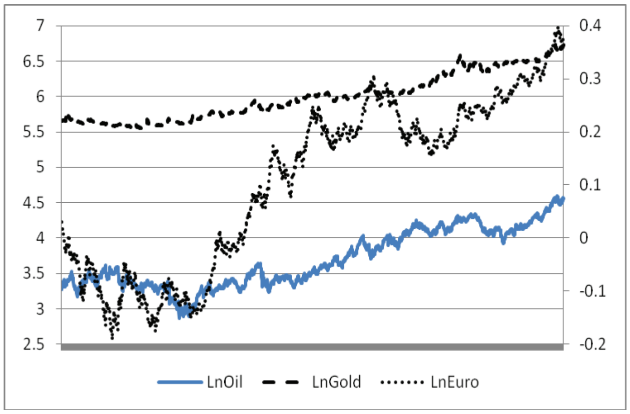


Fig. 1. Natural logs of the three data series.

### A. *Test of Stationarity*

The stationarity of price is tested with the augmented Dickey and Fuller (ADF) [33], test:

$$X_t - X_{t-1} = b_0 X_{t-1} + \sum_{i=1}^{T} b_i \left( X_{t-i} - X_{t-i-1} \right) + \varepsilon_t \qquad (1)$$

where $X_t$ represents the logarithm of the price of the appropriate variable and is called the level of the variable. The null hypothesis of non-stationarity is $b_0 = 0$. If the null hypothesis cannot be rejected for the level of the variable but is rejected for the first difference, then the variable is stationary in the first difference and it is said that the variable is integrated of order 1, denoted by I(1). An I(1) series has an infinite memory, that is the influence of the starting value of the series persists. Model (1) can be extended to include a constant and/or a trend as indicated in Table I.

### B. *Tests of Cointegration*

If two time series, $X_t$ and $Y_t$, are both nonstationary but stationary in the first difference, it is said that variables, $X_t$ and $Y_t$, are I(1). If two variables, $X_t$ and $Y_t$, are both I(1), their linear combinations, $Z_t = X_t - \alpha Y_t$, are generally also I(1). However, if there is an $\alpha$ such as that $Z_t$ is I(0), then $Z_t$ is integrated of order 0 or stationary in level. If $Z_t$ is I(0), then the linear combination of $X_t$ and $Y_t$ is stationary and it is said that the two variables are cointegrated. Cointegration represents a long-run equilibrium relationship between two variables. The intuition behind cointegration is that beyond the random walk followed by each variable such randomness preserves a relationship between the two variables.

Engle and Granger [34] propose several methods to test for cointegration between two time series. This study follows the approach of first running the cointegration regression:

$$X_t = \alpha_0 Y_t + \varepsilon_t \qquad (2)$$

and then running the ADF regression

$$\varepsilon_t - \varepsilon_{t-1} = b_0 \varepsilon_{t-1} + \sum_{i=1}^{T} b_i \left( \varepsilon_{t-i} - \varepsilon_{t-i-1} \right) + \mu_t \qquad (3)$$

on the residuals of (2). The null hypothesis of no cointegration is $H_0$: $b_0 = 0$. If the null hypothesis is rejected, then the variables, $X_t$ and $Y_t$, are cointegrated and there is some long-term relationship between them.

## V. Time Series Results

The results of our empirical testing are presented in Tables I, and II. More specifically we have found the following.

First, the natural logarithms of the prices of oil, gold and the euro follow random walks. These random walks are of three types: a random walk with no constant and no time trend, random walks with a constant and a random walk with a constant and trend. We have also tested these three models with only one lag or several lags, the length of these lags having been decided by the Akaike criterion.

While the log price levels of gold, oil and the euro follow three types of random walks, the hypotheses that their differences are also random walks is rejected in the lower level of Table I. Thus we conclude that oil, gold and the euro are integrated of order one written as I(1).

In Table II we find that there is a long-term relationship between any two of the variables. In other words we find that the logarithms of the variables are cointegrated. The t-statistics indicate that in order of significance the relationship between gold and oil is the strongest. This means that although the two markets appear to move together there is evidence that oil adjusts to gold rather than vice versa. Secondly, oil and the euro have a longrun equilibrium relationship and each market adjust quickly to the other without any one market being the driving force. The weakest relationship is between gold and the euro with some minor evidence that increases in gold generate decreases in the value of the dollar which equivalent to increases in the euro. Combining these results we conclude that gold, oil and the euro follow longrun relationships in such a way that gold influences the price of oil and then the price of oil influences the value of the euro. Oil is influenced by both the price of gold and the price of the euro and then it in turn influences the price of oil and gold. The Euro is influenced by the price of oil primarily and a little less by the price of gold.

