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Research article

A three-way analysis of the relationship between the USD value and the prices of oil and gold: A wavelet analysis

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Abstract: This study examines the relationships among oil prices, gold prices, and the USD real exchange rate. It adopts the wavelet approach as a nonlinear causality technique to decompose the data into various scales over time. Higher-order coherence and partial coherence were used to identify the lead-lag effect and mutual coherence function among the variables. The results show that changes in the USD exchange rate influence the prices of oil and gold negatively in the short- and medium-term. While in the long-term, the oil price has a negative impact on the value of the USD. Oil and gold are significantly linked and correlated because their prices are determined in USD. The findings of this paper have significant implications, particularly for risk management.

Keywords: wavelet; partial wavelet coherence; U.S. dollar value; oil prices; gold prices

1. Introduction

Examining the nexus between oil and gold is an established practice among researchers in the field of economics due to the importance of these variables. Oil is considered the primary driver of the economy. Its price fluctuations impact the entire economy. For example, once the oil prices climb, costs increase and reflect negatively on profits [1]. From another perspective, fluctuations in oil prices may lead to variations in consumer spending, leading to a decline in disposable income and increased inflation. To absorb this issue, gold is regarded as a solution for preserving the value as an asset of international reserve portfolios [2].

Bénassy-quéré et al. [3] state that oil and gold, as international commodities, are exchanged in USD which is the dominant currency for international markets. Hence, variations in the USD affect the relationship between oil and gold prices.

Numerous studies examine the connection among oil prices, gold prices, and the value of USD. However, this paper differs in three ways:

(1) It uses nonlinear causality tests to study the correlation between oil prices and gold prices due to the nature of financial and economic variables. Most empirical studies used linear relationships [2]. However, this method is ineffective because it does not cover certain nonlinear causal relations. Therefore, it is suggested to use the nonlinear method to examine the causality relationships [4–6];
(2) It uses the wavelet method to decompose the data to various time frequencies which enables us to detect the multiscale nonlinear causality relationships between oil and gold. However, most researchers analyzed the time series at their original level using a cointegration which distinguishes two time scales (short and long-term scales). Therefore, it is suggested to use wavelet analysis to examine this relationship [7–9]; and
(3) It uses partial wavelet coherence to examine the relationship between prices of oil and gold while excluding the effect of the USD as a common factor between them.

This paper examines the nexus among oil prices, gold prices, and the value of USD by adopting wavelet coherences, including partial wavelet. It is organized into five sections including the introduction and conclusion. The literature review discusses the relationship between gold and oil, the impact of the USD on gold, and the connection between oil and the USD. The section that follows explains the methodology by highlighting wavelet coherence and partial wavelet coherence while section four illustrates the empirical findings of this research.

2. Literature review

2.1. Gold vs. oil

2.1.1. Oil price influences gold price

Changes in oil price may influence changes in gold prices. According to Le and Chang [2], different scenarios reflect the effect of oil price on the gold price. The first scenario is the effect of high oil prices on the economy. When oil prices are high, it reflects poorly on the growth of the economy of oil importers. Once the economy shrinks, this will push the share prices in stock markets down. Hence, investors will leave the equity markets and focus on the gold market as alternative assets. This scenario reminds us of the dramatic increase in oil prices during the 1970s which consequently led to a long recession in the 1970s in the US and global economy. The second scenario is the effect of oil price on gold price from the revenue generated by oil exporters whereby they use the high revenue from oil sales to invest in gold. Gold is used as a hedge to preserve wealth. Hence, oil and gold prices have a positive relationship where expansion of oil revenue increases the investment the gold market. In the third scenario, high oil prices increase inflation in the economy and gold is considered a well-known tool to hedge against inflation. Once there is an increase in the level of prices due to of the rise in oil prices, this will lead to increased demand for gold which will reflect on the gold price positively.

The literature illustrates a relationship between oil and gold prices. Narayan et al. [10] found a cointegration in the long-term among spot prices and future prices for gold and oil. They concluded oil prices help forecast gold prices. Liao and Chen [11] found that oil price return fluctuations influence the gold price returns. In addition, Zhang and Wei [12] found that changes in the oil return ratio reflect the variations of the gold price return ratio.

2.1.2. Oil and gold prices are correlated

Another approach defines the relationship between oil prices and gold prices as correlated and affected by common factors. It does not support the idea that one commodity influences the other. Oil and gold are traded in USD, and the fluctuation of this common factor would influence the movement of both commodities in the same direction, e.g., a decrease in the value of the USD could increase the prices of oil and gold. Zhang and Wei [12] found high correlations among the value of USD, oil prices and gold prices. Their research shows that the value of USD causes price changes of both commodities.

Others view that the correlation between them is not one of causation. Although the movement of both commodities is within a similar pattern, it does not necessarily indicate that one causes the other. In Turkey, Soytas et al. [13] found that oil price cannot predict gold prices. Once a common stochastic shock hits the economy, Hammoudeh et al. [14] observed that gold prices change first followed by oil prices. From cointegration and causality analysis, Zhang and Wei [12] found that the value of the USD value causes fluctuations in oil and gold prices.

2.2. Gold vs. USD

Gold is a precious metal that can preserve its value and is accepted in business transactions. In addition, it plays a significant role in the derivatives markets for hedging purposes [15]. Concerning gold price and the USD exchange rate, numerous studies found a negative relationship between gold price and value of the USD. Considering that gold is priced internationally in USD, a depreciation in the value of the USD lowers gold prices which motivates investors to buy gold to maintain their wealth. This increases the demand for gold and, consequently, pushes gold prices up. On the contrary, appreciation in the USD value drives gold prices to move down, presenting that they move in opposite direction [16,17].

