Proceedings of the 10th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/2026.34908

The Cointegration Between Gold Price and Stock Market Volatilities: Evidence from S&P500

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Abstract. The purpose of this paper is to delve into the relationship between three economic variables: gold price, stock market volatility and oil spot price, employing a 3-variable Vector Autoregression (VAR) model. Among the three variables, stock market volatility is measured by the CBOE VIX index, while oil prices are gauged by the spot price of WTI crude oil. This paper applies monthly data covering the period from January 2010 to October 2025 in order to test research hypotheses that the three variables are interrelated. The paper employs unit root tests and descriptive statistics to ensure data are stationary, a VAR model to measure the directions of the interrelations and a Granger causality test to further confirm the existence of correlation. Model estimation result demonstrates a unidirectional relation from VIX index to WTI spot, while Granger causality test reveals no direct cause-effect relationship in between, so their interaction can be more complicated. The empirical result validates the safe-haven properties of gold, as evidenced by existing literature.

Keywords: Gold price, Stock market volatility, Crude oil, VAR

1. Introduction

Although gold is no longer used as legal tender in international trade, it is still retained by central banks around the world as a reserve asset due to its nature as a precious metal. Regarded as a key safe-haven asset against economic crises and inflation, gold has strong demand from both individuals and institutions globally. As a means of investment that contains less correlation with other assets, gold and related gold stocks served as a hedge against geopolitical risk and were added into investment portfolios to minimize market risk. Gold is widely recognized as a high-quality safe-haven asset under extreme market conditions including geopolitical uncertainty, although Baur & Lucey's research shows that this property can be short-lived [1]. Furthermore, increasing evidence in recent studies suggests that gold price has significant interactions with other commodities.

Gold prices and stock market fluctuations have widespread impacts on financial investments and broader economic sectors, and the relationship between the two variables has long been a popular research topic in related disciplines, particularly during financial crises and global trade tensions. During periods of economic disruptions, significant fluctuations in gold prices and stock markets can be observed, revealing their close connections with macroeconomic indicators. Existing studies indicate that gold prices are significantly correlated with the scale of economic activities (GDP), inflation rates, and international trade volume [2-4], and thus can indirectly reflect the fluctuations in

DOI: 10.54254/2754-1169/2026.34908

financial markets. Crude oil, similarly, is cointegrated with macro-econometrics by influencing consumer consumption, industrial output and real economy investment. Hence, researchers and investors assume interrelated relationships among gold price, stock market volatility and crude oil.

The aim of this paper is to examine whether the long-run relationship exists among three variables, gold price, stock market volatility and crude oil, over the period of 15 years by applying a 3-vector VAR model. Granger causality test is adapted to distinguish the causation of the three variables. Existing papers focus solely on the pairwise relationships between the two; this research addresses the limitation by incorporating the three vectors in the model, justifying their interrelationship with a causation approach. Empirical result aids investors in understanding the interplay between the financial market and commodity market, thereby facilitating the decision-making process for market participants. paves the way for future research in the subject area.

2. Literature review

Early literature explores gold price and its relationships with a range of econometric variables like GDP, inflation and the forex rates, while in recent years more studies have been discussing the implications of gold price on stock market returns. Cai et al. argue that the GDP and inflation rate have a strong impact on the volatility of gold price returns [5]. Capie et al. contend that gold serves as a good hedge against foreign exchange market volatility [6]. Research by Baur and McDermott exploring the influence of gold prices on financial market data from 1979 to 2009 found that gold acts as a safe-haven in the U.S. and EU stock markets [7]. The research of Batten et al. analysing a 30-year spanning market data with a GARCH regression model also drew a significant result that gold is a good safe-haven in most developed markets, especially during financial crises [8].