TABLE I.
AUGMENTED DICKEY-FULLER TESTS OF STATIONARY

A. PRICE LEVEL (LN(X))

| | Lags | Only Lags | Lags and Constant | Lags, Constant, and Trend |
|---|---|---|---|---|
| Gold | | | | |
| | 0 | 2.361 | 0.667 | -2.837 |
| | 5 | 2.364 | 0.694 | -2.844 |
| | 20 | 2.374 | 0.766 | -2.863 |
| Oil | | | | |
| | 0 | 1.192 | -0.626 | -2.760 |
| | 5 | 1.314 | -0.462 | -2.542 |
| | 20 | 1.368 | -0.235 | -2.457 |
| Euro | | | | |
| | 0 | 0.632 | -0.079 | -3.035 |
| | 5 | 0.659 | -0.050 | -3.064 |
| | 20 | 0.521 | -0.294 | -2.658 |

B. FIRST PRICE DIFFERENCES (LN(XT) - LN(XT-1))

| | Lags | Only Lags | Lags and Constant | Lags, Constant, and Trend |
|---|---|---|---|---|
| Gold | | | | |
| | 0 | -46.656 | -46.779 | -46.817 |
| | 5 | -18.687 | -18.867 | -18.934 |
| | 20 | -9.390 | -9.699 | -9.834 |
| Oil | | | | |
| | 0 | -45.223 | -45.250 | -45.249 |
| | 5 | -19.521 | -19.575 | -19.590 |
| | 20 | -10.211 | -10.311 | -10.357 |
| Euro | | | | |
| | 0 | -46.051 | -46.077 | -46.104 |
| | 5 | -17.925 | -17.972 | -18.020 |
| | 20 | -9.112 | -9.214 | -9.259 |

In Table I, the model is:

$$\Delta X_t = a_0 + a_1 \cdot t + a_2 \cdot X_{t-1} + \sum_{i=1}^{T} c_i \cdot \Delta X_{t-i}$$

The null hypothesis is $H_0$: $a_2 = 0$ (variable is not stationary). The MacKinnon critical values for rejection of the null hypothesis of only lags are 1% critical value = -2.58, 5% critical value = -1.95, and the 10% critical value = -1.62. The MacKinnon critical values for rejection of the null hypothesis of lags and constant are 1% critical value = -3.43, 5% critical value = -2.86, 10% critical value = -2.57. The MacKinnon critical values for rejection of the null hypothesis of lags, constant, and trend are 1% critical value = -3.96, 5% critical value = -3.41, 10% critical value = -3.12.

TABLE II.
ENGLE AND GRANGER TEST OF COINTEGRATION OF LN(PRICE)

| Dep Var (X) | Indep Var (Y) | $b_0$ | t-stat |
|---|---|---|---|
| Gold | Oil | -0.009211 | -2.920998 |
| Oil | Gold | -0.010399 | -3.122336 |
| | | | |
| Gold | Euro | -0.003219 | -1.723030 |
| Euro | Gold | -0.003753 | -1.950192 |
| | | | |
| Oil | Euro | -0.006973 | -2.584827 |
| Euro | Oil | -0.006324 | -2.512779 |

In Table II, the model is

$$X_t = a_0 + a_1 \cdot Y_t + \varepsilon_t$$

$$\Delta\varepsilon_t = b_0 \cdot \varepsilon_{t-1} + \sum_{t=1}^{T} \Delta\varepsilon_{t-1} + \mu_t$$

The null hypothesis is $H_0$: $b_0 = 0$ (variable is not stationary). The MacKinnon critical values for rejection of the null hypothesis are 1% critical value = -2.58, 5% critical value = -1.95, 10% critical value = -1.62.

