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OIL AND GOLD: CORRELATION OR CAUSATION?

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Abstract

This study using the monthly data spanning 1986:01-2011:04 to investigate the relationship between the prices of two strategic commodities: gold and oil. We examine this relationship through the inflation channel and their interaction with the index of the US dollar. We used different oil price proxies for our investigation and found that the impact of oil price on the gold price is not asymmetric but non-linear. Further, results show that there is a long-run relationship existing between the prices of oil and gold. The findings imply that the oil price can be used to predict the gold price.

Key words: oil price fluctuation, gold price, inflation, US dollar index, cointegration.

JEL: E3.

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1. INTRODUCTION

There is a common belief that the prices of commodity tend to move in unison. The reason why commodity prices tend to rise and fall together is because they are influenced by common macroeconomic factors such as interest rates, exchange rates and inflation (Hammoudeh et al, 2008). Oil and gold, among others, are the two strategic commodities which have received much attention recently, partly due to the surges in their prices and the increases in their economic uses. Crude oil is the world's most commonly traded commodity, of which the price is the most volatile and may lead the price procession in the commodity market. Gold has a critical position among the major precious metal class, even considered the leader of the precious metal pack as increases in its prices seem to lead to parallel movements in the prices of other precious metals. (Sari et al, 2010). Gold is not only an industrial commodity but also an investment asset which is commonly known as a "safe haven" to avoid the increasing risk in the financial markets. Using gold is, among others, one of risk management tools in hedging and diversifying commodity portfolios. Greenspan (1994) cited gold as a "store of value measure which has shown a fairly consistent lead on inflation expectations and has been over the years a reasonably good indicator"[2]. Investors in both advanced and emerging markets often switch between oil and gold or combine them to diversify their portfolios (Soytas et al, 2009).

The above feature descriptions of crude oil and gold justify the economic importance of investigating the relationship between these two commodities. Particularly, since the crude oil and gold are considered the representatives of the large commodity markets, their price movement may provide some reference information for forecasting the price trends of the whole large commodity market. Beahm (2008) opines that the price relationship between oil and gold is one of the five fundamentals that drive the prices of precious metals. Further, their

[2] Quoted in "Greenspan Takes the Gold". The Wall Street Journal, Feb 28, 1994.

special features make the prices of gold and oil not only influenced by the ordinary forces of supply and demand, but also by some other forces. Therefore, it is of crucial practical significance to figure out how oil price return is related to gold price return and whether oil prices have forward influences on the prices of gold. Despite this fact, researches on oil price-gold price relationship are rather sparse and most of which are carried out recently when oil and gold prices entered in a boom time since the first half of 2008. Therefore, it is worth our efforts to research on this area. The goal of this paper is to examine the relationship between price returns of oil and gold. Particularly, we attempt to address the following questions: Is there a causal and directional relationship between gold and oil? Is the relationship between their price returns weak or strong? Who drives who?

Our study made two significant contributions to the oil price-gold price relationship literature. First, to the best of our knowledge, this is among the first studies investigating the relationship between oil price and gold price. We propose the theoretical frameworks for testing oil price-gold price relationships through inflation channel and their interaction with the US dollar index. Second, we employed several oil price proxies for our empirical examination, which have not been used before in studies on the topic, in order to explore the nonlinear and asymmetric effects of oil price changes. Discussion of the topic is of crucial importance for investors, traders, policymakers and producers when they play catch up with each other and when they have feedback relationships with oil and exchange rate.

The balance of the paper is organized as follows. Section 2 reviews the literature on oil price-gold price relationships. Section 3 discusses data and methodology. Section 4 presents the empirical results. Section 5 concludes with the principal findings in this study and a brief suggestion for further studies.

2. OIL PRICE-GOLD PRICE RELATIONS

Commonly, the relationship between oil price and gold price is known to be positive, implying that oil and gold are close substitutes as safe havens from fluctuations in the US dollar's value (see, for instance, Kim and Dilts, 2011). The two following arguments are proposed to explain this common thought.

2.1. First hypothesis: oil price influences gold price

The first argument proposes a unidirectional causal relationship running from oil to gold. This implies that changes in gold prices may be monitored by observing movements in oil prices. First, high oil price is bad for the economy, which adversely affects the growth and hence pushes down share prices. Consequently, investors look for gold as one of alternative assets. We can observe such a scenario during end of the 1970s when the oil cartel reduced the oil output, and hence resulted in a surge in oil price. This 1973 oil crisis shockwaves through the US and global economy and led to the long recession in the 1970s.

Second, the impact of oil price on gold price could be established through the export revenue channel (Melvin and Sultan, 1990). In order to disperse market risk and maintain commodity value, dominant oil exporting countries use high revenues from selling oil to invest in gold. Since several countries including oil producers keep gold as an asset of their international reserve portfolios, rising oil prices (and hence oil revenues) may have implications for the increase of gold prices. This holds true as long as gold accounts for a significant part in the asset portfolio of oil exporters and oil exporters purchase gold in proportion to their rising oil revenues. Therefore, the expansion of oil revenues enhances the gold market investment and this causes price volatility of oil and gold to move in the same direction. In such a scenario, an oil price increase leads to a rise in demand (and hence price) of gold.

Third, crude oil price spikes aggravate the inflation, whereas gold is renowned as an effective tool to hedge against inflation. Hence, inflation, which is strengthened by high oil price, causes an increase in demand for gold and thus leads to a rise in gold price (Pindyck and Rotemberg, 1990). Narayan et al (2010) opine that inflation channel is the best to explain the linkage between oil and gold markets. A rise in oil price leads to an increase in the general price level. Several studies have established this link empirically (e.g. Hunt, 2006; Hooker, 2002). When the general price level (or inflation) goes up, the price of gold, which is also a good, will increase. This gives rise to the role of gold as an instrument to hedge against inflation. On the other hand, when gold price fluctuates due to changes in demand for jewelry, being hoarded as a reserve currency and/or being used as an investment asset, it is unlikely to have anything related to oil return (Sari et al, 2010).

Several studies support this hypothesis by empirically showing that oil price fluctuations lead to changes in gold prices. Using daily time series data, Sari et al (2010) explored the directional relationships between spot prices of four precious metals (gold, silver, platinum, and palladium), oil and USD/euro exchange rate. These authors found a weak and asymmetric relationship between oil price return and that of gold. Particularly, gold price returns do not explain much of oil price returns while oil price returns account for 1.7% of gold price returns. On examining the long-term causal and lead-and-lag relationship between crude oil and gold markets, Zhang et al (2010) reported a significant cointegrating price relationship between the two commodities. The results indicated that percentage changes of crude oil returns significantly and linearly Granger causes the percentage change of the gold price returns. Further, at 10% level, there is no significant nonlinear Granger causality between the two markets, implying that their interactive mechanism is fairly direct. Liao and Chen (2008) employed GARCH and TGARCH models to analyze the relationship among oil prices, gold prices, and individual industrial sub-indices in Taiwan. The results showed that oil price return fluctuations influence the gold prices returns but the latter has no impact on the former. Narayan et al. (2010) studied the long-run relationship between gold and oil futures prices at different levels of maturity and found co-integration relationships existing for all pairs of sport and futures gold and oil prices. The findings suggest oil prices can be used to predict gold prices, thus the two markets are jointly inefficient.

