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**Article**

## Effects of the 2008 financial crisis on the linkages among the oil, gold, and platinum markets

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## FINANCIAL ECONOMICS | RESEARCH ARTICLE

# Effects of the 2008 financial crisis on the linkages among the oil, gold, and platinum markets

Kentaka Aruga<sup>1\*</sup> and Sudha Kannan<sup>2</sup>

**Abstract:** To find out if gold remains to be unlinked with the crude oil market after the 2008 financial crisis, we investigated how long-run price linkages and price causalities among crude oil and gold markets changed before and after the crisis. To have a good reference, we also tested the same issue for the oil-platinum relationship. Using the cointegration methods, we found little evidence that gold began to have a price linkage with the crude oil market after the 2008 financial crisis. Conversely, we identified a long-run relationship between the crude oil and platinum markets after the crisis. Hence, we found that compared to the platinum market, the gold market remained unlinked with the oil market after the 2008 financial crisis indicating that it continued to be independent of the crude oil market.

**Subjects:** Environment & Economics; Statistics for Business, Finance & Economics; Iron, Steel & Metals Industries

**Keywords:** 2008 financial crisis; crude oil; gold; platinum; cointegration; Granger causality

### ABOUT THE AUTHORS

Kentaka Aruga is an associate professor at Saitama University, Japan. He received his PhD from the Department of Environmental and Natural resource Economics at the University of Rhode Island. He has been investigating market linkages among various commodities such as energy, metals, and agricultural products focusing on the effects of structural breaks in time series data. Recently he is working on the consumers' altruistic behavior regarding their willingness to purchase food products from the regions damaged by natural disasters to help these regions to recover from their damages.

Sudha Kannan is a PhD student in the Department of Community Sustainability at Michigan State University, USA. Her previous degrees are in Environmental and Natural Resource Economics, Economics, and Econometrics. She has professional experience in the fields of Environmental Economics and Energy Economics. Her current research focuses on energy access and gender equality in developing countries.

### PUBLIC INTEREST STATEMENT

As both gold and oil markets became stagnant after the 2008 financial crisis, the study investigated if gold started to have market linkages with oil, which is one of the major indicators of global economic conditions. To have a reference, we also investigated the platinum-oil relationships. As platinum is recently becoming more closely related to the automobile industry, we expected that the platinum market will have market linkages with the crude oil. Our results indicated that the platinum market indeed began to have linkages with the crude oil market after the crisis. However, the gold remained unlinked with the crude oil market implying that the crisis did not change the gold-oil relationship. Hence, the study revealed that even after the 2008 financial crisis where most of the commodities had a declining trend, the gold market continued to be independent of other markets.

## 1. Introduction

The 2008 financial crisis is considered by many economists as one of the most serious financial crises since the Great Depression of the 1930s (Temin, 2010). While most of the commodity prices declined after the 2008 financial crisis, the price of gold continued to increase and never seemed to decline. As gold is often referred to as a “safe haven” asset, studies have shown that gold does function as safe haven even in extreme financial market conditions (Baur & Lucey, 2010). However, recently, the gold price has been steadily falling after the COMEX gold futures price hit an all-time high of 1,923.70 US dollars an ounce in 2011 (Kitco News, 2011). On the other hand, since the financial crisis of 2008, the crude oil price has been lower than its peak price before the financial crisis, and due to the increased US oil production related to the US shale revolution, the crude oil price will likely remain low from its peak. As both gold and crude oil prices are falling, it could be that gold began to have price linkage with the crude oil after the financial crisis.

Another possible reason for oil and gold markets to have a price linkage is because when oil price increases, it often leads to inflation as the global economy depends highly on oil price while demand in gold could increase during such an inflationary period because more people start to hedge risk against such inflation (Capie et al., 2005). Indeed, Narayan et al. (2010) suggest that investors are using the gold market to hedge against inflation when the oil price is increasing, and the oil price can be used to forecast the gold price and vice versa. Before the 2008 financial crisis, both crude oil and gold prices were increasing sharply (Narayan et al., 2010), so we could expect to find a market linkage between oil and gold markets for periods before the crisis.

However, if gold remains unlinked with other commodities, it could be that the price drop in gold is not directly related to price shocks that occurred in other commodities after the crisis. Indeed, the price fall in gold occurred in 2011, three years after the 2008 financial crisis. However, this price drop was not as sharp as other commodities. If gold does remain independent of other markets, the gold market should not be affected by shocks in the crude oil, which is one of the major indicators of global economic conditions. If so, gold is likely to not have a price linkage with the crude oil market after the economic crisis. This will imply that the price discovery process of gold remains independent from other commodity markets during the crisis.

Understanding whether gold is independent of other commodities and identifying whether it can be used as a hedge to cope with the risk of dramatic changes in various commodity prices after the 2008 financial crisis is an imperative issue for the investors making decisions to rebalance their investment portfolio. Investigating the oil-gold price linkage for periods before and after the crisis is also important for policymakers to mitigate the effects of the financial crisis on the crude oil sector. If we can learn that the oil-gold linkage exists after a financial crisis, it tells us that the gold market began to be related to the crude oil market and its price can be used for forecasting the crude oil market. On the other hand, if we find no price linkage between the crude oil and gold market after a crisis, it will imply that gold continues to be independent of other commodity markets.