The studies conducted by Awartani et al. and Mensi et al. both examined the correlation and volatility transmission channel across precious metals, oil, and equity markets, uncovering that US equities significantly affect the gold and oil price volatility [9, 10]. Similarly, Patel inspected the Granger causation between domestic gold price and stock price return and found the bidirectional Granger-cause relationship between the two variables in the Indian market [11]. Recent research by Pata et al. focusing on the Turkish market further corroborates that both crude oil and gold prices have significant impacts on the Turkish stock market volatility [12]. Nonetheless, evidence from other markets identifies correlations among gold, oil and stock market volatility, a study on Brent oil and gold does not confirm a stable bidirectional causal relationship, particularly over longer sample periods. Moreover, during economic crises, causal flows can fracture suddenly [13]. Overall, relevant research on related topics remain inconclusive, as the findings may vary depending on the market data from which they are derived.

3. Methodology

3.1. Data

The data employed in this paper consists of the rate of change (ROC) for gold price, VIX index and the WTI crude oil spot, denoted by roc_gold, roc_vix and roc_wti, respectively. Data consists of monthly data spanning from January 2010 to October 2025, while this timeframe encompasses multiple crisis periods: European sovereign debt crisis, the global pandemic and the Ukraine war.

The first variable, roc_ gold, is defined as the natural logarithm of the ratio of the monthly quoted gold prices, which is sourced from World Gold Council (WGC), by its preceding month's price.

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Noted that the data of monthly quoted gold price achieved from WGC is denominated in USD per troy ounce.

VIX, obtained from Chicago Board Options Exchange (CBOE), is known as the "fear gauge" and computed by averaging S&P500 put and call options, regarded as an important measure of market volatility. Datasets of roc_vix is derived from natural logarithmic difference of the monthly VIX (S&P500 implied volatility) to its preceding value.

WTI crude oil spot is the West Texas Intermediate spot price at Cushing, Oklahoma, available from EIA (U.S. Energy Information Administration). The variable, roc_crude, is obtained by taking natural logarithm of ratio of the current month's spot price to the preceding month spot price.

The descriptive statistics show that the original data of gold price, volatility, and WTI spot data are non-stationary, but their ROC terms are tested as stationary. Hence, their percentage forms, roc_gold, roc_vix and roc_wti, are applied in the model (see Figure 1, Figure 2 and Figure 3).

```
.  dfuller roc_gold, lags (4)

Augmented Dickey-Fuller test for unit root

Variable: roc_gold                          Number of obs  = 184
                                            Number of lags =   4

H0: Random walk without drift, d = 0

                                          Dickey-Fuller
                   Test       -------- critical value ---------
              statistic             1%           5%          10%
---------------------------------------------------------------
 Z(t)            -4.178         -3.482       -2.884       -2.574
---------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0007.
```

Figure 1. Unit root test for roc_gold

```
. dfuller roc_vix, lags (4)

Augmented Dickey-Fuller test for unit root

Variable: roc_vix                           Number of obs  = 184
                                            Number of lags =   4

H0: Random walk without drift, d = 0

                                          Dickey-Fuller
                   Test       -------- critical value ---------
              statistic             1%           5%          10%
---------------------------------------------------------------
 Z(t)            -8.387         -3.482       -2.884       -2.574
---------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000.
```

Figure 2. Unit root test for roc_vix

DOI: 10.54254/2754-1169/2026.34908

```
. dfuller roc_wti, lags (4)

Augmented Dickey-Fuller test for unit root

Variable: roc_wti                          Number of obs  = 184
                                           Number of lags =   4

H0: Random walk without drift, d = 0

                                       Dickey-Fuller
                   Test       -------- critical value ---------
              statistic           1%           5%          10%
---------------------------------------------------------------
 Z(t)            -6.806       -3.482       -2.884       -2.574
---------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000.
```

Figure 3. Unit root test for roc_wti

3.2. Model specification

To investigate the long-run interdependence between gold price and stock market volatility in a system jointly, the primary focus of this paper, a Vector Autoregression (VAR) model is adopted to examine the interrelation of three variables: roc_gold, roc_vix and roc_wti.