2.2. Second hypothesis: oil price and gold price are only correlated

The second argument proposes that oil and gold prices are driven by common factors. In this regard, the fact that oil price and gold price move in sympathy is not because one influences the other, but because they are correlated to the movement of the driving factors.

For instance, both oil and gold are traded in US dollar. Therefore, volatility of the US dollar may cause fluctuations of international crude oil price and gold price to move in the same direction. For instance, the continuous depreciation of the US dollar might force the volatile boost of the crude oil price and gold price. Specifically, it is argued that during expected inflation, when the US dollar weakens against the other major currencies, especially euro, investors move from dollar-denominated soft assets to dollar-denominated physical assets (Sari et al, 2010). However, a deterioration of US dollar vis-à-vis euro may also push up oil prices as oil price in denominated in the former. Zhang et al (2010) bring evidence for high correlations between the US dollar exchange rate and the prices of oil and gold and of Granger causality from the US dollar index to the price changes of both commodities. Also, geopolitical events are another factor that may impact the prices of crude oil and gold simultaneously. In fact, both the commodity markets are very sensitive to the turmoil of international political situation. For instance, in the worry of financial crises, investors often rush to buy gold. Consequently, the price of gold sees an ascending.

Among the three hypotheses on oil and gold relationship, the third hypothesis reminds us of a common saying in sciences and statistics that “correlation does not imply causation”, which means that a similar pattern observed between movements of two variables does not necessarily imply one causes the other. In line with this hypothesis, Soytas et al. (2009) showed that the world oil price has no predictive power of the prices of precious metals including gold in Turkey. In reality, the situation can become even more complicated, as we can observe that the oil and gold relationship is not stable over time. For instance, during the 1970s, the oil price might have had a much bigger influence on gold than it is now.

There are several studies which do not support any of the two abovementioned hypotheses. Specifically, some papers found two-way feedback relationships between oil price and gold price (e.g. Wang et al, 2010). Some indicated that the price of gold, among others, is the forcing variable of the oil price, implying that when the system is hit by a common stochastic shock, the price of gold moves first and the oil price follows (Hammoudeh et al, 2008). This finding does not support the common belief that oil is the leader of the price procession. Further, some papers bring evidence on the conditional relationship between oil price and gold price. For instance, Chiu et al. (2009) employed Granger causality tests based on the corresponding asymmetric ECM-GARCH with generalized errors distribution (GED), and results showed that a unidirectional causality runs from WTI oil to gold. These authors stated, however, that gold price is not affected by Brent oil price when the latter becomes more unstable. The implication for individual and institutional investors is that gold can be used to hedge against inflation caused by stable oil price hikes, but not when oil price fluctuations become much more volatile.

Besides the sparse number of studies focusing on oil price-gold price relationships, to the best of our knowledge, we find four major shortcomings of existing research on this area. First, neither the empirical literature nor economic theory has provided enough information about the directional relationships between oil and gold, whether they have a leader or a driver, and how they are related to each other. Second, it is the lack of statistical evidence showing long run and stable relationship between the two typical large commodity markets, given their similar price trends. Third, there are little studies on whether the gold-oil relationship is linear or nonlinear. Last but not least, no study is found on the interactive mechanism of the two markets. Our study thus aims to fill these gaps.

3. DATA AND METHODOLOGY

3.1. Data

The monthly sample spans from January-1986 to April-2011 inclusive for a total of 304 observations for each series. The West Texas Intermediate (WTI) crude oil price is chosen as a representative of world oil price. The original WTI crude oil spot price (quoted in US dollar) is acquired from the US's Energy Information Administration (EIA).[3] The gold price is the monthly average of the London afternoon (pm) fix obtained from the World Gold Council.[4] The monthly consumer price index (CPI) of the US and US dollar index data are obtained from CEIC data sources. The US dollar index is a measure of the value of the United States dollar relative to a basket of foreign currencies, including: Euro, Japanese yen, Pound sterling, Canadian dollar, Swedish krona and Swiss franc. When the US dollar index goes up, it means that the value of US dollar is strengthened compared to other currencies. All the data series are seasonally adjusted using the Census X12 method in Eviews to eliminate the influence of seasonal fluctuations. Monthly inflation rate is computed as the growth rate of the US CPI (2005=100). All the variables are transformed into natural logarithms to stabilize the variability in the data.

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[3] http://www.eia.doe.gov/dnav/pet/pet_pri_spt_s1_m.htm
[4] http://www.gold.org/investment/statistics/prices/average_monthly_gold_prices_since_1971/

3.2. Non-linear transformation of oil price variables

Several previous studies have shown that oil price fluctuations have asymmetric effects on gold and macroeconomic variables (see, for example, Wang and Lee, 2011; Sari et al, 2010; Chiu et al, 2009; Hooker, 2002). We present seven possible proxies to oil price shocks in order to model the asymmetries between the impact of oil price increases and decreases on the gold prices and inflation, as the follows.

Proxy 1 is the monthly growth rate of oil price, defined as: $\Delta op_t = lnop_t - lnop_{t-1}$.

Proxy 2 considers oil price increases only (Δop_t^+) and is defined as:

$$\Delta op_t^+ = \max(0, \Delta op_t).$$

Proxy 3 considers oil price decreases only (Δop_t^-) and is defined as:

$$\Delta op_t^- = \min(0, \Delta op_t)$$

Proxy 4 is the net oil price measure ($netop_t$), constructed as the percentage increase in the previous year's monthly high price if that is positive and zero otherwise:

$$netop_t = \max\,[0, op_t - \max(lnop_{t-1}, lnop_{t-2}, lnop_{t-3}, \dots, lnop_{t-12})]$$

This proxy is proposed by Hamilton (1996) who argues that as most of the increases in oil price since 1986 have immediately followed even larger decreases; they are corrections to the previous decline rather than increases from a stable environment. Therefore, he suggests that if one wants to correctly measure the effect of oil price increases, it seems more appropriate to compare the current price of oil with where it has been over the previous year, rather than during the previous month alone. Hamilton refers to this net oil price measure as the maximum value of the oil price observed during the preceding year and shows that the historical correlation between oil price shocks using this measure and the macroeconomy prior to the mid-1980s remains intact.