Since the variables are co-integrated we also test for causality and find that Granger causality holds among any pair of variables. Finally we also form an error correction model in Table III. The key findings of this test indicate that three longrun relationships emerge as judged by the t-statistics: gold has a longrun relationship to oil and also the euro has a significant relationship to oil. This finding suggests that beyond the specific microfoundations of the oil market, one must consider both the behavior of gold and euro as determinants of the price of oil. We also find that the price of gold has a strong longterm relationship to the euro. Short-term the euro and oil are also interrelated. Table III is shown in three parts due to the width of the table. The null hypotheses are: No long-run relationship from X to Y: H0: ai = 0 and No short-run relationship from X to Y: H0: ci = 0

TABLE III.
ERROR-CORRECTION MODEL TESTING
PART A.

| **Dep Var** | **Indep Var** | **$a_1$ (t-stat)** | **$c_1$ (t-stat)** | **$c_2$ (t-stat)** |
|---|---|---|---|---|
| Gold | Oil | 0.00 | 0.00 | 0.00 |
| | | (-0.93) | -0.26 | (-0.059) |
| Oil | Gold | -0.01 | -0.10 | -0.02 |
| | | (-2.85) | (-1.97) | (-0.30) |
| Gold | Euro | 0.00 | 0.12 | 0.01 |
| | | -0.13 | -2.91 | -0.19 |
| Euro | Gold | 0.00 | -0.02 | 0.01 |
| | | (-2.22) | (-1.33) | -0.81 |
| Oil | Euro | -0.01 | -0.04 | 0.03 |
| | | (-2.66) | (-0.52) | -0.37 |
| Euro | Oil | 0.00 | 0.00 | 0.00 |
| | | (-0.84) | -0.39 | (-0.51) |

PART B.

| Dep Var | Indep Var | $c_3$ (t-stat) | $c_4$ (t-stat) | $c_5$ (t-stat) |
|---|---|---|---|---|
| Gold | Oil | 0.01 | 0.00 | 0.00 |
| | | -0.92 | -0.05 | -0.25 |
| Oil | Gold | -0.01 | -0.01 | -0.06 |
| | | (-0.17) | (-0.099) | (-1.14) |
| Gold | Euro | -0.05 | -0.03 | -0.06 |
| | | (-1.12) | (-0.61) | (-1.36) |
| Euro | Gold | -0.01 | 0.01 | 0.00 |
| | | (-0.44) | -0.76 | -0.16 |
| Oil | Euro | 0.08 | -0.07 | -0.29 |
| | | -0.92 | (-0.87) | (-3.41) |
| Euro | Oil | 0.00 | 0.00 | 0.00 |
| | | -0.26 | (-0.68) | -0.32 |

PART C.

| $H_0$: No Relationship | | F stat Prob. | | |
|---|---|---|---|---|
| Dep Var | Indep Var | No LT Imp. | No ST Imp. | No LT or ST |
| Gold | Oil | 0.86 | 0.19 | 0.34 |
| | | -0.35 | -0.97 | -0.92 |
| Oil | Gold | 8.09 | 1.09 | 2.10 |
| | | 0.00 | -0.37 | -0.05 |
| Gold | Euro | 0.02 | 2.23 | 1.86 |
| | | -0.90 | -0.05 | -0.08 |
| Euro | Gold | 4.92 | 0.77 | 1.47 |
| | | -0.03 | -0.57 | -0.18 |
| Oil | Euro | 7.10 | 2.75 | 3.34 |
| | | -0.01 | -0.02 | 0.00 |
| Euro | Oil | 0.71 | 0.20 | 0.29 |
| | | -0.40 | -0.96 | -0.94 |

## VI. Neural Network Results

We first selected a random 10 percent of the data from each year of the data set from 2000 through 2007 to use as a validation set. We built a forecast for the euro, then oil, and lastly, gold. The architecture for each network used 15 input variables (5 lags each of gold, oil, and the euro), one hidden layer with 30 neurons, and one output (either LGold, LOil, or LEuro). Each neural network was developed using the SPSS package Clementine. Clementine develops the neural network using a 50/50 split of the data set for training and testing-while-training. This split helps prevent over-training. It stops when a specified accuracy level is reached then uses the best network as the final one. A sigmoid function is used, alpha is set to 0.9, and the initial eta is 0.3. The output of the generated model in Clementine lists the variables by order of importance to the model. This is determined by which input variable led to the greatest reduction in the variance of the output.