Vector Autoregression (VAR) model is a statistical model designed to capture the interdependencies among multiple time series. Instead of testing each variable alone, the VAR model is used to identify the dynamic relations among variables in the system over time. In this paper, the model is employed to examine the pairwise relationships amongst the three variables. Relationships can be bidirectional, unidirectional or irrelevant. Descriptive data and unit root tests are conducted to prove the stationarity of the variables. In addition, the Granger Causality test is performed to determine the potential direction of their causality.

Assuming u_{1t} and u_{2t} are white noise terms or stochastic error terms, the multi-length bivariate VAR(p) model can be represented as:

$$roc\_gold_t = a_1 + \sum_{i=1}^{m} b_i roc\_gold_{t-i} + \sum_{j=1}^{m} c_j roc\_vix_{t-j} + \sum_{k=1}^{m} d_k roc\_wti_{t-k} + u_{1t} \quad (1)$$

$$roc\_vix_t = a_2 + \sum_{i=1}^{m} b_i roc\_gold_{t-i} + \sum_{j=1}^{m} c_j roc\_vix_{t-j} + \sum_{k=1}^{m} d_k roc\_wti_{t-k} + u_{2t} \quad (2)$$

$$roc\_wti_t = a_3 + \sum_{i=1}^{m} b_i roc\_gold_{t-i} + \sum_{j=1}^{m} c_j roc\_vix_{t-j} + \sum_{k=1}^{m} d_k roc\_wti_{t-k} + u_{3t} \quad (3)$$

Where:

a_1, a_2 and a_3 are constants;

b_i, c_j and d_k are lagged values of roc_gold, roc_vix and roc_wti, respectively;

DOI: 10.54254/2754-1169/2026.34908

m is the optimal lag length of VAR model

The lag length, m, is determined by applying multiple selection criterion, including the Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC) and Schwarz Bayesian Information Criterion (SBIC). As shown in Figure 4, although HQIC and SBIC information criteria indicate that the optimal lag length is 1, the value of AIC criteria is more negative and signifying, thereby the model with lag 2 is better at balancing accuracy and parsimony.

```
. varsoc roc_gold roc_vix roc_wti, maxlag(12)

Lag-order selection criteria

  Sample: 2011m2 thru 2025m10                             Number of obs = 177
```

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	494.649				7.8e-07	-5.55536	-5.53353	-5.50153
1	518.283	47.267	9	0.000	6.6e-07	-5.72071	-5.63338*	-5.50538*
2	531.425	26.285	9	0.002	6.3e-07*	-5.76752*	-5.61469	-5.39069
3	534.627	6.4037	9	0.699	6.7e-07	-5.702	-5.48367	-5.16367
4	542.095	14.936	9	0.093	6.8e-07	-5.68469	-5.40087	-4.98486
5	551.637	19.083*	9	0.024	6.8e-07	-5.69081	-5.34149	-4.82948
6	555.756	8.2382	9	0.510	7.2e-07	-5.63566	-5.22084	-4.61283
7	560.58	9.6481	9	0.380	7.5e-07	-5.58847	-5.10815	-4.40414
8	561.958	2.7565	9	0.973	8.2e-07	-5.50235	-4.95653	-4.15652
9	564.946	5.9769	9	0.742	8.8e-07	-5.43442	-4.82311	-3.9271
10	568.069	6.2445	9	0.715	9.5e-07	-5.36801	-4.6912	-3.69918
11	573.476	10.814	9	0.289	9.9e-07	-5.32741	-4.5851	-3.49708
12	581.268	15.584	9	0.076	1.0e-06	-5.31376	-4.50595	-3.32194

```
* optimal lag
Endogenous: roc_gold roc_vix roc_wti
 Exogenous: _cons
```