Proxy 5 is the scaled oil price ($\Delta op_t/\sigma_t$) suggested by Lee et al (1995). This transformation of oil price changes has achieved popularity in the macroeconomics literature. In order to construct this proxy, we estimate a GARCH (1,1) model with the following conditional mean equation[5]: $\Delta op_t = \phi_0 + \sum_{i=1}^{12} \phi_1 \Delta op_{t-i} + a_t$

In which $a_t = \sigma_t \varepsilon_t$ where $\varepsilon_t \sim NID(0,1)$

And the conditional variance equation: $\sigma_t^2 = \alpha_0 + \alpha_1 a_{t-1}^2 + \beta_1 \sigma_{t-1}^2$

The volatility-adjusted oil price (or scaled oil price) is: $sop_t = \Delta op_t/\sigma_t$

Proxy 6 is the scaled oil price increase (sop_t^+), computed as: $sop_t^+ = \max(0, sop_t)$

Proxy 7 is the scaled oil price decreases (sop_t^-), constructed as: $sop_t^- = \min(0, sop_t)$

Table 1 summarizes descriptive statistics of the series in level and in log. The coefficient of standard deviation (indicator of variance) indicates that the gold price series has the highest volatility among the others, followed by the price of oil. In log, oil price series has the highest volatility and followed by the price of gold. Further, the statistics of skewness, kurtosis and Jarque-Bera of gold both in level and in log all reveal that gold prices are non-normal.

[Please place Table 1 here]

Table 2 reported the correlation among the seven oil price proxies. It shows clearly that monthly percentage changes of oil price Δop_t is highly correlated with the other five oil price proxies (above 0.8), with the only exception of $netop_t$ where the correlation is just above

[5] Since we are using the monthly data, we need to include 12 lags in the conditional mean equation in order to be consistent with the measure.

0.5. Interestingly, both Δop_t^+ and Δop_t^- are highly correlated with Δop_t (0.84 and 0.83, respectively) and both sop_t^+ and sop_t^- are highly correlated with sop_t (0.85 and 0.83, respectively). Hence, it seems to be an equal dispersion between percentage increases and decreases of oil prices. Figure 1 plots the graphs of different oil price proxies. From the graph, we can see that Δop_t^- is the difference between Δop_t and Δop_t^+. Also, sop_t^- is the difference betweensop_t and sop_t^+.

[Please place Table 2 and Figure 1 here]

3.3. Methodology

As stated at the beginning of this study, in the first part of our empirical analysis, we examine the unidirectional causality running from oil price to gold price through the inflation channel. Specifically, we perform pairwise Granger causality analysis on following the three proposed hypotheses:

- Hypothesis a: a rise in oil price generates inflation.
- Hypothesis b: inflation leads to a rise in gold price.
- Hypothesis c: if the two above hypotheses are correct, a rise in oil price leads to a rise in gold price.

The regression equations for Granger causality tests are follows:

Hypothesis a:

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . \Delta op_{t-i} + \varepsilon_t \qquad [E.q. 1.1]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . \Delta op_{t-i}^+ + \varepsilon_t \qquad [E.q. 1.2]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . \Delta op_{t-i}^{-} + \varepsilon_t \qquad [E.q. 1.3]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . netop_{t-i} + \varepsilon_t \qquad [E.q. 1.4]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . sop_{t-i} + \varepsilon_t \qquad [E.q. 1.5]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . sop_{t-i}^{+} + \varepsilon_t \qquad [E.q. 1.6]$$

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . sop_{t-i}^{-} + \varepsilon_t \qquad [E.q. 1.7]$$

Hypothesis b:

$$\Delta lggoldp_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \beta_{2i} . \pi_{t-i} + \varepsilon_t \qquad [E.q. 2]$$

Hypothesis c:

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . \Delta op_{t-i} + \varepsilon_t \qquad [E.q. 3.1]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . \Delta op_{t-i}^{+} + \varepsilon_t \qquad [E.q. 3.2]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . \Delta op_{t-i}^{-} + \varepsilon_t \qquad [E.q. 3.3]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . netop_{t-i} + \varepsilon_t \qquad [E.q. 3.4]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . sop_{t-i} + \varepsilon_t \qquad [E.q. 3.5]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . sop_{t-i}^{+} + \varepsilon_t \qquad [E.q.3.6]$$

$$\Delta lggoldp_t = \gamma_0 + \sum_{i=1}^{k} \gamma_{1i} \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \gamma_{2i} . sop_{t-i}^{-} + \varepsilon_t \qquad [E.q.3.7]$$

In each equation, the optimal lag length is determined so as to minimize both AIC and SC. For instance, in the following equation:

$$\pi_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} . \pi_{t-i} + \sum_{i=1}^{k} \alpha_{2i} . \Delta op_{t-i} + \varepsilon_t$$

We regress π_t only on its lagged variables of various lag length without including Δop_t. And we select the optimal lag length m = m* where both AIC and SC are minimized. Next we fix the value of m at m* and keep on adding the lagged variables of Δop_tuntil we obtain the lag length n* where AIC and SC are minimized. The overall optimal lag length in the above equation will be (m*, n*). If the value of m based on AIC is different from that based on SC, then for each of two different lags, the lagged variables of Δop_t are added and the overall optimal lag length is determined where AIC and SC are minimized. That is, if $m_1 = argminAIC(m, n = 0)$ and $m_2 = argminSC(m, n = 0)$, then (m*, n*) will be the unique solution to the following two constrained optimization problems:

$$minAIC(m, n)\ s.t. m = m_1\ or\ m_2$$

$$minSC(m, n)\ s.t. m = m_1\ or\ m_2$$

And if $n_1 = argminAIC(m *, n) \neq n_2 = argminSC(m *, n)$ then the Granger causality test is performed for both lags $(m *, n_1)\ and\ (m *, n_2)$. The same procedure is applied to the rest of equations to obtain the optimal lag lengths for each of them.

In equations [1.1] to [1.7], the null hypothesis $H_0: \alpha_{21} = \alpha_{22} = \cdots = \alpha_{2k} = 0$ means that oil price changes does not Granger cause inflation. In equation [2], the null hypothesis $H_0: \beta_{21} =$

$\beta_{22} = \cdots = \beta_{2k} = 0$ means that inflation does not Granger cause gold price changes. In equations [3.1] to [3.7], the null hypothesis $H_0: \gamma_{21} = \gamma_{22} = \cdots = \gamma_{2k} = 0$ means that oil price changes does not Granger cause gold price changes. The tests for these hypotheses are performed by a traditional F-test resulting from an OLS regression for each equation.

The second part of our empirical analysis investigates the US dollar index as an interactive mechanism in oil price-gold price relationship. For this purpose, we model the three variables into an unrestricted trivariate VAR system. Depending on whether they are stationary in level or integrated of order one respectively, the variables are entered in level or their first differences into the VAR system of order p which has the following form:

$$Z_t = \alpha + \sum_{i=1}^{p} A_i \,.\, Z_{t-i} + v_t$$

Where Z_t is the (3x1) vector of endogenous variables discussed above, α is the (3x1) intercept vector, A_i is the i^{th} (3x3) matrix of autoregressive coefficients for i=1,2…p, and v_t is a (3x1) vector of reduced form white noise residuals.