Considering the negative correlation between gold and USD implies that when the major currencies, on average, are appreciating against the USD, gold also appreciates. In other words, gold performs similarly to other currencies. Therefore, when the USD exchange rate depreciates against the main currencies, it means that the USD also loses its value against gold. The relationship would then be a correlation without referring to a causal relationship where the USD exchange rate influences gold prices [18]. Unlike the prior argument which is based on observed reality, Capie et al. [16] identified other reasons such as the significance of political instability and its effect on gold prices.

Additionally, when there is an unpredictable economy, gold is a tool to reduce the risk of exchange rate variations and is used to maintain wealth. Capie et al. [16] found a negative relationship among the value of the British pound to USD and gold prices, and between the value of Japanese Yen to USD and gold prices. In addition, Tully and Lucey [19] examined the response of gold spot and future prices to macroeconomic variables and revealed that the USD was significant among other macroeconomic variables that affect fluctuations in gold prices. Since the fall of the Bretton Woods System, gold prices have been more volatile due to the inconsistency of exchange rates [20]. Therefore, gold prices are influenced by the USD exchange rate.

2.3. *Oil vs. the USD*

The USD is used in international crude oil trading which makes the relationship between these variables an interesting study. Gillman and Nakov [1] found strong proof for causality from the price of oil to inflation. They advocate that shocks in oil price are signs of cyclical inflation fluctuations.

Research found that the connection between oil price and USD is cointegrated. For example, an increase in the oil price matches with the rise in the value of USD, and oil price significantly explains the fluctuation in the value of the USD in the long-term [3,21–24].

Furthermore, Alhajji [25] stated that depreciation of USD reduced the price of oil in countries with appreciating currencies, e.g., the Euro. In addition, Amano and van Norden [26] studied the relationship of these variables in different countries and noticed the oil price is an exogenous and primary driving factor of exchange rates in the long-term. This is justified by Coudert et al. [27] who stated that once the oil price increased, this might improve the position of US net foreign assets compared to other countries. Consequently, the impact of this process increased the USD exchange rate. Additionally, Krugman [28] and Golub [29] observed the influence of oil price on the value of USD through the balance of payments. The rise of oil price causes a wealth transfer from oil importers to oil exporters whereby oil exporters may use generated revenue to buy products quoted in USD, which causes an increase in the USD exchange rate and vice versa.

However, some studies found that movements in the USD may explain oil price movements. Zhang et al. [30] stated that weakness of the USD pushes up the oil price. Moreover, Novotný [31] found that there is an opposite correlation between the USD value and the oil price. The reason for this might be the further speculative demand for oil as a substitutional financing tool. The following table summarizes the significant changes in oil price vis-à-vis global events.

3. Methodology

This paper used the wavelet technique instead of time series due to its ability to analyze both time domain and frequency domain. Time domain analysis, i.e., time series analysis, examines the development of an economic factor with the consideration of time, where period changes keep the time-frequency constant so as to examine the tentative features of the factor at a given frequency. On the other hand, frequency domain analysis, i.e., spectral analysis, studies the development of the factor with regards to frequency, where frequency changes with keeping time constant examine the factor feature over the frequency spectrum [7].

Unlike Fourier and spectral analysis, wavelet analysis decomposes an original time series data to many scales and does not require stationarity of the variables [32]. It is essential to mention that most of the economic and financial variables are non-stationary in which every variable contains three features: trend, seasonal, and random components. By changing the variable stationary, trend component, i.e., the long-term effect, will be removed from the variable [7].

Gençay et al. [33] suggested two kinds of wavelet, i.e., father wavelet (S) and mother wavelet (D). S presents the smooth and low frequency, i.e., trend component, while D describes the detailed and high frequency, seasonal and random components. S and D are explained as:

$$S_{N,k}(z) = \int_{-\infty}^{\infty} \tau_{N,k} f(z) dz \tag{1}$$

$$D_{n,k}(z) = \int_{-\infty}^{\infty} \vartheta_{n,k} f(z) dz \ (n = 1,2, \dots, N) \tag{2}$$

where $S_N(z)$ represents smooth approximations and $D_n(z)$ represents detailed approximations. The highest-level approximation $S_N(z)$ is the smooth, while the details $D_1(z)$, $D_2(z)$, …, $D_n(z)$ are linked with oscillations of length 2-4, 4-8,..., 2^N-2^{N+1}.

3.1. Wavelet coherency

Wavelet coherency is a suitable method to identify any likely interaction among two variables via studying scale space and time intervals. This method improves correlation analysis by exposing intermittent correlations between two variables and their significant correlation relationship within time domain and scale space. Consequently, wavelet coherence can find, more efficiently, the correlation among oil prices, gold prices, and the value of USD. This method is used to apply to relationship analysis research [9,34]. The wavelet coherency is given by Torrence and Webster [35] as:

$$R_n^2(s) = \frac{\left|\forall\left(s^{-1} W_n^{XY}(s)\right)\right|^2}{\forall\left(s^{-1}\left|W_n^X(s)\right|^2\right)\forall\left(s^{-1}\left|W_n^Y(s)\right|^2\right)} \tag{3}$$

where $R_n^2(s)$ is the squared wavelet coherency value and $\forall$ is a smoothing operator determined as $\forall(W) = \forall_{scale}(\forall_{time}(W_n(s)))$, in which $\forall_{scale}$ denotes smoothing over the wavelet scale axis and $\forall_{time}$ indicates smoothing in time.