Figure 4. multiple lag-order selection criterion

Hence, the VAR model should be reformulated as:

$$roc\_gold_t = a_1 + \sum_{i=1}^{2} b_i roc\_gold_{t-i} + \sum_{j=1}^{2} c_j roc\_vix_{t-j} + \sum_{k=1}^{2} d_k roc\_wti_{t-k} + u_{1t} \quad (4)$$

$$roc\_vix_t = a_2 + \sum_{i=1}^{2} b_i roc\_gold_{t-i} + \sum_{j=1}^{2} c_j roc\_vix_{t-j} + \sum_{k=1}^{2} d_k roc\_wti_{t-k} + u_{2t} \quad (5)$$

$$roc\_wti_t = a_3 + \sum_{i=1}^{2} b_i roc\_gold_{t-i} + \sum_{j=1}^{2} c_j roc\_vix_{t-j} + \sum_{k=1}^{2} d_k roc\_wti_{t-k} + u_{3t} \quad (6)$$

In the next step, estimation is performed and diagnostics are presented in the next section. Notably, the Lagrange Multiplier test is performed to check for residual autocorrelation, and the Granger test will tell the Granger relationships between variables.

DOI: 10.54254/2754-1169/2026.34908

4. Empirical results

The model estimation result is presented in Figure 5, while Figure 6 and 7 show the residual plots and autocorrelation test results. Figure 8 displays the result of Granger causality test.

```
. var roc_gold roc_vix roc_wti,lags(1/2)

Vector autoregression

Sample: 2010m4 thru 2025m10                     Number of obs     =       187
Log likelihood =   566.3634                     AIC               =  -5.832763
FPE            =   5.88e-07                     HQIC              =  -5.685735
Det(Sigma_ml)  =   4.70e-07                     SBIC              =  -5.469911

Equation           Parms      RMSE     R-sq      chi2     P>chi2
------------------------------------------------------------------
roc_gold               7      .0327   0.1131   23.84432   0.0006
roc_vix                7      .2271   0.1052   21.97678   0.0012
roc_wti                7    .099255   0.1529   33.74519   0.0000
------------------------------------------------------------------
```

	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
roc_gold						
roc_gold						
L1.	.338116	.0734825	4.60	0.000	.1940929	.4821391
L2.	-.1039578	.0745707	-1.39	0.163	-.2501138	.0421981
roc_vix						
L1.	.0123034	.010593	1.16	0.245	-.0084585	.0330653
L2.	-.0103906	.0106206	-0.98	0.328	-.0312066	.0104255
roc_wti						
L1.	-.0062083	.0231682	-0.27	0.789	-.0516172	.0392007
L2.	-.0186347	.0230659	-0.81	0.419	-.063843	.0265736
_cons	.0052998	.0024104	2.20	0.028	.0005755	.0100241
roc_vix						
roc_gold						
L1.	-.1957707	.5103372	-0.38	0.701	-1.196013	.8044718
L2.	.0234658	.5178948	0.05	0.964	-.9915894	1.038521
roc_vix						
L1.	-.3228997	.0735685	-4.39	0.000	-.4670913	-.178708
L2.	-.109933	.0737604	-1.49	0.136	-.2545007	.0346347
roc_wti						
L1.	.0629792	.1609038	0.39	0.695	-.2523865	.3783448
L2.	-.2013212	.1601929	-1.26	0.209	-.5152936	.1126512
_cons	.0038716	.0167402	0.23	0.817	-.0289387	.0366818
roc_wti						
roc_gold						
L1.	-.2747497	.2230457	-1.23	0.218	-.7119113	.1624119
L2.	.3887108	.2263488	1.72	0.086	-.0549247	.8323464
roc_vix						
L1.	.0259977	.0321535	0.81	0.419	-.0370221	.0890174
L2.	.0733249	.0322374	2.27	0.023	.0101408	.1365091
roc_wti						
L1.	.3238175	.0703239	4.60	0.000	.1859852	.4616499
L2.	-.2416721	.0700132	-3.45	0.001	-.3788955	-.1044487
_cons	-.0020867	.0073164	-0.29	0.775	-.0164266	.0122532