Table IV gives the estimated accuracy of the forecast on the training set and the MSE of the networks on both the training and validation sets. Accuracy in Clementine is defined as the average, over all records on the training data, of (1.0 – abs(Actual – Predicted)/(Range of Output Field)) * 100.0. The estimated accuracy is above 98% for all three models, indicating that the inputs are of value to the target, or that the markets do move in ways that provide information to each other. The MSE results are similar for both the training and the validation sets, indicating model robustness for each of the forecasts. Thus the neural networks are able to use information from the cointegrated variables to develop a good forecast.

TABLE IV.
NEURAL NETWORK RESULTS

| | LEuro | LGold | LOil |
|---|---|---|---|
| Est. Acc. | 99.186 | 99.385 | 98.955 |
| Training MSE | 0.000039 | 5.30 | 0.000596 |
| Validation MSE | 0.000043 | 5.24 | 0.000487 |

Also of interest are the particular variables identified as most important to the forecast. The neural network generates a sensitivity analysis that ranks the variables in order of their importance to the network. This relative influence of each of the input variables for the three networks can be seen in Table V. The top 5 variables for each model are shown in bold. In all networks, the first

TABLE V.
NN VARIABLE SIGNIFICANCE

| Target<br>Rel Imp of Inputs | LEuro<br>Signif. | LGold<br>Signif. | LOil<br>Signif. |
|---|---|---|---|
| LEuroM1 | **0.790** | 0.031 | 0.010 |
| LEuroM2 | 0.026 | 0.048 | 0.024 |
| LEuroM3 | 0.036 | 0.014 | 0.023 |
| LEuroM4 | 0.029 | **0.051** | 0.041 |
| LEuroM5 | 0.023 | 0.039 | **0.050** |
| **LGoldM1** | **0.160** | **0.857** | **0.067** |
| **LGoldM2** | **0.095** | **0.055** | **0.056** |
| LGoldM3 | 0.017 | 0.023 | 0.040 |
| LGoldM4 | 0.013 | 0.024 | 0.009 |
| LGoldM5 | 0.026 | 0.022 | 0.014 |
| **LOilM1** | **0.057** | **0.087** | **0.775** |
| **LOilM2** | **0.044** | **0.076** | **0.074** |
| LOilM3 | 0.013 | 0.011 | 0.041 |
| LOilM4 | 0.015 | 0.032 | 0.020 |
| LOilM5 | 0.015 | 0.020 | 0.022 |

variable of importance is the first lag of the target variable. That is, current value placement is most influenced by the immediate past of the variable.

After the first variable, the one and two-day lags of oil and gold are prominent in each of the three models. Yesterday's euro price is valuable only to the euro model, while the euro 4 and 5 days ago is picked up by the gold and oil models, respectively, as the fifth variable in importance. Looking at the sizes of these significance values, we see that the euro is more sensitive to variations in gold than those in oil, oil is more sensitive to variations in gold than those in the euro, and gold is more sensitive to variations in oil than variations in the euro. Also, the one-day lag of gold affects the euro more than it does oil and the one-day lag of oil affects gold more than it does the euro. Euro lags affect gold and oil after several days and is similar in it effect on each of them.

## VII. Conclusions

In this paper we first offer a review of the markets for oil and gold prior to the last eight years. This analysis demonstrates that the oil and gold markets had limited inter-relationships between them. Since the euro did not exist prior to 1999, it did not play any role in oil and gold prices. In contrast, during the past eight years, the gold, oil and euro markets have moved together.

This paper analyzes these inter-relationships among the futures price behavior of gold, oil and the euro using a standard time series methodology. Traditionally, gold is a leading indicator of future inflation and such inflation influences both short and long-term interest rates that in turn influence the value of the dollar measured in terms of other currencies such as the euro. Oil and the energy complex also play an important role in the determination of inflation. While in the past, increases in the price of oil impacted inflation, the price of gold and the price of the dollar, we show in this paper that the weakness of the US dollar as measured by the euro and fears of future inflation as measured by the price of gold, both have influenced the price of oil.

In particular, the statistical evidence of time series analysis demonstrates that both short-term and long-term relationships exist between the three variables. Both the time series and neural network results indicate that the series move together though they identify slightly different relationships. The time series results imply that oil adjust to gold while the neural network indicates that oil impacts gold more than gold impacts oil. The times series results also find no leader between the euro and oil; they adjust to each other. The neural network finds that oils affect on the euro is greater than the euro's effect on oil. Last, the time series indicates that the weakest relationship is between gold and the euro while the neural network shows gold's impact on the euro is greater and faster than the euro's impact on gold.

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