Based on the unrestricted VAR model, we estimated the generalized impulse response functions (IRFs) and the generalized forecast error variance decompositions (VDCs) of Koop et al. (1996) and Pesaran and Shin (1998). The IRF and VDC analysis enables us to understand the impacts and responses of the shocks in the system. Further, the generalized approach is preferred compared to the traditional orthogonalized approach. This is because the orthogonalized approach is sensitive to the order of the variables in a VAR system which determines the outcome of the results, whereas the generalized approach is invariant to the ordering of variables in the VAR and produce one unique result.

4. RESULTS AND INTERPRETATIONS

4.1.Testing for the significance of oil-gold relationship via the inflation channel

4.1.1. Unit root tests

Since the Granger causality test is relevant only when the variables involved are either stationary or nonstationary but cointegrated, we employ unit roots test to examine the order of integration of the series data in our study. For this purpose, the three tests Augmented Dickey-Fuller (Dickey and Fuller, 1981), Phillips Perron (Phillips and Perron, 1988) and Kwiatkowski, Phillips, Schmidt, Shin (Kwiatkowski et al, 1992) – with constant and trend, and without trend are performed on levels and first differences of all the logged series: gold prices, US monthly CPI and US dollar index, and the seven oil price proxies. Table 3a and b reports the results. Considering the fact that the three unit root tests do not account for a structural break, the Zivot-Andrews (Zivot and Andrews, 1992) test is employed to examine our variables for the existence of a unit root. Results are reported in Table 4a and b. All the tests have a common suggestion that, at conventional significance levels, all the logged series are non-stationary while their first differences and the oil price proxies are stationary.

[Please place Table 3a, b and Table 4a, b here]

4.1.2. Johansen cointegration test

Since all the series are nonstationary in level and integrated of the same order, I(1), this suggests a possibility of the presence of cointegrating relationship among variables. In order to explore such a possibility, Johansen cointegration tests (Johansen, 1988 and Johansen and Juselius, 1990) are performed to test for the existence of cointegrating relationships between each pair: oil price change and inflation, inflation and gold price change, and gold price and oil price changes. As pre-test of the testing procedure, logged variables are entered as levels into VAR models with different lag lengths and F-tests are used to select the optimal number of lag lengths needed in the cointegration analysis. Three criterions, the Akaike information criterion (AIC) (Akaike, 1969), Schwarz criterion (SC) and the likelihood ration (LR) test are applied to determine the optimal lag length. Since the tests are very common and standardized, we will not report the results of this procedure here in order to conserve space. Table 5 presents the results of Johansen multivariate cointegration tests, which overall show that each pairs of variables under our examination are co-integrated at 5% significance level. This implies that there exist long-run relationships between oil price and inflation, between gold price and inflation, and between the prices of oil and gold.

[Please place Table 5 here]

4.1.3. Granger causality tests

Since the variables are all stationary in the first differences and co-integrated of order 1, the next step we perform the Granger causality analysis. The optimal lag lengths selected for each regression equation based on the procedure described in the previous section are reported in Table 6.

[Please place Table 6 here]

F-test in Table 7 reports the null hypothesis that all determined lags of oil price measures can be excluded. All the F-statistics are significant with the use of different oil price proxies, suggesting that there is no non-linear relationship between oil price change and inflation. The signs of impact are identical and the same as expected in our hypothesis for all seven oil price proxies. F-test in Table 8 reports the null hypothesis that all determined lags of inflation can be excluded. The results indicate that, at 5% level, we cannot reject the null hypothesis with lag 1 month of inflation variable but we can reject it with lag 2 months of inflation. Further, the impact of inflation on gold price changes has the same sign as expected, indicating that a rise in inflation will increase the gold price immediately. F-test in Table 9 reports the null hypothesis that all determined lags of oil price measures can be excluded. The results bring evidence that non-linear relationships might exist between the price changes of oil and gold. Specifically, when monthly changes in oil price and the positive oil price changes are used as proxies of oil prices, the evidence of causality is much clearer. With the use of the volatility-adjusted oil price and the negative oil price changes, the evidence is relatively weaker. The signs of impact are identical for all cases and the same as expected in our hypothesis.

[Please place Table 7, 8, 9 here]

4.1.4. Testing for asymmetries

According to Lee et al. (1995), Hamilton (1996, 2000), oil prices may have asymmetric effects on macroeconomic variables such as inflation and possibly also on gold price. For the purpose of testing the asymmetries, oil price increases and decreases are entered as separated variables in bivariate estimation equations for gold price changes as follows:

$$\Delta lggoldp_t = \varphi_0 + \sum_{i=1}^{k} \varphi_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \varphi_{2i} . \Delta op_{t-i}^{+} + \sum_{i=1}^{k} \varphi_{3i} . \Delta op_{t-i}^{-} + \varepsilon_t \qquad [E.q. 4.1]$$

$$\Delta lggoldp_t = \varphi_0 + \sum_{i=1}^{k} \varphi_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \varphi_{2i} . sop_{t-i}^{+} + \sum_{i=1}^{k} \varphi_{3i} . sop_{t-i}^{-} + \varepsilon_t \qquad [E.q. 4.2]$$

We construct a Wald coefficient test to examine whether the coefficients of positive and negative oil price shocks in the VAR are significant different. The null hypothesis is $H_0: \sum_{i=1}^{k} \varphi_{2i} = \sum_{i=1}^{k} \varphi_{3i}$. F-statistic for Equation 4.1 is F(1,298) = 1.726 (p-value = 0.1899) and F-statistic for Equation 4.2 is F(1,286) = 0.045 (p-value = 0.8320). The results indicate that oil price changes have no asymmetric effects on the growth rate of gold price.

4.1.5. Trivariate relationship

A trivariate model is estimated to test whether the impact of oil price on gold price is through inflation channel or through an additional mechanism. For this purpose, the generalized impulse response function is estimated for based on the following model:

$$\Delta lggoldp_t = \mu_0 + \sum_{i=1}^{k} \mu_{1i} . \Delta lggoldp_{t-i} + \sum_{i=1}^{k} \mu_{2i} . \pi_{t-i} + \sum_{i=1}^{k} \mu_{3i} . \Delta op_{t-i}^{+} + \varepsilon_t \quad [E.q. 4.3]$$

We use the proxy Δop_t^+ for oil price shocks since its impact on gold price changes is highest among those of the other oil price proxies. The results in Figure 2 shows that a one standard deviation shock of Δop_t^+ has a significant and positive impact on growth rate of gold price even when inflation is included in the regression equation. This implies that the relationship between oil price and gold price cannot be solely explained by the effect of oil price changes on inflation. Thus in the next section we will include the US dollar index as an interactive mechanism for examining the oil price-gold price relationship.