More studies need to be done to investigate how the oil-gold price linkage is affected by a financial crisis to mitigate the economic loss from price shocks after the crisis but only a few studies exist that examined this issue. To shed light on this situation, this study identifies how the long-run price linkages and price causalities among the crude oil and precious metal markets changed before and after the 2008 financial crisis. Instead of only focusing on the oil-gold market linkage, our study also investigates the oil-platinum linkage. This is because both gold and platinum belong to the same precious metal group, but the platinum market is more closely related to the crude oil market. Recently, nearly 40% of the platinum produced globally is used for automobile catalysts (World Platinum Investment Council (WPIC), 2017), and it is probable that the platinum market is more directly influenced by the crude oil market. Hence, the oil-platinum linkage will provide a good comparison to the oil-gold linkage. To investigate how the market linkage among the crude oil and precious metal markets is affected by a financial crisis, this study

examines the spot price linkage among the Brent and WTI crude oil, and the London gold and platinum prices during periods before and after the 2008 financial crisis.

In the next section, we introduce studies that are relevant to this study. In the third section, we explain the methods and data used to pursue the research objective. Fourth, we present the results of the analysis and concludes in the last section.

## 2. Literature review

We present our review of previous studies from four aspects: whether gold is a safe haven or hedge against other markets, the relationship between gold and exchange rate, the relationship between gold and crude oil, and the volatility aspects of the relationship between gold and crude oil. Table 1 provides a summary of relevant studies introduced in this study.

Table 1. Summary of relevant literature			
Publication year	Authors	Type of study	Approach
2005	Capie et al	Studying whether gold is a safe haven against other markets.	Cross-correlations, ARCH, GARCH, EGARCH
2010	Baur and Lucey	Studying whether gold is a safe haven against other markets.	Asymmetric GARCH process
2010	Baur and Mcdermott	Studying whether gold is a safe haven against other markets.	GARCH
2010	Sari et al.	Investigating the relationship between gold and exchange rate.	ARDL
2011	Joy	Studying whether gold is a safe haven against other markets.	DCC-GARCH
2012	Le and Chang	Volatility aspects of the relationship between gold and crude oil.	Multivariate VAR
2013	Guimaraes	Studying whether gold is a safe haven against other markets.	Linear rression
2013	Reboredo	Examining the oil and gold relationship.	Copula
2015	Bampinas and Panagiotidis	Examining the oil and gold relationship.	Granger causality test
2015	Bildirici and Turkmen	Examining the oil and gold relationship.	Nonlinear ARDL
2015	Charles et al.	Volatility aspects of the relationship between gold and crude oil.	Automatic variance ratio and portmanteau tests
2015	Tiwari and Sahadudheen	Volatility aspects of the relationship between gold and crude oil.	GARCH, EGARCH
2016	Raza et al.	Volatility aspects of the relationship between gold and crude oil.	Nonlinear ARDL
2016	Yaya et al.	Volatility aspects of the relationship between gold and crude oil	Constant Conditional Correlation (CCC) modelling, VARMA-MGARCH
2017	Iqbal	Studying whether gold is a safe haven against other markets, investigating the relationship between gold and exchange rate.	EGARCH
2017	Kumar	Examining the oil and gold relationship.	Nonlinear ARDL
2018	Tursoy and Faisal	Examining the oil and gold relationship.	ARDL bounds testing approach
2019	Liao and Goo	Studying whether gold is a safe haven against other markets.	GARCH, GJR-GARCH, Hybrid Momentum TAR-GARCH (HMTAR-GARCH)

There is a growing body of literature on whether gold acts as a safe haven or hedge against market risks by comparing the gold market with the stock markets or through examining the gold return volatility. Capie et al. (2005), Baur and Lucey (2010), and Joy (2011) investigate this issue in a general manner, while Baur and Mcdermott (2010), Guimaraes (2013), and Iqbal (2017) test the hypothesis for specific regions. Gold has been considered a safe haven and a hedge as it does not get devalued in case of any market instability. However, some of the recent literature point to the nuances in this claim. For example, Baur and Mcdermott (2010) analyze the role of gold as a safe haven and find that gold is both a hedge and a safe haven for major European and the US stock markets but not for Australia, Canada, Japan, and BRIC countries. Similarly, Joy (2011) analyses the potential of gold to act as a hedge against the US dollar or as a safe haven. Using a DCC-GARCH model to understand the conditional correlations between the price of gold and exchange rate, the study concludes that gold acts as a strong investment hedge against the US dollar. However, gold did not act as a consistent safe haven with respect to weekly movements in international share prices.

Among the studies on the relationship between gold and exchange rate, Sari et al. (2010) examine the directional relationships between the spot prices of gold, silver, platinum and palladium, oil price, and euro-US dollar exchange rate. The authors also examine which of these is a driver in the long-run. They find that despite the strong correlations among the precious metals in the short run, the oil prices, precious metal prices, and exchange rates do not collectively drive each other in the long run and that the variations in these prices are due to their innovation. They also find that the spot prices of precious metals and the exchange rate may be closely linked in the short run after market shocks. In a more recent study by Iqbal (2017), an EGARCH model is applied to daily and monthly data of stock prices, commodity prices and exchange rates in India, Pakistan, and the US. The study concludes that the hedging potential of gold is dependent on the state of the gold market itself.