3.1.1. Higher order coherency: Partial wavelet coherence

When three variables, or more, are specified to determine who is the leader among them and to assess the association between two of them, it is central to consider the influence with the other variables. In this perspective, there is a similarity with the Fourier spectral situation. Mihanovic et al. [36] used partial wavelet coherence to examine a correlation between two variables after removing the effect of a common variable in marine sciences.

Like partial correlation, partial wavelet coherence is a method to calculate wavelet coherence between two series, x and y, after eliminating the impact of their common variable, z. Therefore, comparable to the traditional correlation coefficient, it can be sensed from wavelet coherence as a localized correlation in the time-scale space [34]. As expressed in equation (3), wavelet coherence between x and y, y and z, and x and z can be written as:

$$R_n^{XY}(s) = \frac{|\forall(s^{-1}W_n^{XY}(s))|}{\forall(s^{-1}|W_n^{X}(s)|)\forall(s^{-1}|W_n^{Y}(s)|)} \tag{4}$$

$$(R_n^{XY})^2(s) = R_n^{XY}(s) \times R_n^{XY}(s)^* \tag{5}$$

$$R_n^{YZ}(s) = \frac{|\forall(s^{-1}W_n^{YZ}(s))|}{\forall(s^{-1}|W_n^{Y}(s)|)\forall(s^{-1}|W_n^{Z}(s)|)} \tag{6}$$

$$(R_n^{YZ})^2(s) = R_n^{YZ}(s) \times R_n^{YZ}(s)^* \tag{7}$$

$$R_n^{XZ}(s) = \frac{|\forall(s^{-1}W_n^{XZ}(s))|}{\forall(s^{-1}|W_n^{X}(s)|)\forall(s^{-1}|W_n^{Z}(s)|)} \tag{8}$$

$$(R_n^{XZ})^2(s) = R_n^{XZ}(s) \times R_n^{XZ}(s)^* \tag{9}$$

According to Mihanovic et al. [36], the concept of partial wavelet coherence can be extended from simple linear correlation. Therefore, the partial wavelet coherence squared between x and y after eliminating the impact of z, can be defined as:

$$PR_n^{XYZ^2}(s) = \frac{|R_n^{XY}(s) - R_n^{XZ}(s) \times R_n^{XY}(s)^*|^2}{(1-R_n^{XZ}(s))^2(1-R_n^{ZY}(s))^2} \tag{10}$$

Where $PR_n^{XYZ^2}(s)$ is the squared partial wavelet coherency value which ranges from 0 to 1, like simple wavelet coherence. In that case, if the partial wavelet coherency value is a low squared while it was a high squared at wavelet coherence, it means that the two-time series, x and y, are not significantly correlated on that given time frequency space. Also, it denotes that time series z affects the variance of x and y, and contrariwise for the opposite case. If both $PR_n^{XYZ^2}(s)$ and $PR_n^{XZY^2}(s)$ are significant, means that both y and z are significantly having an impact on x. The coherences found in this method do not depend on the number of input time series.

The value of wavelet coherence and partial wavelet coherency varies between 0 and +1 which depicts all features of the correlation by wave method between two non-stationary time variables at a specific time over particular scale [37,38]. The arrow's angle, θ_{xy}, of the wavelet coherence and partial wavelet coherence is known as a phase difference. Zero phase difference indicates that the time series x and y move simultaneously at specific time space and scale space. When $\theta_{xy} \in (3\pi/2, 2\pi)$ $and \in (0, \pi/2)$ x and y move in-phase, i.e., same direction, while when $\theta_{xy} \in (\pi/2, \pi)$ $and \in (\pi, 3\pi/2)$ x and y move out-of-phase, i.e., opposite direction. Regarding leader variable, x leads y if $\theta_{xy} \in (\pi/2, \pi)$ $and \in (3\pi/2, 2\pi)$, i.e., the arrow indicates right down or left up, whereas y leads x if $\theta_{xy} \in (0, \pi/2)$ $and \in (\pi, 3\pi/2)$, i.e., arrow indicates right up or left down. The following figure shows the phase difference among time series x and y.

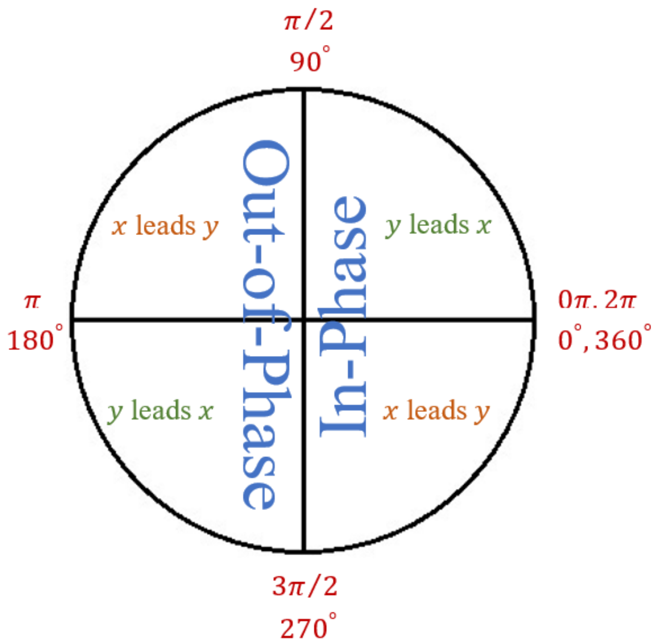

Figure 1. Phase difference circle.

4. Data and empirical findings

To examine the interactions among oil prices, gold prices, and the USD real exchange rate, daily observations from 02 January 1986 to 30 November 2016 were collected from the DataStream, due to the need for many observations when using the wavelet method. The dataset includes oil prices represented by Crude Oil Prices: West Texas Intermediate (WTI), gold prices represented by Gold Fixing Price (closing price) in the London Bullion Market based on the USD, and the USD real exchange rate represented by Trade Weighted the USD with major currencies index. Zhang et al. [30] stated that the nominal price should be considered as a significant basis for the final price. This study, therefore, used the change in nominal log data to conduct the analysis.