4.2. The VAR approach to investigate the interaction of oil and gold prices with the US dollar index

The main purpose of this study is to examine if and how oil price shocks influence gold price. As we conclude from the previous section that inflation is not the only mechanism that explains the linkage between oil price and gold price. Therefore, in this section, we will allow for the interaction of the two variables with another factor which is the value index of US dollar. From Table 3a, b and 4a, b we know that all the three variables: gold price, oil price and US dollar index are nonstationary in levels (natural log forms) and stationary in first differences. Therefore, all variables are entered in the first differences into the VAR system of order p as described above.

Table 10 reports the Johansen cointegration test performed on the three variables. Given the assumption of only intercepts in cointegrating equations, both the maximum eigenvalues and Trace statistics found two cointegrating vectors existing among the three variables. This result indicates that there is a long-run relationship existing among the prices of oil and gold and US dollar value and this relationship is driven by two forces. However the results are robust to other forms of transformations, e.g. allowing for a linear trend in cointegrating equations where the tests show different results. Specifically, the Trace test suggests one cointegrating relationship while the maximum eigenvalue indicates no cointegrating relationship among the variables. Since scholars generally prefer the maximum eigenvalue test over the Trace test, we may conclude that when allowing for a trend in cointegrating equations, there is no cointegrating relationship existing among the three variables.

[Please place Table 10 here]

We used the first differences of the logged oil price, logged gold price and logged US dollar index data series in the unrestricted VAR to estimate the generalized IRFs and the generalized forecast error VDCs. The IRF illustrates the impact of a unit shock to the error of each equation of the VAR. The results in Table 11 suggest that the gold price is immediately responsive to innovations in oil price. The response is persistently positive and dies out quickly in 2-3 months after the oil price shock. As for fluctuations in US dollar index, gold price also reacts instantaneously and persistently negative. The response also dies out after 2-3 months of the shock. Thus, the sign of gold price's responses to innovation in oil price and US dollar index are the same as expected in theory.

[Please place Table 11 and Figure 3 here]

The forecast error VDC analysis provides a tool of analysis to determine the relative importance of oil price shock in explaining the volatility of the gold price. Due to its dynamic nature, VDC accounts for the share of variations in the endogenous variables resulting from the endogenous variables and the transmission to all other variables in the system (Brooks, 2008). We applied the similar ordering as the IRFs to the VDCs. The results reported in Table 12 indicate that most of the variations in each of the three series are due to its own innovation. The oil price is shown to have significant contribution to explaining variations in gold price. Specifically, oil price percentage change accounts for about 4.04% of the variation in gold price. Compared to that of oil price, the US dollar index appears to have more significantly role in explaining volatilities in gold price when accounting for 15.84% of the variation in gold price. Further, for both oil price and US dollar index, the contributions to variations in gold price are increasing overtime and become stable after 3-4 months of the innovations. This finding is in line with what we have found from the previous section.

[Please place Table 12 here]

As a final step, the VAR for generalized impulse responses and variance decompositions is checked for stability. The results indicate that the VAR system is stable in that all inverse roots of AR characteristic polynomial are within the unit circle.

5. CONCLUSION

This paper investigates the price relationship between oil and gold by means of studying the indirect impact of oil price on gold price through the inflation channel and studying their interactions with the US dollar index. Besides adding to the sparse literature on oil price-gold price relationship, the major contribution of this study is the use of different oil price proxies in order to consider the asymmetric and non-linear effect of oil price changes on inflation and gold price. Our principal findings in this study are following. First, we found co-integrating (long-run) relationships existing between oil price and inflation, inflation and gold price, and the prices of oil and gold. This finding suggests that the pairwise relationships among the variables are not only limited to the short-run. The results from Granger causality analysis support our proposed hypothesis on oil price-gold price relationship through inflation channel. It means that, in the long-run, rising oil price generates higher inflation which strengthens the demand for gold and hence pushes up the gold price. Moreover, the short optimal lag lengths in the regression equations (i.e. 1-2 months) imply that the relationships between each pair of the three variables are not significantly lead-and-lag.

Second, when different oil price proxies are used, we show that oil price fluctuation has no asymmetric impact on inflation and gold price. Further, the results indicate that oil price has non-linear effect on inflation. Specifically, the significance of the oil price percentage increase proxy indicates that oil price increases appear to have greater impact on the gold price when they follow a period of lower price increases. However, we do not find evidence enough to assume that oil price has asymmetric effect on gold price volatility.

Third, we study the trivariate relationship among oil price, gold price and the US dollar index. Results show that there is a co-integrating long-run relationship among the prices of oil and gold and US dollar index. However, the results are robust to the other specification of the cointegration tests. Moreover, in generalized IRF analysis, we found positive and negative responses of gold price to oil price and US dollar index, respectively, which are the same as expected in theory. We also observe from the IRFs that the responses of gold price to innovations in oil price and US dollar index are instantaneous and dying out quickly. This confirms that fact that oil price-gold price relationship does not lag long. In reality, as the information on oil price and US dollar index has been readily available, other relevant markets including the gold market appear to respond quickly to movements in the two variables. The generalized forecast error VDCs indicate that variation in gold price is better explained by fluctuations of US dollar index, compared to that of oil price.

Our findings have two major implications. First, the role of gold as a hedge against inflation is strengthened. Second, the oil price does nonlinearly cause the gold price and can be used to predict the gold price. Since the number of studies on oil price-gold price relationships is very limited, it gives rise to many opportunities for further studies on the area. For instance, future work can focus on the dynamic and time-varying interaction between oil price and gold price. Moreover, further researches can be conducted on evaluating the volatility, risk and spillover effects between the two markets and/or other markets such as those of other precious metals.