Figure 5. VAR model estimation result

DOI: 10.54254/2754-1169/2026.34908

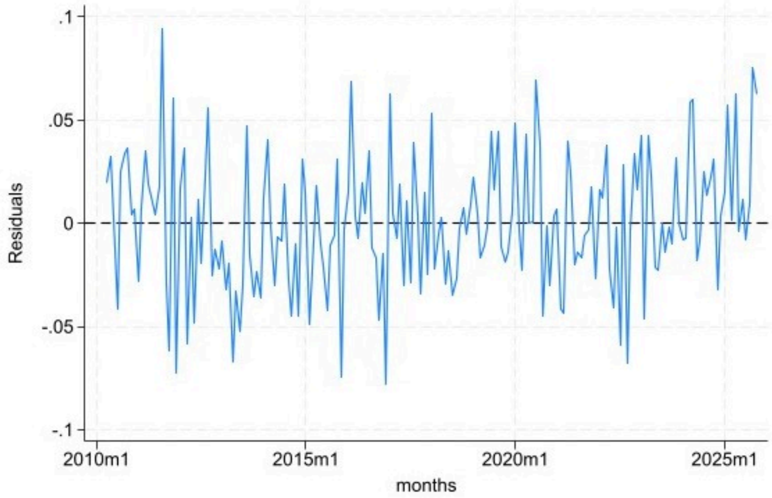

Figure 6. Residual plots

. varlmar

Lagrange-multiplier test

lag	chi2	df	Prob > chi2
1	7.3938	9	0.59619
2	12.7680	9	0.17339

H0: no autocorrelation at lag order

Figure 7. LM test for residual autocorrelation

. vargranger

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
roc_gold	roc_vix	3.2711	2	0.195
roc_gold	roc_wti	.88818	2	0.641
roc_gold	ALL	3.9822	4	0.408
roc_vix	roc_gold	.15104	2	0.927
roc_vix	roc_wti	1.5858	2	0.453
roc_vix	ALL	1.7172	4	0.788
roc_wti	roc_gold	3.5749	2	0.167
roc_wti	roc_vix	5.1927	2	0.075
roc_wti	ALL	7.8358	4	0.098

Figure 8. Pairwise Granger causality test

From the estimated results of VAR model, a preliminary conclusion can be drawn that changes in gold price are significantly independent from the other two variables. In contrast, changes in stock market volatility have unidirectional implications on the changes in WTI spot price at a 5% significance interval.

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To further explore the direction of causality between the variables, Granger causality test is performed. The result shows that none of the variables Granger-cause each other at a 5% confidence interval, failing to confirm the existence of long-term causation flow suggested by the previous estimation outcome. Although the result implies that if the confidence interval is set at 10%, the result will be overturned: the historical data of change in volatility in the stock market can Granger-cause the change in WTI spot price.

5. Conclusion

This study analyses the causal relationship between gold, stock market volatility and oil using a 3-vector VAR approach, supplemented by a Granger causality test to examine implied predictability amongst the variables. With the data sample covering multiple crisis periods, the test shows some interesting findings. Different from evidence found in emerging markets like India and Turkey, gold functions as a safe-haven asset in the US market during extreme oil price (WTI spot) fluctuations and excessive equity market turbulence (as implied by VIX). VAR model justifies a unidirectional causal relation from stock market volatility to crude oil price. However, their Granger causation is tested as insignificant at a 5% confidence level. This finding suggests that the interaction between oil and stock market volatility is non-linear and the two variables may interact through more complex mechanisms.