The variables are charted in Figure 2. Oil and gold prices were mostly static and horizontal, prior to a significant boost after mid-2005. While the USD exchange rates were fluctuating, it shaped into a parabola curve before 2002, followed by a remarkable diminish. Additionally, Figure 2 shows a lessening for three variables during the subprime mortgage crisis. However, since 2009, both oil and gold prices have risen to fall again after 2014, while the USD exchange rates were on the rise post-crisis. Thus, Figure 2 illustrates that there is a co-movement among oil prices, gold prices and USD exchange rates. Additionally, considering the common movement observed in these three series, the relationship between these variables reveals some noteworthy aspects.

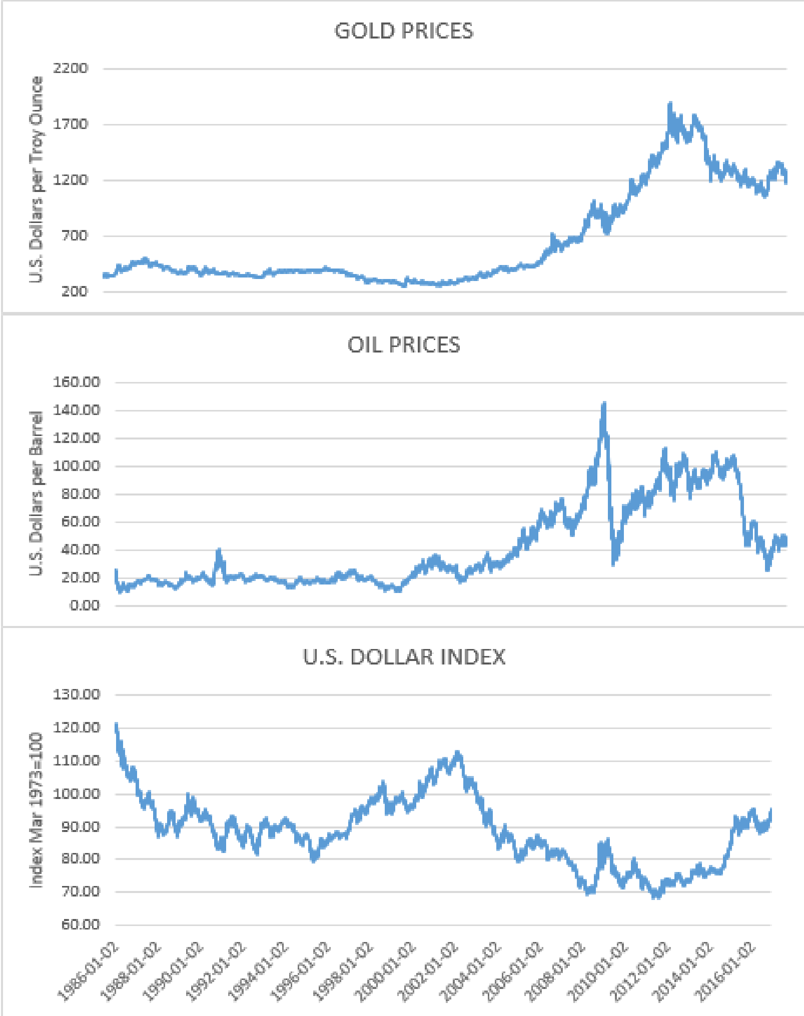

Figure 2. The dynamics of oil prices, gold prices and USD index.

To define the features of the nexus among oil prices, gold prices, and the value of USD, wavelet coherence and partial wavelet coherence were applied which exhibit the lead-lag relationship and the dynamics of co-movement among the variables with respect to time and frequency domains. In respect to the coherence of oil prices and gold prices, Eq 3 was estimated and the empirical results are plotted in Figure 3. The horizontal axis is tied to period, i.e., time, while the vertical axis linked to scale, i.e., frequency in day units. The color gradation indicates cohesion varying from 0, navy blue, to +1, dark red. The areas with warmer colors denote a significant interrelationship while areas with colder colors mean lower dependency and the insignificant relationship between two series. The arrow angels, i.e., phase difference, indicate the movement direction and lead-lag relationship.

Per the coherency function, Figure 3 shows a significant interrelation between oil and gold prices in different horizons. The early 1990s, 2003 and 2008, record significant interrelations between oil and gold in different scales, 16–32, 64–128, and 256–512 days. In the short-run, 16–64 days, arrows point to up-right, i.e., a positive relationship, indicating that oil was lagging with a cyclical effect. However, in the medium-term and long-term, 64–256 and 256–512 days respectively, arrows point down and to the right, i.e., a positive relationship, and up-left, i.e., a negative relationship, which means the oil price movement causes fluctuations in gold price.