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Table 1: Descriptive statistics

	Gold price	Oil price	US CPI	USD index
Level				
Mean	475.8516	35.20132	84.75586	92.89587
Std. dev.	256.2063	25.43289	16.90498	10.79047
Skewness	2.033076	1.550841	0.032031	0.628330
Kurtosis	6.417506	4.521876	1.926191	3.022601
Jarque-Bera	357.3639	151.1961	14.65748	20.00958
Probability	0.000000	0.000000	0.000656	0.000045
Observations	304	304	304	304
Log				
Mean	6.065196	3.360899	4.419231	4.524958
Std. dev.	0.410795	0.596610	0.205182	0.113658
Skewness	1.331069	0.806669	-0.259014	0.350805
Kurtosis	3.936264	2.447558	2.038137	2.766382
Jarque-Bera	100.8718	36.83532	15.11809	6.926563
Probability	0.000000	0.000000	0.000521	0.031327
Observations	304	304	304	304

Table 2: Correlation of monthly oil prices Δop_t with alternative oil price proxies

	Δop_t	Δop_t^+	Δop_t^-	$netop_t$	sop_t	sop_t^+	sop_t^-
Δop_t	1.000000						
Δop_t^+	0.842014	1.000000					
Δop_t^-	0.825356	0.390378	1.000000				
$netop_t$	0.544202	0.655285	0.242912	1.000000			
sop_t	0.980087	0.830057	0.803886	0.536376	1.000000		
sop_t^+	0.832834	0.976077	0.399749	0.639998	0.850282	1.000000	
sop_t^-	0.816035	0.406115	0.967623	0.252283	0.832028	0.415798	1.000000

Table 3a: Results of Unit root tests without a structural break (in log level)

	ADF	PP	KPSS
Intercept			
Oil price	-0.894536	-0.206335	1.691717
Gold price	2.327841	2.409120	0.964025
CPI	-2.567288	-2.011489	2.092665
US dollar index	-2.240482	-2.425294	0.494023
Intercept and trend			
Oil price	-2.596944	-2.749776	0.397149
Gold price	0.789024	0.886082	0.463509
CPI	-2.147472	-1.586051	0.359187
US dollar index	-2.367781	-2.471507	0.252689

Without trend, critical values for ADF, PP and KPSS tests are respectively: at 1% = -3.45, -3.45, and 0.74; at 5% = -2.87, -2.87, and 0.46; at 10% = -2.57, -2.5, and 0.35. With trend, critical values for ADF, PP, and KPSS tests are respectively: at 1% = -3.99, -3.99, and 0.22; at 5% = -3.42, -3.43, and 0.15; at 10% = -3.14, -3.14, and 0.12.

Table 3b: Results of Unit root tests without a structural break

	ADF	PP	KPSS
Intercept			
Δop_t	-14.01946	-13.90614	0.154060
Δop_t^+	-14.30261	-14.30520	0.246141
Δop_t^-	-13.66706	-13.64151	0.065943
$netop_t$	-11.42817	-11.50797	0.177725
sop_t	-13.87254	-13.81695	0.162335
sop_t^+	-14.49507	-14.49507	0.392448
sop_t^-	-14.57387	-14.53521	0.027254
$\Delta goldp_t$	-15.80148	-15.80832	1.079552
π_t	-10.92531	-10.51219	0.395637
$\Delta USDI_t$	-13.25183	-13.18147	0.131982
Intercept and trend			
Δop_t	-14.00981	-13.89219	0.023728
Δop_t^+	-14.35683	-14.35048	0.062959
Δop_t^-	-13.63016	-13.60234	0.053400
$netop_t$	-11.47095	-11.53910	0.041338
sop_t	-13.92271	-13.81315	0.024548
sop_t^+	-14.63809	-14.67736	0.037260
sop_t^-	-14.55242	-14.51191	0.022283
$\Delta goldp_t$	-16.22625	-16.18656	0.207229
π_t	-11.24674	-10.53118	0.070765
$\Delta USDI_t$	-13.22840	-13.15770	0.130336

Without trend, critical values for ADF, PP and KPSS tests are respectively: at 1% = -3.45, -3.45, and 0.74; at 5% = -2.87, -2.87, and 0.46; at 10% = -2.57, -2.5, and 0.35. With trend, critical values for ADF, PP, and KPSS tests are respectively: at 1% = -3.99, -3.99, and 0.22; at 5% = -3.42, -3.43, and 0.15; at 10% = -3.14, -3.14, and 0.12.

Table 4a: Results of Zivot-Andrews unit root test (in log level)

	[k]	t-statistics	Break point
Oil price	1	-4.675187	1997M02
Gold price	2	-4.215443	2000M03
CPI	3	-4.257470	1990M01
US dollar index	2	-3.978297	1999M02

The critical values for Zivot and Andrews test are -5.57,-5.30, -5.08 and -4.82 at 1%, 2.5%, 5% and10% levels of significance respectively.

Table 4b: Results of Zivot-Andrews unit root test

	[k]	t-statistics	Break point
Δop_t	4	-8.380363	1999M01
Δop_t^+	0	-14.73982	1990M10
Δop_t^-	4	-7.804398	1991M07
$netop_t$	0	-11.79658	1990M11
sop_t	0	-14.08059	1999M01
sop_t^+	0	-15.07534	1990M10
sop_t^-	1	-10.04956	1991M03
$\Delta goldp_t$	1	-14.00649	2001M05
π_t	2	-9.206813	1990M11
$\Delta USDI_t$	1	-12.14658	2002M02

The critical values for Zivot and Andrews test are -5.57,-5.30, -5.08 and -4.82 at 1%, 2.5%, 5% and10% levels of significance respectively.

Table 5: Johansen-Juselius multivariate cointegration test results

Table 5a:

Oil price and inflation					
r	n-r	λ_{max}	95%	Tr	95%
1st assumption: the level data have linear deterministic trends but the cointegrating equations have only intercepts (Lag = 6)					
$r = 0*$	$r = 1$	31.67878	14.26460	31.82087	15.49471
$r \leq 1$	$r = 2$	0.142084	3.841466	0.142084	3.841466
2nd assumption: The level data and the cointegrating equations have linear trends (Lag = 6)					
$r = 0*$	$r = 1$	50.24029	19.38704	56.24233	25.87211
$r \leq 1$	$r = 2$	6.002040	12.51798	6.002040	12.51798

Note: r = number of cointegrating vectors, n-r = number of common trends, λ_{max} = maximum eigenvalue statistic, Tr = trace statistic. * denote rejection of the hypothesis at the 0.05 level.

Table 5b:

Gold price and inflation					
r	n-r	λ_{max}	95%	Tr	95%
1st assumption: the level data have linear deterministic trends but the cointegrating equations have only intercepts (Lag = 1)					
$r = 0*$	$r = 1$	102.1102	14.26460	107.3183	15.49471
$r \leq 1*$	$r = 2$	5.208106	3.841466	5.208106	3.841466
2nd assumption: The level data and the cointegrating equations have linear trends (Lag = 1)					
$r = 0*$	$r = 1$	110.1389	19.38704	119.9741	25.87211
$r \leq 1$	$r = 2$	9.835283	12.51798	9.835283	12.51798

Note: r = number of cointegrating vectors, n-r = number of common trends, λ_{max} = maximum eigenvalue statistic, Tr = trace statistic. * denote rejection of the hypothesis at the 0.05 level.