Several studies examine the causal relationships between crude oil and gold prices. Bampinas and Panagiotidis (2015) study the causal relationship between crude oil and gold spot prices before and after the 2007–08 financial crisis. They perform linear and nonlinear Granger causality tests on daily time series data. Their analysis indicates a bidirectional nonlinear causality relationship after the financial crisis as compared to the linear and unidirectional causality from oil to gold in the pre-crisis period. Bildirici and Turkmen (2015) study the relationship between oil price and prices of gold, silver and copper. They analyze how these prices react to negative and positive changes in oil price in the short-run and long-run. They find that bidirectional causality exists between gold and oil and copper and oil. Additionally, they find that there is a unidirectional Granger causality from oil price to silver price. Kumar (2017) examines the causal relationship between oil and gold prices in the Indian context. Using the Hiemstra and Jones (1994) nonlinear Granger causality test and nonlinear ARDL tests, the study concludes that the relationship between oil and gold prices is nonlinear and asymmetric and that positive shock in oil prices have more effects than negative shocks on gold prices. Tursoy and Faisal (2018) study the long-run and short-run interaction between stock prices, gold prices and crude oil prices for Turkey. The results indicate a negative relationship between stock and gold prices and that crude oil positively impacts stock prices but there exists no causality between stock prices and crude oil. Reborado (2013) analyzes the dependence structure between gold and oil to understand the role of gold as a hedge or a safe haven against oil prices. The study applies different copula functions to weekly data from January 2000 to September 2011 and finds that gold and oil are positively and significantly dependent, which precludes it from being a hedge against oil prices. However, during periods of stress in oil markets, gold is found to be an effective safe haven.

Finally, studying the interrelationships between gold and crude oil as well as between other precious metal markets will deepen our understanding of how these relationships are affected by shocks and magnitude of volatilities. For example, Le and Chang (2012) study the relationship between oil price shocks and gold returns using a multivariate VAR approach on a monthly sample data and find that oil price shocks affect gold returns significantly and positively contemporaneously within one month of

the shock and that the effect of oil price shocks on gold returns is non-linear. Charles et al. (2015) study the market efficiency (or return predictability) of gold, silver, and platinum using automatic variance ratio test (Kim, 2009) and the automatic portmanteau test (Escanciano & Lobato, 2009) and find that these markets have a time-varying return predictability over time and the predictability depends on economic and political conditions.

Tiwari and Sahadudheen (2015) study the relationship between real oil price and real gold price using the GARCH and EGARCH models and reveal that an increase in oil price has positive effects on gold and that positive and negative shocks have a different effect on gold price in terms of magnitude. They find that these two commodities are positively correlated and that during the financial crisis of 2006–2008, gold was more volatile compared to other periods. Raza et al. (2016) study the asymmetric impact of gold and oil prices, and their associated volatilities on the stock prices of emerging markets both in the short and long run. They use a nonlinear ARDL approach on the monthly data of Chinese, Indian, Russian, South African, Mexican, Malaysian, Thai, Chilean and Indonesian markets and find that gold prices seem to have a positive impact on stock prices and gold volatility had a negative impact on emerging stock markets. Yaya et al. (2016) study the price cointegration, price causality, and price discovery between the crude oil and the gold markets using daily data from January 2000 to March 2008. The empirical analysis shows that the volatility magnitude of crude oil price is greater than that of the gold price in the sampling period and that there exists a long-term equilibrium relationship between these two.

In this paper, we analyze the changes in the gold-oil relationship before and after the 2008 financial crisis. While our framework is similar to that of Bampinas and Panagiotidis (2015), our study is different from theirs as we compare the gold-oil relationship to that of platinum-oil relationship. The platinum market plays a crucial role in both the auto and the oil industry, and hence, our study provides more helpful insights for market participants that are trading between the gold and oil markets. Furthermore, until now, only a few studies have investigated how the 2008 financial crisis influenced the cointegration relationship between the gold and oil markets considering the effects of a structural break in time series data.

### 3. Materials and methods

Only a few studies exist that examine the gold-oil price relationship using the cointegration method by considering the effects of a structural break. Thus, our study applies three types of cointegration tests. The conventional Johansen test (Johansen & Juselius, 1990), recursive Johansen test, and the Gregory-Hansen (Gregory & Hansen, 1996) test. Recursive Johansen test reveals how the cointegration relationship has changed during our investigated time period and Gregory-Hansen test considers an endogenous structural break in the time series data of interest and tests the cointegration relationship with the effect of a structural break.

Our cointegration tests to identify the long-run relationships among the oil and precious metal markets are performed on three sample periods. The first period covers our entire sample period, the 2001:1 to 2019:4 period. Our second sample contains the period before the 2008 financial crisis. As a sharp decline in the real economy started to become apparent after the bankruptcy of Lehman Brothers on 15 September 2008 (Adrian & Shin, 2010), we assume that the 2008 financial crisis began in September 2008. Hence, our second sample period, the period before the 2008 financial crisis, is the 2001:1 to 2008:8 period. Finally, the third sample consists of the period after the financial crisis, the 2008:9 to 2019:4 period.