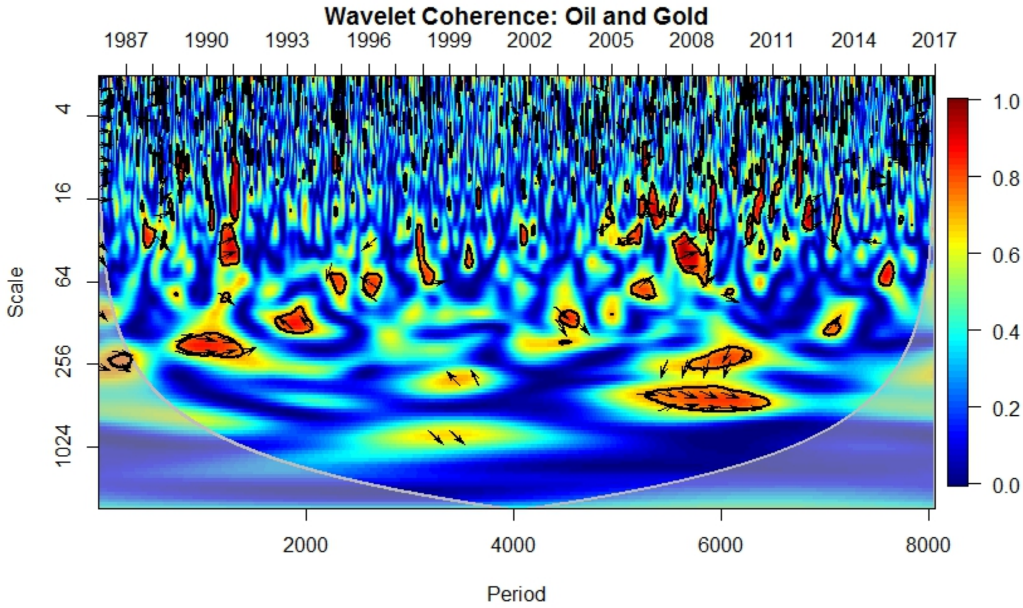

Figure 3. The cross-wavelet coherency: oil and gold, 1986–2016.

The resemblance of the interrelations among oil and gold prices spotted in the short-run can be clarified by the aspect of oil-gold shocks that happened during these periods. The 1990s, 2003 and 2008 coincided with the Gulf War, Iraq War and financial debt crisis, respectively. During wars and crisis, world economies tend to succumb to preventative demand shocks. Investors opt to buy gold and consider it a safe-haven in times of geopolitical or financial crisis [39]. This nature of a gold shock illustrates the results that gold prices are leading in the short-run. In the medium- and long-term, it shows there is a positive correlation between oil and gold where oil is leading. Oil shocks affect gold prices through monetary policy. Therefore, a rise in the prices of oil causes the consumer price index to increase along with gold prices. Since oil prices are affected by monetary policy, which takes time to adjust, for this reason, oil is leading in the medium- and long-term. This is supported by the results of Narayan et al. [10], Aggarwal et al. [40], and Malliaris and Malliaris [41].

After eliminating the impact of the USD real exchange rate on the oil-gold relationship, Eq 10 was estimated to find the partial coherence of oil prices and gold prices as shown in Figure 4. Figure 4 obtains a different result whereby the blue regions were dominating in long-term frequency. After removing the effect of the USD value, the coherence of the oil and gold prices are remarkably low even though spotting mixture in terms of lead–lag effect among the variables. During the Gulf and Iraq Wars, and financial debt crisis, gold is leading, while post-war and post-financial debt crisis oil takes the lead which means that the relationship between oil and gold is an instantaneous effect. Since the value of Eq 10, ${PR_n^{OilGold\$XRT}}^2$, is a low squared while the value of Eq 3, ${R_n^{OilGold}}^2$, was a high squared at wavelet coherence. It means that oil and gold are not significantly correlated. Also, it denotes that the value of the USD leads the impact on the variance oil and gold prices. This is because oil and gold are USD-denominated assets. They are significantly linked and correlated merely because the price of both products is determined in USD, indicating that USD is a common variable between oil and gold. By eliminating it, there is no relationship between oil and gold in the long-run [19,30,12,42,43].

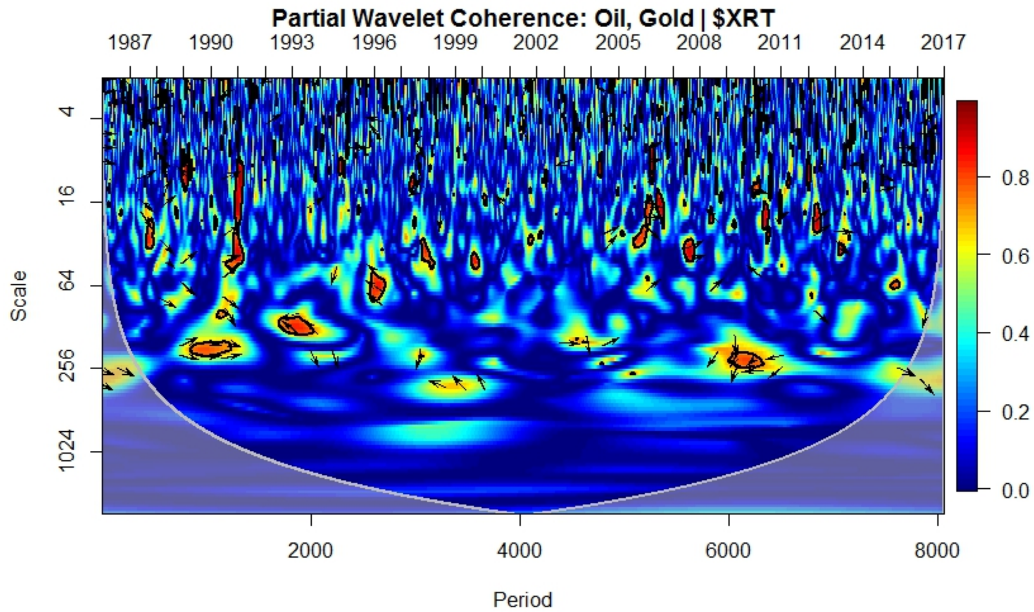

Figure 4. The partial cross-wavelet coherency: oil & gold|$XRT, 1986–2016.