Table 5c:

Gold price and oil price					
r	n-r	λ_{max}	95%	Tr	95%
1st assumption: the level data have linear deterministic trends but the cointegrating equations have only intercepts (Lag = 3)					
$r = 0*$	$r = 1$	16.51619	14.26460	17.54749	15.49471
$r \leq 1$	$r = 2$	1.031299	3.841466	1.031299	3.841466
2nd assumption: The level data and the cointegrating equations have linear trends (Lag = 3)					
$r = 0$	$r = 1$	19.33186	19.38704	26.47793*	25.87211
$r \leq 1$	$r = 2$	7.146075	12.51798	7.146075	12.51798

Note: r = number of cointegrating vectors, n-r = number of common trends, λ_{max} = maximum eigenvalue statistic, Tr = trace statistic. * denote rejection of the hypothesis at the 0.05 level.

Table 6: Optimal lags for Granger causality testing regression equations

Equation	Optimal lags	
	m*	n*
$\boldsymbol{E.q.1.1}$	3	1
$\boldsymbol{E.q.1.2}$	3	1
$\boldsymbol{E.q.1.3}$	3	1 and 2
$\boldsymbol{E.q.1.4}$	3	1
$\boldsymbol{E.q.1.5}$	3	1
$\boldsymbol{E.q.1.6}$	3	1
$\boldsymbol{E.q.1.7}$	3	1
$\boldsymbol{E.q.2}$	1	1 and 2
$\boldsymbol{E.q.3.1}$	1	1 and 2
$\boldsymbol{E.q.3.2}$	1	1
$\boldsymbol{E.q.3.3}$	1	1 and 2
$\boldsymbol{E.q.3.4}$	1	1
$\boldsymbol{E.q.3.5}$	1	1
$\boldsymbol{E.q.3.6}$	1	1
$\boldsymbol{E.q.3.7}$	1	1

Table 7: Test of causality of inflation with different oil price proxies

	Δop_t	Δop_t^+	Δop_t^-	$netop_t$	sop_t	sop_t^+	sop_t^-
$\boldsymbol{\alpha_{20}}$ **[t-value]**	0.014652 [9.14125]	0.015522 [5.36754]	0.024443 [9.34625]	0.029380 [6.90467]	0.001002 [7.89682]	0.001178 [5.37814]	0.001684 [7.65134]
n*	1	1	1 and 2	1	1	1	1
F-test op [p-value]	**37.94782** [0.0000]	**15.06456** [0.0001]	**35.42905** [0.0000]	**4.081762** [0.0443]	**41.67078** [0.0000]	**16.25538** [0.0001]	**40.43426** [0.0000]
			19.75048 [0.0000]				

Figures in bold are statistically significant at 5% level.

Table 8: Test of causality of gold oil price changes

	π_t
$\boldsymbol{\beta_{20}}$ **[t-value]**	2.777745 [0.0002]
n*	1 and 2
F-test op [p-value]	1.706981 [0.1924]
	3.804235 [0.0234]

Figure in bold is statistically significant at 5% level.

Table 9: Test of predictability of gold price changes with different oil price proxies

	Δop_t	Δop_t^+	Δop_t^-	$netop_t$	sop_t	sop_t^+	sop_t^-
γ_{20} [t-value]	0.088458 [0.0002]	0.149494 [0.0001]	0.093844 [0.0160]	0.119741 [0.0448]	0.006981 [0.0001]	0.009780 [0.0009]	0.010072 [0.0011]
n*	1 and 2	1	1 and 2	1	1	1	1
F-test op [p-value]	2.065760 [0.1517]	**3.751519** [0.0537]	0.207718 [0.6489]	0.014191 [0.9053]	2.569695 [0.1100]	2.135153 [0.1451]	1.435315 [0.2319]
	2.615704 [0.0748]		2.143240 [0.1191]				

Figures in bold are statistically significant at 10% level.

Table 10: Johansen-Juselius multivariate cointegration test results for oil price, gold price and US dollar value relationships

r	n-r	λ_{max}	95%	Tr	95%
1st assumption: the level data have linear deterministic trends but the cointegrating equations have only intercepts (Lag = 3)					
$\boldsymbol{r = 0}$*	$r = 1$	21.35604	21.13162	38.18378	29.79707
$\boldsymbol{r \leq 1}$*	$r = 2$	16.50032	14.26460	16.82775	15.49471
$\boldsymbol{r \leq 2}$	$r = 3$	0.327429	3.841466	0.327429	3.841466
2nd assumption: The level data and the cointegrating equations have linear trends (Lag = 3)					
$\boldsymbol{r = 0}$	$r = 1$	22.83168	25.82321	47.43282*	42.91525
$\boldsymbol{r \leq 1}$	$r = 2$	17.18933	19.38704	24.60113	25.87211
$\boldsymbol{r \leq 2}$	$r = 3$	7.411799	12.51798	7.411799	12.51798

Note: r = number of cointegrating vectors, n-r = number of common trends, λ_{max} = maximum eigenvalue statistic, Tr = trace statistic. * denote rejection of the hypothesis at the 0.05 level.

Table 10: Generalized impulse responses of growth rate of gold price to one SE shock

Unrestricted VAR (lag = 1)			
Period	Gold price	Oil price	USD index
1	0.033684	0.006773	-0.013406
2	0.002853	0.003163	-0.003394
3	0.000680	0.001006	-0.001113
4	0.000208	0.000317	-0.000368
5	6.59E-05	0.000101	-0.000121
6	2.11E-05	3.24E-05	-3.94E-05
7	6.79E-06	1.04E-05	-1.28E-05
8	2.19E-06	3.37E-06	-4.16E-06
9	7.08E-07	1.09E-06	-1.35E-06
10	2.29E-07	3.53E-07	-4.37E-07

Note: Generalized impulse response functions are performed on the first differences of logged variables.

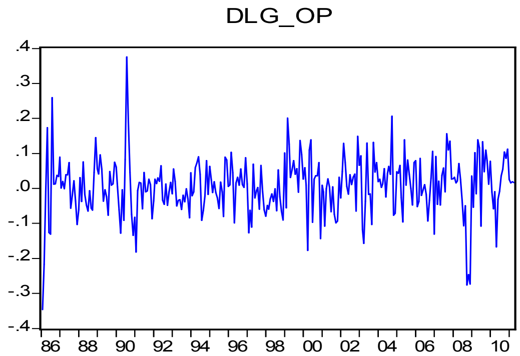
Table 11: Generalized variance decomposition for growth rate of gold price

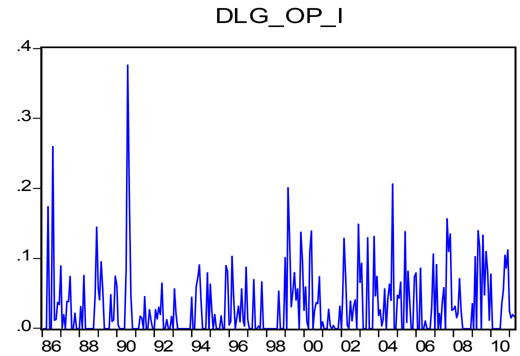
Unrestricted VAR (lag = 1)			
Period	Gold price	Oil price	USD index
1	1.00000	.040430	.15840
2	.98932	.048375	.16557
3	.98801	.049166	.16635
4	.98786	.049245	.16644
5	.98785	.049253	.16645
6	.98785	.049253	.16645
7	.98785	.049253	.16645
8	.98785	.049253	.16645
9	.98785	.049253	.16645
10	.98785	.049253	.16645