First, we performed the stationarity tests on all the price series analyzed in this study for the above-mentioned sample periods. For this purpose, we used the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), KPSS, and Lee-Strazicich (LS) (Lee & Strazicich, 2013) unit root tests. Since the ADF, PP, and KPSS tests do not consider the effects of a structural break in their test models, we also performed the LS test considering one structural break in its test model. We included the lagged augmentation terms in our stationarity tests. For identifying the lag order, we used the

Schwarz information criterion in the ADF, PP, and KPSS tests, while the general to specific procedure (Ng & Perron, 1995) was used in the LS test.

To identify the long-run market linkages among the crude oil and precious metal markets, we conducted three types of cointegration tests: the Johansen, the recursive trace, and the Gregory-Hansen tests.

Let  $P_t$  be the column vector of the  $k$  price series of our interests. Then our Johansen test is performed using the following vector error correction model:

$$\Delta P_t = \pi P_{t-1} + \sum_{i=1}^{n-1} \Gamma_i \Delta P_{t-i} + \gamma_0 + \varepsilon_t, \quad t = 1, \dots, T \quad (1)$$

where  $\Delta$  is the first difference operator,  $\pi$  is a  $k \times r$  matrix with  $r$  cointegrating ranks.  $\gamma_0$  is a constant vector,  $\varepsilon_t$  is a vector of distributed independent and identically, and normally distributed random disturbance term, and  $\Gamma_i$  is a  $k \times k$  fixed matrix of coefficient parameters. Whether the price series become cointegrated depends on the rank of  $\pi$ . This rank is identified by the trace and maximum eigenvalue test statistics, which is obtained by the estimated values of the characteristic roots from  $\pi$ .

The recursive Johansen test is first performed by estimating the Johansen trace test over an initial sample. The basic econometric model used in this test is the same as the model in equation (1). In our study, this base initial sample was set to the 2001–01–2001:10 period. Then, additional observations are added to this base sample, and at each iteration, the trace statistic is re-estimated recursively. This recursive estimation continues until the final sample period, Apr. 2019, is reached. The estimation is done with CATS 2.0 package in RATS Version 10.0. The results of these test statistics are plotted and evaluated graphically. In our study, the recursive Johansen trace statistics are scaled to unity by their 5% critical values. In the figure with plots of the estimated trace statistics, the critical values that are larger than one indicate that the two series are cointegrated.

The Gregory-Hansen test considers a structural change in its cointegration model. The structural change is defined as:

$$\varphi_{tr} = \begin{cases} 0 & \text{if } t \leq T_{SC} \\ 1 & \text{if } t > T_{SC} \end{cases}$$

where  $T_{SC}$  is the date of the structural change. In our study, we used the Model 2 “regime shift” model of Gregory-Hansen, considering a level shift with a time trend in the model. Then, our Gregory-Hansen cointegration test model can be expressed as:

$$Y_{1t} = \alpha_1 + \alpha_2 \varphi_{tr} + \beta_1 t + \beta_2 Y_{2t} + e_t, \quad t = 1, \dots, n, \quad (2)$$

where  $Y_{1t}$  and  $Y_{2t}$  are our test variables,  $\alpha_1$  is the intercept term before the structural change and  $\alpha_2$  is the intercept at the time of the shift from the change.  $\beta_1$  and  $\beta_2$  are the coefficient parameters, and  $e_t$  is an error term assumed as  $I(0)$ . The modified ADF, and Phillips  $Z_t$  and  $Z_\alpha$  test statistics (1987) are used to test the stationary of  $e_t$  in Equation (2).

The Toda and Yamamoto (1995) causality test is used for identifying the price causalities among the crude oil and precious metal markets. This modified Granger causality test is useful since the investigator does not need to difference the price series by using the  $k + d$  lags in the vector autoregressive model (VAR). In this test,  $k$  is the optimal number of lags in the VAR model, and  $d$  is the maximal order of integration (Aruga & Li, 2015). We identified the order of  $k$  by the Schwarz information criterion and  $d$  is based on the Johansen cointegration test.



Figure 1 illustrates the crude oil and precious metal prices used in the study. The period we used for the investigation is 2001:1–2019:4. It is noticeable that before the 2008 financial crisis, the platinum price was consistently higher than the gold price, but after the crisis this gap shortened, and since mid-2015, the gold price began to exceed the platinum price. Unlike the gold price, the platinum price dropped sharply similarly to the crude oil prices after September 2008. We can also see the change in the Brent and WTI crude oil markets for periods before and after the 2008 financial crisis. Before the crisis, these two crude oil markets were persistently moving similarly with a very small gap. However, after the crisis, there are periods where these oil markets are moving apart with some price gaps.