The relationship between gold prices and USD is explained in Figure 5 cross-wavelet coherency. It is observed that the relationship is significant from 1987 to 2017, particularly the late 1980s, late 1990s and from 2004 to 2010 at different frequencies. Significant coherences were found in high-frequency bands, short- and medium-term, and the phase difference is $\in (\pi, 3\pi/2)$ which means out-of-phase, i.e., negative, rea lationship where the value of USD leads the changes in gold prices. In the short- and medium-term, gold prices are subject to the negative impact of the USD. According to Wang and Chueh [44], the negative relationship is due to the importance of gold as a value-conserving commodity. Since USD is an important reserve currency, its losing value encourages investors to purchase gold, which is denominated in USD. Therefore, the capital will be transferred from the money market to the gold market thereby raising gold prices. Hence, investors can protect the value of their wealth and hedge risks at the same time.

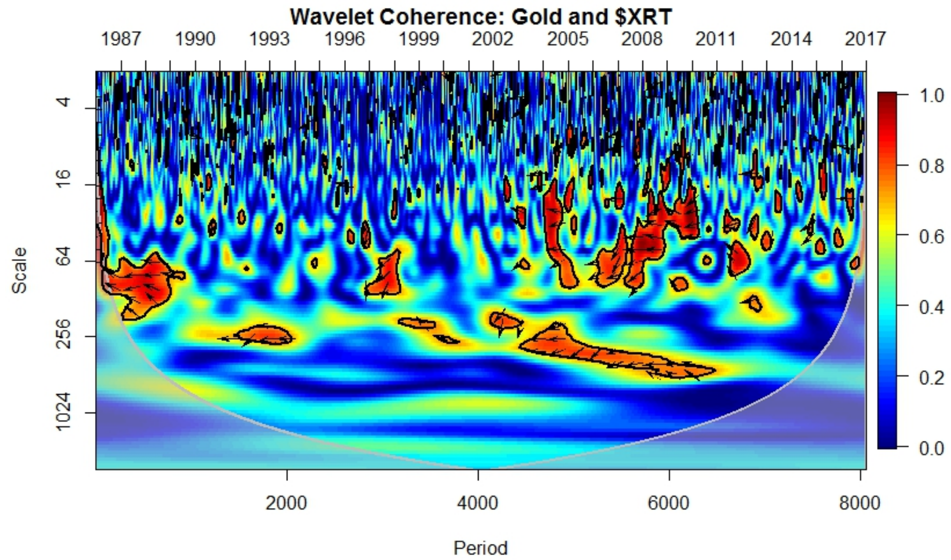

Figure 5. The cross-wavelet coherency: gold and $XRT, 1986–2016.

Figure 6 illustrates the partial cross-wavelet coherency of the relationship between gold prices and USD after eliminating the impact of oil prices. Partial cross-wavelet coherency provides evidence in line with cross-wavelet coherency in high and medium frequencies in which the relationship between these variables, in the short- and medium-term, is not affected even after eliminating the impact of oil prices. This means that there is a negative relationship making gold an exchange hedge in the short- and medium-term. This is in accordance with the empirical findings of Capie et al. [16] and Pukthuanthong and Roll [45].

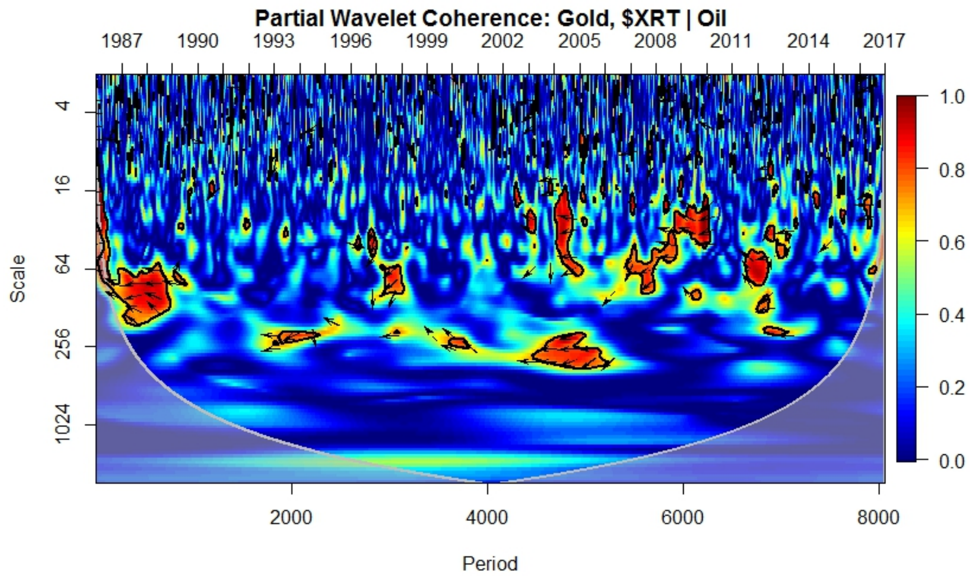

Figure 6. The partial cross-wavelet coherency: gold & $XRT|oil, 1986–2016.

However, the blue regions were dominating in low frequency indicating that the value of Eq 10, $PR_n^{Gold\$\mathrm{XRTOil}^2}$, is a low squared while the value of Eq 3, $R_n^{Gold\$XRT^2}$, was a high squared at wavelet coherence. It means that gold and the USD exchange rate are not significantly correlated in the long-run. Also, it denotes that the value of the oil prices affects gold prices and the value of the US dollar in the long-run.