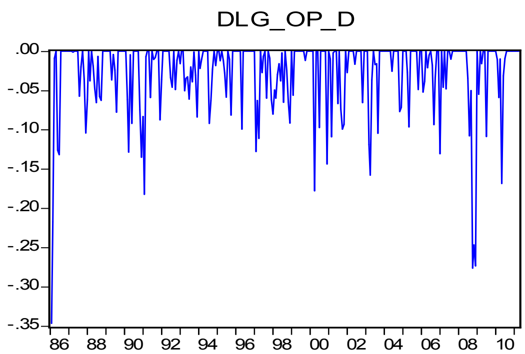
Note: Generalized forecast error variance decompositions are performed on the first differences of logged variables.

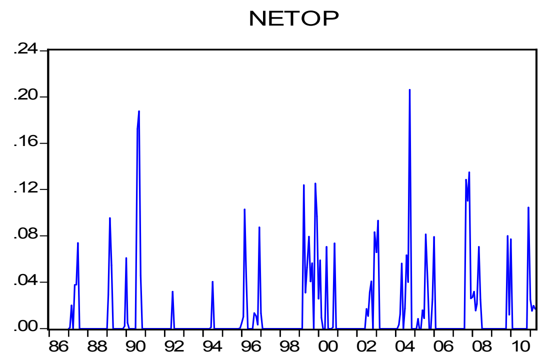
Figure 1: Different oil price measures

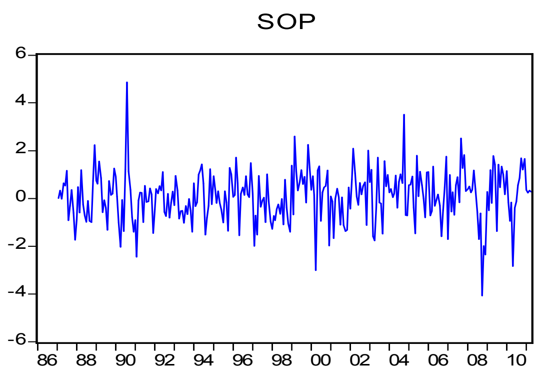
Note: The figures present the graphs of the seven oil price proxies, respectively: $\Delta op_t, \Delta op_t^+, \Delta op_t^-, netop_t, sop_t, sop_t^+$ and sop_t^-.

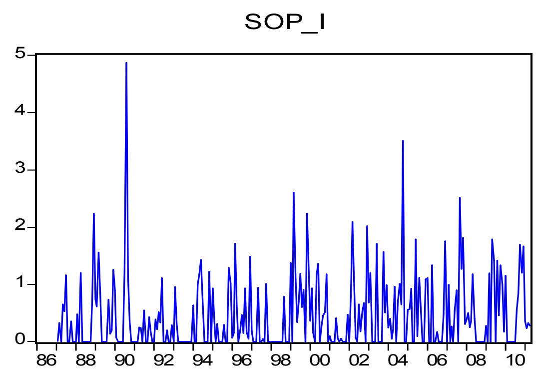

DLG_OP
.4
.3
.2
.1
.0
-.1
-.2
-.3
-.4
86 88 90 92 94 96 98 00 02 04 06 08 10


DLG_OP_I
.4
.3
.2
.1
.0
86 88 90 92 94 96 98 00 02 04 06 08 10


DLG_OP_D
.00
-.05
-.10
-.15
-.20
-.25
-.30
-.35
86 88 90 92 94 96 98 00 02 04 06 08 10


NETOP
.24
.20
.16
.12
.08
.04
.00
86 88 90 92 94 96 98 00 02 04 06 08 10


SOP
6
4
2
0
-2
-4
-6
86 88 90 92 94 96 98 00 02 04 06 08 10


SOP_I
5
4
3
2
1
0
86 88 90 92 94 96 98 00 02 04 06 08 10

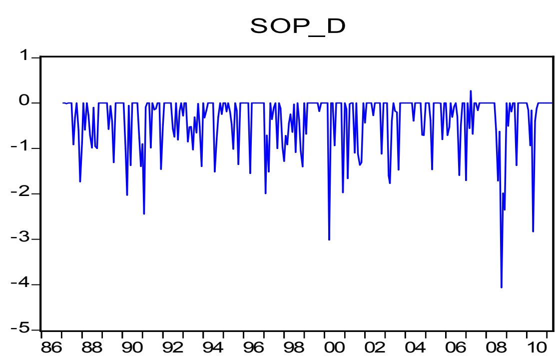
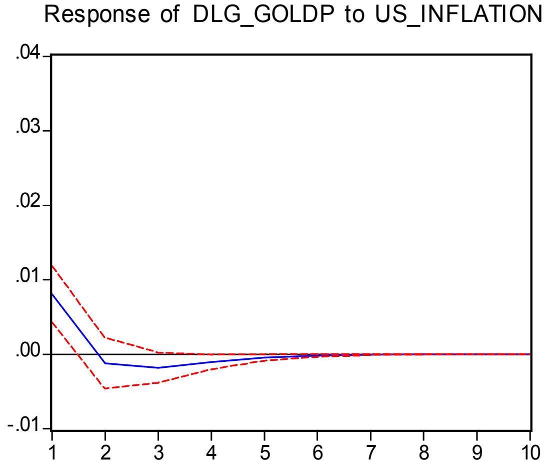

SOP_D
1
0
-1
-2
-3
-4
-5
86 88 90 92 94 96 98 00 02 04 06 08 10

Figure 2: Impulse response of gold prices to US inflation and Δop_t^{+}



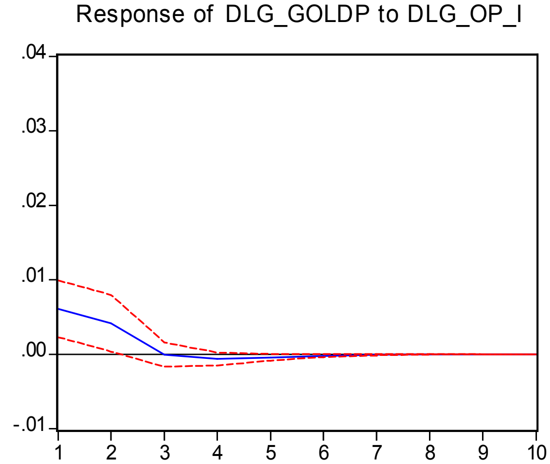


Figure 3: Generalized impulse responses of gold prices to one SE shock in oil prices in the trivariate VAR model