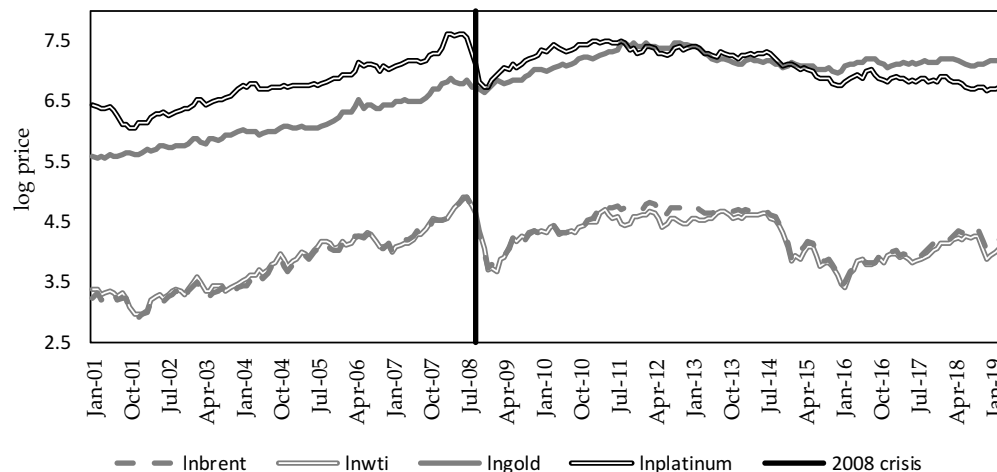
We used the monthly US dollars per barrel prices of West Texas Intermediate light crude oil and the Brent light blend crude oil. These price series are obtained from the International Monetary Fund (IMF) Primary Commodity Prices. For the gold and platinum prices, we used the London Fix gold and platinum prices. We used the London prices because London precious metal market is the world’s oldest, largest, and most influential organized market (Ntim et al., 2015). These precious metal prices are provided in US dollars per troy ounce and we used the monthly price series. All the metal price data used in the study are downloaded from the homepage of The Perth Mint.

#### 4. Results and discussions

To investigate the order of integration of our price series, we conducted four types of unit root tests on the variables. Table 2 depicts the results of these stationarity tests for our three sample periods. The test confirms that based on at least one of the test statistics that the test variables are integrated at order one: I(1). For the entire period, the ADF and PP test suggests that the variables are I(1), and for the period before the 2008 financial crisis, the ADF, PP, and KPSS tests demonstrate that the variables are I(1). For the period after the 2008 crisis, the PP and LS tests indicate that the variables are I(1).

As the precondition for performing cointegration tests is met, we investigated the cointegration relationship among the crude oil and precious metal price series. Table 3 shows the results of the Johansen test. The test performed on the entire period suggests that while gold did not have long-run relationships with both Brent and WTI crude oil markets, the platinum market had a price linkage with the WTI crude oil market. The result of gold not having cointegration relationships with the crude oil markets is consistent with the test results of Bampinas and Panagiotidis (2015). The contrastive result of the platinum having a relationship with the WTI crude oil could be because recently the Platinum market is becoming a better market for hedging inflation risk compared to gold (McCown & Shaw, 2017). This result is implying that the platinum-oil price linkage is stronger than the gold-oil linkage.

**Figure 1. Crude oil and precious metal log prices.**



**Table 2. Unit root tests**

	Level				First differences			
	ADF	PP	KPSS	LS	ADF	PP	KPSS	LS
Entire period (2001:1–2019:4)								
Brent	-2.050	-1.988	0.833 ***	-3.342	-11.050 ***	-10.990 ***	0.135	-10.948 ***
WTI	-2.280	-2.070	0.729 **	-3.597	-2.280 ***	-10.346 ***	0.112	-10.117 ***
Gold	-2.165	-2.093	1.629 ***	-3.633	-12.959 ***	-12.935 ***	0.528 **	-13.133 ***
Platinum	-2.010	-1.852	0.727 **	-4.454 **	-10.413 ***	-10.365 ***	0.189	-10.519 ***
Before the financial crisis (2001:1–2008:8)								
Brent	0.004	0.266	1.202 ***	-3.342	-4.380 ***	-8.953 ***	0.156	-10.948 ***
WTI	0.309	0.353	1.189 ***	-3.597	-6.017 ***	-7.733 ***	0.188	-10.117 ***
Gold	0.728	-0.081	1.217 ***	-3.633	-4.634 ***	-9.422 ***	0.065	-13.133 ***
Platinum	-0.255	-0.428	1.174 ***	-4.454 **	-5.317 ***	-6.527 ***	0.102	-10.519 ***
After the financial crisis (2008:9–2019:4)								
Brent	-2.333	-2.091	0.423 *	-3.173	-7.429 ***	-7.074 ***	0.100	-7.935 ***
WTI	-2.676 *	-2.409	0.501 **	-3.511	-7.645 ***	-7.291 ***	0.119	-7.948 ***
Gold	-2.583 *	-2.352	0.220	-2.811	-9.212 ***	-9.183 ***	0.383 *	-8.483 ***
Platinum	-1.669	-1.344	0.845 ***	-3.368	-8.236 ***	-8.249 ***	0.076	-9.644 ***

The ADF, PP, and KPSS unit root tests include only a constant. The Lee-Strazicich (LS) test has both constant and trend with one structural break in the test model. \*\*\*, \*\*, \* denote significance at 1%, 5%, 10%.