The wavelet coherency between oil prices and USD exchange rate are shown in Figure 7. A significant coherency in various scales, short, 16–64 days, medium, 64–256 days, and long-term with more than 256 days was detected. In the short-run, during the early 1990s, the interdependence between oil prices and the USD value shows an in-phase relationship with leading USD value in which an appreciation (depreciation) of USD generally makes oil cheaper. This is contrary to the findings of several studies [e.g., 3,44,46,47] that show the relationship between oil and the value of USD is negative. This special case is due to the oil shock that happened during the Gulf War which led to a shortage of oil production, which decreased the oil supply.

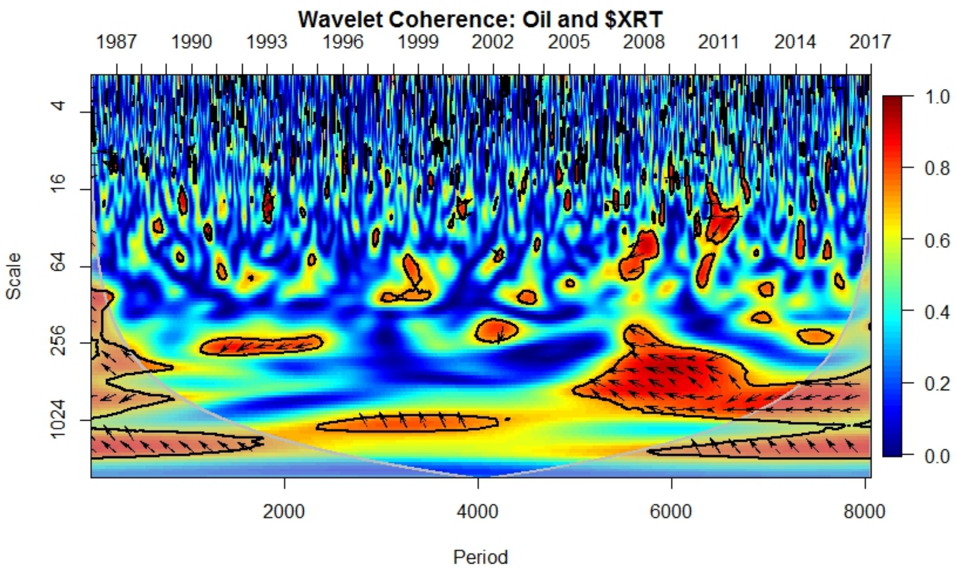

Figure 7. The cross-wavelet coherency: oil and $XRT, 1986–2016.

Unlike the 1990 oil price shock, the short-, medium- and long-term relationships appear negative. In the short-run, between the 2008 financial debt crisis to 2014, a rise in the oil price coincided with the dollar's depreciation [47]. Regarding the medium-term, prior to 1995 an out-of-phase relationship where the depreciation (appreciation) of USD caused the oil prices to increase (decreased). This medium-term negative relationship is due to the ongoing expansionary monetary policy after the Gulf War which increased the prices of oil and the expectation of inflation [44,48].

The interrelation between oil and USD after 1995 shifted to a long-term relationship. Negative wavelet coherence was observed from 1995 to 2015 where an increase (decrease) in oil price led to depreciation (appreciation) of the USD. This result signifies the dominant role of oil price in the US economy and indicates that oil price is the primary factor driving the appreciation of the USD during the crisis periods. Hamilton [49], Kilian [50] and Hammoudeh et al. [51] argued that oil prices play an important part in affecting production cost, investment and consumption due to its role in production. Thus, increases in oil prices increase the inflation levels and cause a global economic downturn. Therefore, the central banks try to increase the interest rates to balance the adverse effects of oil price increases. Accordingly, the variations in federal funds rate are a significant factor in commodity price adjustments.

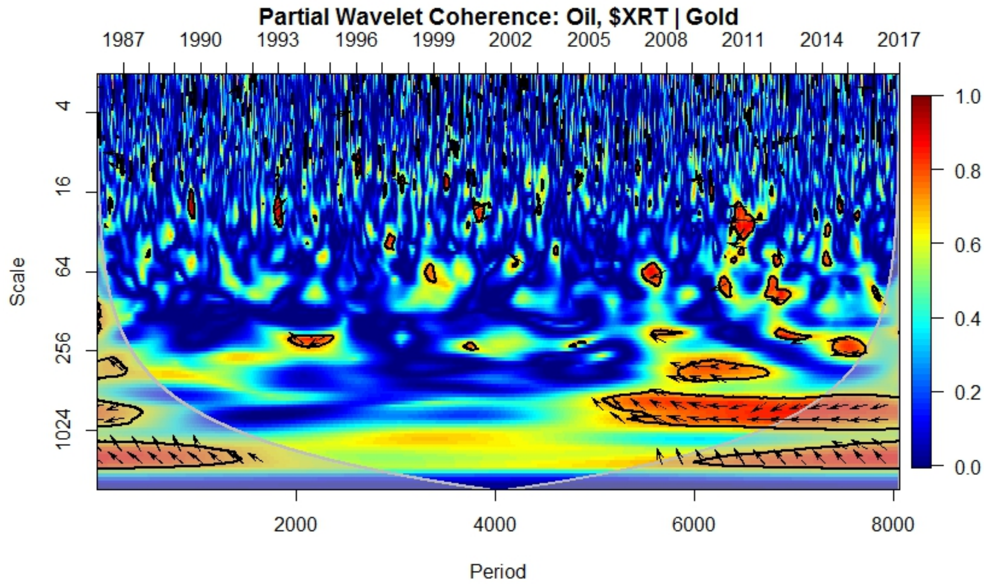

Figure 8. The partial cross-wavelet coherency: oil & $XRT|gold, 1986–2016.