These findings offer practical insights for investors and policymakers attempting to grasp how commodity markets interact with financial markets. It helps investors to forecast commodity prices under extreme market conditions and incorporate precious metals into portfolios as a hedge against abnormal turbulence in oil prices and equity markets. Policymakers can better understand the interplay between commodity markets and financial market volatility during market disruptions with the evidence found in this paper.

Future studies in this subject may improve results by employing non-linear causality models or causality-in-quantile methods to further investigate the complex causation relations. Notably, monthly data may overlook the short-term implications between variables, so future studies should acquire higher-frequency market data, i.e., on a weekly or daily basis, to ensure the data captures short-term dynamics effectively.

References

[1] Baur, D.G. and Lucey, B.M. (2010) 'Is gold a hedge or a safe haven? an analysis of stocks, bonds and gold', Financial Review, 45(2), pp. 217–229. doi: 10.1111/j.1540-6288.2010.00244.x.

[2] Gokmenoglu, K. K., & Fazlollahi, N. (2015). The interactions among gold, oil, and stock market: Evidence from S& P500. Procedia Economics and Finance, 25, 478–488. https: //doi.org/10.1016/s2212-5671(15)00760-1

[3] Thaver, R. L. and Lopez, J. (2016). Unemployment as a Determinant of Gold Prices: Empirical Evidence. The International Journal of Business and Finance Research, v. 10 (10) p. 43-52. https: //ssrn.com/abstract=2913179

[4] A, L., Qin, Q., Kamran, H. W., Sawangchai, A., Wisetsri, W., & Raza, M. (2021). Retracted: How macroeconomic indicators influence gold price management. Business Process Management Journal, 27(7), 2075–2087. https: //doi.org/10.1108/bpmj-12-2020-0579

[5] Cai, J., Cheung, Y.-L., & Wong, M. C. S. (2001). What moves the gold market? Journal of Futures Markets, 21(3), 257–278. https: //doi.org/10.1002/1096-9934(200103)21: 3%3C257: : aid-fut4%3E3.0.co; 2-w

[6] Capie, F., Mills, T. C., & Wood, G. (2005). Gold as a hedge against the dollar. Journal of International Financial Markets, Institutions and Money, 15(4), 343–352. https: //doi.org/10.1016/j.intfin.2004.07.002

[7] Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. Journal of Banking & Finance, 34(8), 1886–1898. https: //doi.org/10.1016/j.jbankfin.2009.12.008

[8] Batten, J. A., Ciner, C., & Lucey, B. M. (2010). The macroeconomic determinants of volatility in precious metals markets. Resources Policy, 35(2), 65–71. https: //doi.org/10.1016/j.resourpol.2009.12.002

DOI: 10.54254/2754-1169/2026.34908

[9] Awartani, B., Aktham, M., & Cherif, G. (2016). The connectedness between crude oil and financial markets: Evidence from implied volatility indices. Journal of Commodity Markets, 4(1), 56–69. https: //doi.org/10.1016/j.jcomm.2016.11.002
[10] Mensi, W., Beljid, M., Boubaker, A., & Managi, S. (2013). Correlations and volatility spillovers across commodity and stock markets: Linking energies, food, and gold. Economic Modelling, 32, 15–22. https: //doi.org/10.1016/j.econmod.2013.01.023
[11] Patel, S. A. (2013). Causal Relationship Between Stock Market Indices and Gold Price: Evidence from India. IUP Journal of Applied Finance, 19(1).
[12] Pata, U. K., Usman, O., Olasehinde-Williams, G., & Ozkan, O. (2023). Stock Returns, Crude Oil and Gold Prices in Turkey: Evidence from Rolling Window-Based Nonparametric Quantile Causality Test. Asia-Pacific Financial Markets, 31(3), 779–797. https: //doi.org/10.1007/s10690-023-09430-x
[13] Raggad, B., & Bouri, E. (2023). Gold and crude oil: A time-varying causality across various market conditions. Resources Policy, 86, 104273. https: //doi.org/10.1016/j.resourpol.2023.104273