We also see that a long-run linkage sustained within the crude oil and precious metal markets. This result is expectable because Brent and WTI crude oil are highly substitutable and gold and platinum are both precious metals and are considered as substitutable by investors when hedging against inflation.

Before the 2008 financial crisis, no cointegration relationship existed in all the relationships examined in Table 3. In contrast, we found that the gold market began to be cointegrated with the two crude oil markets after the crisis. However, this relationship was only identified at the 10% significance level.

To understand the dynamics of the cointegration relationship among oil and metal markets for periods before and after the 2008 financial crisis, we conducted the recursive Johansen tests. Figure 2 illustrates the results of this test. First, it is clear from the figure that gold market was not cointegrated with the crude oil market in most periods. The figure reveals that gold was only linked for a short period between 2011 and 2013 and in general does not have a long-run relationship with the crude oil market. This is perhaps why the gold market was only cointegrated at the 10% significance level for the period after the 2008 financial crisis in the Johansen test (see Table 3). Second, the figure demonstrates that the platinum market started to become cointegrated with the crude oil markets after the financial crisis. It is also discernible from the figure that the platinum-WTI linkage was more significant compared to the platinum-Brent linkage. However, we did not see such change in the platinum-oil linkages from the Johansen test, so these linkages are later investigated with the Gregory-Hansen test. Third, cointegration relationships within the crude oil and precious metal markets were not cointegrated in most of our investigated period and did not have a clear distinction in the relationship when comparing the dynamics for periods before and after September 2008.

As the recursive Johansen test revealed that some of the results are different from the Johansen test in Table 3, we also performed the Gregory-Hansen cointegration test. This test considers the effect of a structural change in the price series when testing cointegration relationships. Table 4 depicts the test result. Interestingly, the result of the Gregory-Hansen test for the oil and metal relationship is consistent with the recursive cointegration test. It shows that the gold market was

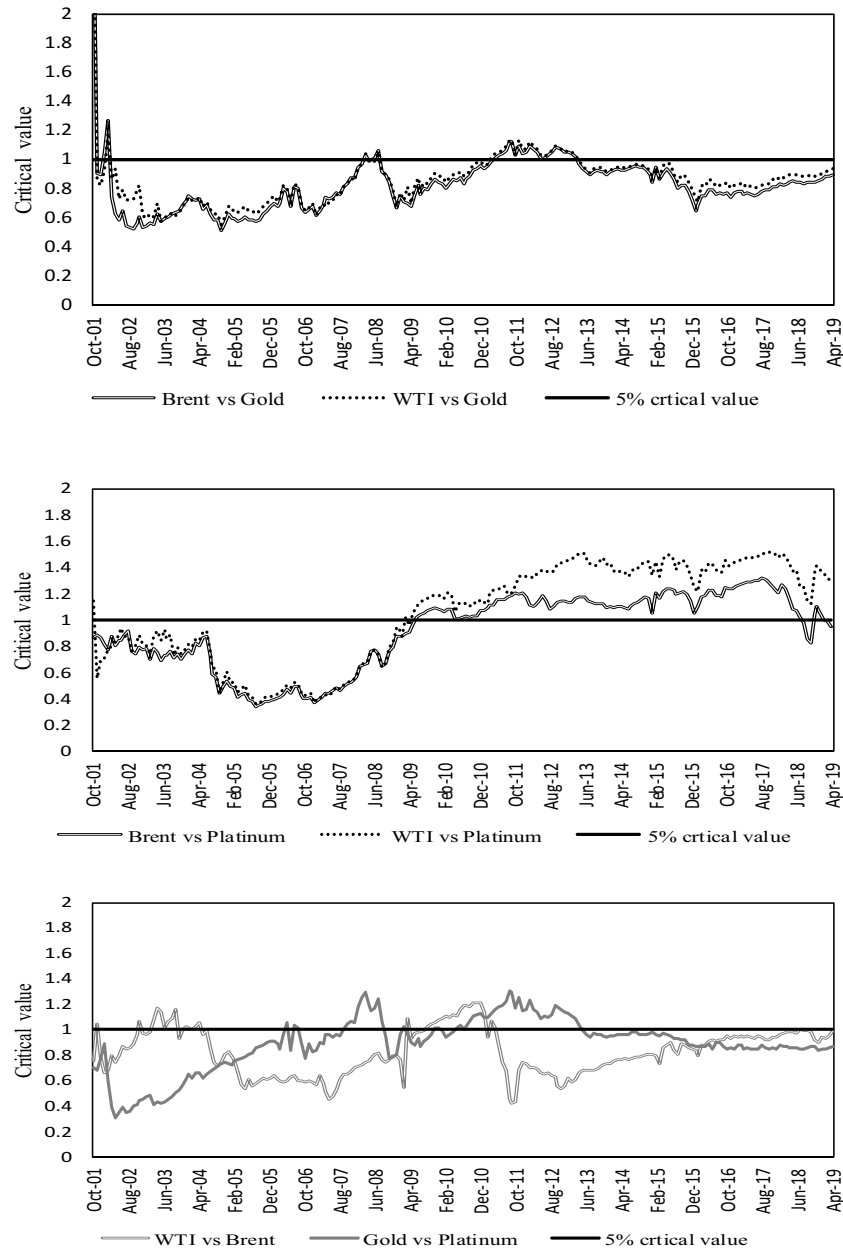
**Table 3. Bivariate cointegration tests**