In like manner, partial cross-wavelet coherency between oil & the USD exchange rate after removing the impact of gold, as shown in Figure 8, provides evidence in which the relationship between these variables is ineffectual even after eliminating the impact of gold prices. Since the partial wavelet coherency value of the Eq 10, $PR_n^{Oil\$XRTGold^2}$, is a high squared, particularly in the low frequency scale, like wavelet coherency value of the Eq 3, $R_n^{Oi\ l\$XRT^2}$, it means that oil prices and the USD exchange rate are significantly correlated. Also, it denotes that gold prices are lagging the impact on the variance of oil prices and the USD exchange rate.

This is supported by the results from Figures 6 and 4 where changes in the value of USD causes changes in oil and gold prices in the short- and medium-term. From these results, oil price significantly explains the fluctuation in the USD value in the long-term [3,21–24]. Coleman [52] and Zhang and Wei [12] noted that the essential drivers of oil price are oil supply, demand factors, political factors, Organization of Petroleum Exporting Countries production, geopolitics, supply/demand balances, world economic growth, and the value of USD.

One of the more significant findings to emerge from this study is that oil price has a negative impact on the value of USD in the long-run. In the short-run, changes in the exchange rate of the

USD negatively influence the prices of oil and gold. The following table summarizes the findings from this study.

Table 1. History of oil price shocks.

Year	Event	Oil Price Change
1973	The Yom Kippur War, OPEC embargo	Increased from \$14 to over \$50
1979–1981	Iranian Revolution, Iran-Iraq War	Increased to over \$90
1981–1983	Netback pricing formula, The futures exchange market emerges	Decreased to \$28
1990	Gulf War	Increased to \$33
1997	Asian financial crisis	Decreased to \$10
2008	World financial crisis Speculative behavior	Increased to \$145
2014–2016	The slowdown in demand from China, India, and Europe Increased in supply by Shale oil	Decreased from \$105 to \$32

Source: Zhang [53] & Authors.

Table 2. Findings summary.

Frequencies	Cross-wavelet coherency	Partial cross-wavelet coherency
	Oil & Gold	**Oil & Gold|\$XRT**
High frequency	$\uparrow Gold \rightarrow \uparrow Oil$	No relationship
Medium frequency	$\uparrow Oil \rightarrow \uparrow Gold$ $\uparrow Oil \rightarrow \downarrow Gold$	No relationship
Low frequency	$\uparrow Gold \rightarrow \uparrow Oil$	No relationship
	Gold & \$XRT	**Gold & \$XRT|Oil**
High frequency	$\uparrow \$XRT \rightarrow \downarrow Gold$	$\uparrow \$XRT \rightarrow \downarrow Gold$
Medium frequency	$\uparrow \$XRT \rightarrow \downarrow Gold$	$\uparrow \$XRT \rightarrow \downarrow Gold$
Low frequency	No relationship	No relationship
	Oil & \$XRT	**Oil & \$XRT|Gold**
High frequency	$\uparrow \$XRT \rightarrow \downarrow Oil$	$\uparrow \$XRT \rightarrow \downarrow Oil$
Medium frequency	$\uparrow \$XRT \rightarrow \downarrow Oil$	$\uparrow \$XRT \rightarrow \downarrow Oil$
Low frequency	$\uparrow Oil \rightarrow \downarrow \$XRT$	$\uparrow Oil \rightarrow \downarrow \$XRT$

Note:↑ denotes an increase in; ↓ denotes a decrease in; → denotes the variable on the left side of arrow leads the variable on the right side of the arrow.

5. Conclusion

This paper discusses the interrelationships among three essential variables of oil prices, gold prices, and USD in the economic system. The aim is to recognize the lead-lag effect and mutual coherence function among these variables. By using the wavelet technique, their functions simultaneously across several scales over time are easily examined. The next remarks have been obtained from the analysis of empirical finding.

Firstly, the interdependencies between oil prices and gold prices were positive where their relationship decreased in dependency as the frequency is low, indicating that short- and medium-term coherences were more significant than the long-term relationship. However, removing the effect of the USD value shows a weak correlation between oil and gold indicating that the USD value leads to the price fluctuation of oil and gold in the short- and medium-term [19,30,42,43].

Secondly, the connection between gold prices and the USD value did not differ across scales over time. In the short- and medium-term, gold prices are subject to an adverse impact on the USD value. When the USD loses its value, investors are encouraged to purchase gold as a safe-haven, particularly during geopolitical or financial crises [16,12,45,39].

Finally, the short-run nexus between oil and the USD occurred after 1995, where a decrease of the USD exchange rate pushed oil prices up. The only long-term relationship is between oil prices and the value of USD after the debt crisis in 2008, whereby an increase (decrease) in oil prices depreciated (appreciation) the USD value. This result is in line with the fact that oil price is the focal factor leading to the increase of the USD exchange rate [21–24,3,46].

The findings of this paper have substantial implications for investors and regulators. (I) As the long-run relationship exists between oil and the USD, investors who own assets quoted in USD and pursue long-run hedging, are suggested to buy oil futures or successive gold short-term hedging. (II) Since the USD drives the price changes of oil and gold in the short-run, gold and oil are suitable for hedging when the USD depreciates during financial crises. (III) As depreciation (appreciation) of the USD value increases (decrease) oil prices, the US monetary regulator who endeavors a quantitative easing policy in times of recession and contraction policy in expansionary times need to be conscious of the policy impacts on the value of the USD and oil price. On the flip side, the regulators of oil-importing countries shall not react in the situation oil prices increase whereby their inflationary pressures may be balanced by a decrease in the USD exchange rate against their national currencies.

Conflict of interest

The authors declare no conflict of interest in this paper.

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