Variables	H <sub>0</sub> : rank = r	Trace test	Max test	Granger Causality tests	Chi-sq test
Entire period (2001:1–2019:4)					
Brent vs Gold	r = 0	20.33 **	12.52	ΔBrent ⇌ ΔGold	0.02
	r ≤ 1	7.81 *	7.81 *	ΔGold ⇌ ΔBrent	1.57
Brent vs Platinum	r = 0	14.50	9.85	ΔBrent ⇌ ΔPlatinum	0.86
	r ≤ 1	4.65	4.65	ΔPlatinum ⇌ ΔBrent	12.74 ***
WTI vs Gold	r = 0	22.25	13.05	ΔWTI ⇌ ΔGold	0.04
	r ≤ 1	9.20	9.20 **	ΔGold ⇌ ΔWTI	3.00 *
WTI vs Platinum	r = 0	20.78 **	16.16 **	ΔWTI ⇌ ΔPlatinum	4.38 **
	r ≤ 1	4.61	4.61	ΔPlatinum ⇌ ΔWTI	24.59 ***
WTI vs Brent	r = 0	22.80 **	17.73 **	ΔWTI ⇌ ΔBrent	0.53
	r ≤ 1	5.07	5.07	ΔBrent ⇌ ΔWTI	3.39 *
Gold vs Platinum	r = 0	21.38 **	15.94 **	ΔGold ⇌ ΔPlatinum	0.09
	r ≤ 1	5.45	5.45	ΔPlatinum ⇌ ΔGold	0.20
Before the financial crisis (2001:1–2008:8)					
Brent vs Gold	r = 0	18.53 *	10.37	ΔBrent ⇌ ΔGold	0.30
	r ≤ 1	8.16 *	8.16 *	ΔGold ⇌ ΔBrent	5.93 **
Brent vs Platinum	r = 0	13.12	11.26	ΔBrent ⇌ ΔPlatinum	0.03
	r ≤ 1	1.85	1.85	ΔPlatinum ⇌ ΔBrent	10.44 ***
WTI vs Gold	r = 0	18.38 *	9.95	ΔWTI ⇌ ΔGold	0.16
	r ≤ 1	8.43 *	8.43 *	ΔGold ⇌ ΔWTI	5.89 **
WTI vs Platinum	r = 0	12.98	11.08	ΔWTI ⇌ ΔPlatinum	0.07
	r ≤ 1	1.90	1.90	ΔPlatinum ⇌ ΔWTI	10.86 ***
WTI vs Brent	r = 0	15.52	12.84	ΔWTI ⇌ ΔBrent	0.91
	r ≤ 1	2.68	2.68	ΔBrent ⇌ ΔWTI	0.22
Gold vs Platinum	r = 0	21.45 **	11.69	ΔGold ⇌ ΔPlatinum	11.88 ***
	r ≤ 1	9.76 **	9.76 **	ΔPlatinum ⇌ ΔGold	0.91
After the financial crisis (2008:9–2019:4)					
Brent vs Gold	r = 0	19.26 *	14.65 *	ΔBrent ⇌ ΔGold	0.27
	r ≤ 1	4.61	4.61	ΔGold ⇌ ΔBrent	14.71 ***
Brent vs Platinum	r = 0	7.50	4.83	ΔBrent ⇌ ΔPlatinum	0.52
	r ≤ 1	2.67	2.67	ΔPlatinum ⇌ ΔBrent	6.38 ***
WTI vs Gold	r = 0	20.12 *	15.23 *	ΔWTI ⇌ ΔGold	0.40
	r ≤ 1	4.89	4.89	ΔGold ⇌ ΔWTI	12.79 ***
WTI vs Platinum	r = 0	11.91	8.91	ΔWTI ⇌ ΔPlatinum	0.50
	r ≤ 1	3.01	3.01	ΔPlatinum ⇌ ΔWTI	7.22 ***
WTI vs Brent	r = 0	20.94 **	17.78 **	ΔWTI ⇌ ΔBrent	4.83 **
	r ≤ 1	3.16	3.16	ΔBrent ⇌ ΔWTI	9.01 ***
Gold vs Platinum	r = 0	15.31	11.45	ΔGold ⇌ ΔPlatinum	0.06
	r ≤ 1	3.86	3.86	ΔPlatinum ⇌ ΔGold	1.46

The test is performed with the level data having no deterministic trends but the cointegrating equations have intercepts. \*\*\*, \*\*, \* denotes significance at 1%, 5%, and 10%.

not cointegrated with the Brent and WTI crude oil markets in both periods before and after the 2008 financial crisis. On the other hand, the result in the table suggests that although the platinum market did not have price linkages with the crude oil markets before the financial crisis, it became

**Figure 2. Recursive plots of Johansen's trace statistic. The recursive trace statistics are scaled to unity by their 5% critical values. The trace statistics above unity imply a rejection of the null hypothesis of rank zero, suggesting that the two series are cointegrated ( $r = 1$ ).**



cointegrated with both the Brent and WTI crude oil markets after the crisis. This is likely indicating that after the financial crisis, the platinum market became more important than the gold market for the investors to hedge against the price risk involved with changes in the crude oil market.

Finally, we explain our findings regarding the price causalities. From Table 3, we can see that there was a Granger causality from the precious metal markets to the crude oil markets in all three sample periods. This indicates that there was a price information flow from the precious metal to crude oil markets and the investors were likely using information from the precious metal market to predict the crude oil market. Comparing the causality results between gold and platinum for periods before and after the 2008 financial crisis, it is visible that before the crisis the gold was the price leader, but this causality from the gold to platinum disappeared after the crisis. Unlike the gold market, the platinum market declined remarkably after the crisis, and presumably, this shift led the platinum market to lose its causal relationship with the gold market.

**Table 4. Gregory-Hansen cointegration tests**

Variables	ADF		$Z_t$		$Z_\alpha$	
	test statistic	Break point	test statistic	Break point	test statistic	Break point
Entire period (2001:1–2019:4)						
Brent vs Gold	-4.61	May-08	-4.03	Jun-08	-31.98	Jun-08
Brent vs Platinum	-4.02	Oct-06	-3.90	Jun-16	-29.75	Jun-16
WTI vs Gold	-4.73 *	May-08	-4.11	Feb-09	-32.51	Feb-09
WTI vs Platinum	-4.61	Jun-16	-4.48	Jun-16	-38.84	Jun-16
WTI vs Brent	-6.02 ***	Feb-11	-6.14 ***	Oct-10	-64.35	Oct-10
Gold vs Platinum	-4.92 *	Sep-03	-4.22	Sep-03	-34.12	Sep-03
Before the financial crisis (2001:1–2008:8)						
Brent vs Gold	-3.62	Sep-05	-3.74	Sep-05	-24.52	Sep-05
Brent vs Platinum	-3.58	Aug-04	-3.61	Aug-04	-18.59	Aug-04
WTI vs Gold	-3.58	Sep-05	-3.69	Sep-05	-23.91	Sep-05
WTI vs Platinum	-3.53	Aug-04	-20.27	Jul-04	-3.58	Jul-04
WTI vs Brent	-6.21 ***	Nov-02	-6.26 ***	Nov-02	-47.72 *	Nov-02
Gold vs Platinum	-3.15	Mar-03	-3.30	Apr-03	-15.89	Aug-03
After the financial crisis (2008:9–2019:4)						
Brent vs Gold	-3.63	Aug-13	-3.53	Jul-13	-20.13	Jul-13
Brent vs Platinum	-4.92 *	Oct-17	-5.01 **	Oct-17	-37.84	Oct-17
WTI vs Gold	-3.68	Aug-13	-3.53	Jul-13	-19.70	Jul-13
WTI vs Platinum	-5.34 **	Jun-17	-4.98 *	Oct-17	-37.21	Oct-17
WTI vs Brent	-4.10	Feb-11	-4.25	Feb-11	-32.23	Feb-11
Gold vs Platinum	-4.74 *	Mar-15	-4.46	Mar-15	-32.38	Mar-15

The 1%, 5%, 10% critical values ADF and  $Z_t$  test statistics are -5.45, -4.99, -4.72, and those for the  $Z_\alpha$  are -57.28, -47.96, -43.22 respectively (Gregory & Hansen, 1996). \*\*\*, \*\*, \* denote significance at 1%, 5%, and 10%.

### 5. Conclusions

The study investigated whether the gold market continued to be independent of the crude oil market after the 2008 financial crisis. We found little evidence that gold started to have a price linkage with the crude oil market after the 2008 financial crisis. Especially, when we considered the effects of a structural change in the long-run relationship between crude oil and gold markets, no price linkage existed between the two markets. Conversely, we identified a long-run relationship between the crude oil and platinum markets after the 2008 financial crisis. No price linkage sustained between oil and platinum before the financial crisis, but they started to become cointegrated after the crisis. As the platinum market is more directly connected to the crude oil market through the automobile industry, it is probable that like other commodities, platinum was influenced by the economic shock after the financial crisis.

Hence, our study reveals that gold did not start to show a market linkage with the crude oil market after the 2008 financial crisis. This indicates that the gold market was independent of the price shock that occurred in the crude oil market after the crisis and it is probable that it remained unlinked with other financial commodities during the crisis. The results of this study could be significant for traders and investors since, in anticipation of the financial crisis, they shift their investments. However, if gold remains independent from other commodity markets, investments in gold can be less susceptible to impacts from other markets.

Finally, we would like to note that our study is limited in the sense that we defined the timing of the 2008 financial crisis as Sept. 2008 because this was the month when the Lehman Brothers

collapsed. The results of our study are likely to change if this assumption of the break date changes, and hence, more studies needed to be done to find out how changing the break date of the financial crisis will affect the study results.

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