Capital Market Volatility During Crises: Oil Price Insights, VIX Index, and Gold Price Analysis

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Abstract. *The study aims to investigate capital market volatility during crises, exploring the relationships between three key financial indicators: oil prices, the VIX index, and gold prices, using monthly data covering the period from January 2013 to May 2023, based on the Granger causality approach and the impulse response function testing empirically the existence of the long-run relationship using Johansen multivariate approach and the estimation of the VAR/VECM model. By analysing their interdependencies, the research sheds light on how these indicators respond to economic turbulence. The study employs robust econometric methods to investigate causal relationships and predictive patterns, providing valuable insights for investors, policymakers, and analysts navigating uncertain financial landscapes. The findings reveal nuanced dynamics, such as the momentum in oil prices, the inverse relationship between oil prices and the VIX index, and a significant Granger causality relationship running from the VIX index to oil and gold prices. Furthermore, based on the impulse response patterns, the shock in the VIX index caused a notable oil price decrease in the second quarter after the shock, followed by oscillations. Gold prices exhibit a minor initial decline after the VIX shock, with no lasting effects.*

Keywords: Capital Market Volatility, Oil Price Insights, VIX Index, Gold Price Analysis, Granger causality analysis, VAR models.

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Introduction

Capital markets are essential to a country's financial infrastructure, as a barometer for an economy's overall health and trajectory. Crises, from geopolitical disturbances to financial ones, can precipitate severe disruptions in these markets, often amplified by the interconnectedness of today's global economy. Three indicators, namely oil price, the VIX index, and gold price, offer valuable insights into the complicated dynamics during these tumultuous periods.

Oil, often dubbed the lifeblood of modern economies, is intrinsically linked to countless sectors, from transportation to production. Any significant fluctuation in oil prices can impact economies, affecting production costs, inflation rates, and consumer spending. Thus, when crises hit, they can often disrupt oil markets directly, through supply chain disturbances, or indirectly, by affecting demand due to economic recessions. An increase in oil price might indicate supply constraints or geopolitical tensions in key oil-producing regions. In contrast, a price decrease might signify a drop in demand, suggesting a potential economic slowdown. Analysts and investors can gather essential information about the impending or ongoing impact of a crisis tracking these changes.

The VIX index, or the “fear index,” is an invaluable tool to gauge the mood and perceptions of market participants. It reflects expectations regarding stock market volatility over the next 30 days. A rising VIX indicates that investors anticipate increased volatility, suggesting a bearish or uncertain outlook, while a declining VIX often indicates an optimistic sentiment and a stable market. The VIX can spike dramatically during crises as uncertainty permeates the market landscape. By monitoring this index, stakeholders can get a real-time picture of the prevailing investor sentiment, allowing them to make informed decisions and potentially anticipate market trends.

Throughout history, gold has stood firm as a bastion of value and reliability. Its intrinsic value is such that investors frequently turn to it as a haven against uncertainty in times of crisis. An increase in the price of gold, especially when juxtaposed with declining stock markets, can indicate a widespread flight to safety. This traditional refuge asset can often offer clues about the depth and duration of a crisis, given its historical role as a hedge against inflation and currency fluctuations.

Understanding the interplay between oil prices, the VIX index, and gold prices is essential for anyone to comprehend crises' multidimensional impact on capital market volatility. These indicators, each representing a unique facet of the market, provide a nuanced and comprehensive view of the broader economic landscape during periods of disturbances. In the face of crises, having a holistic perspective becomes paramount, and these metrics offer just that, allowing stakeholders to navigate.

Therefore, the main aim of the paper is to investigate and analyse the relationships between oil prices, the VIX index and gold prices, and essential financial instruments in the global industry that are considered key indicators of economic and geopolitical conditions. The closing price of oil reflects the worldwide supply and demand for petroleum, and its fluctuations can be influenced by factors such as international policy, geopolitical events, and changes in oil production. The VIX index, which measures the volatility of the US capital market, is considered an indicator of risk and investor sentiment.

An increase in the VIX may indicate uncertainty and instability in the markets, while a decrease can suggest stability and confidence. Multiple factors, including inflation, monetary policy, geopolitical instability, and demand for gold as a safe-haven investment, influence the price of gold. Gold is often seen as a safe haven asset in times of economic uncertainty or volatility in financial markets.

This was achieved using monthly data for the closing prices of oil, the VIX index, and gold over ten years, from 2013 to 2023, based on Johansen co-integration analysis under the VAR model, Granger causality analysis, and impulse response function. The research spans 10 years and considers numerous key occurrences, including the 2008 financial crisis, geopolitical unrest, economic booms, and current global issues. The paper contributes to the literature in several ways. The study provides a holistic analysis of the relationships between the closing price of oil, the VIX index, and the price of gold. This comprehensive examination of these essential financial indicators during 10 years contributes to a deeper understanding of their interconnectedness. By employing the Granger causality approach under the VAR model together with the impulse response function, the research showcases methodological diversity. This approach enhances the robustness of the findings and thoroughly explores the indicators' interactions. The study covers various significant events, including the 2008 financial crisis and more recent challenges. Examining how these indicators react to diverse crises contributes to a deeper understanding of market behaviour during different types of turmoil.

The paper is structured as follows. The section literature review presents the most relevant studies analysing the relationships between oil price, VIX index and gold price. The third section has been dedicated to data and methodology presentation, the fourth section presents the empirical results and the last two sections have been dedicated to discussions and conclusions.

Shedding light on the evolution of oil price, VIX index, and gold price during the period 2013-2023

The monthly changes in Brent closing stock price from 2013 to 2023 displayed a fluctuating trajectory influenced by geopolitical tensions, supply-demand dynamics, and market sentiment. During 2013-2014, Brent crude prices showed relative stability, with moderate fluctuations reflecting supply-demand dynamics and geopolitical tensions.

Economic growth in emerging markets, especially China, influenced oil demand and prices. 2015-2016 witnessed a significant decline in oil prices due to oversupply concerns and OPEC's decision not to cut production. Brent crude prices experienced substantial volatility, contributing to fluctuations in monthly changes. During 2017-2018, geopolitical tensions in the Middle East and production disruptions influenced short-term price spikes, while in 2019, concerns over US-China trade tensions and geopolitical events in the Middle East had intermittent impacts on oil prices. In 2020, the COVID-19 pandemic led to an unprecedented crash in oil demand, causing Brent crude prices to plummet. Negative prices were recorded for the first time due to supply glut and storage constraints. As economies gradually recovered and production cuts were implemented, Brent prices rebounded, but volatility remained high.

In 2021-2023, vaccine distribution and economic recovery efforts helped stabilise oil demand and prices. Discussions on transitioning to greener energy sources impacted market sentiment and expectations. The monthly changes in Brent crude prices reflected ongoing supply adjustments and shifts in global energy policies (Figure 1).

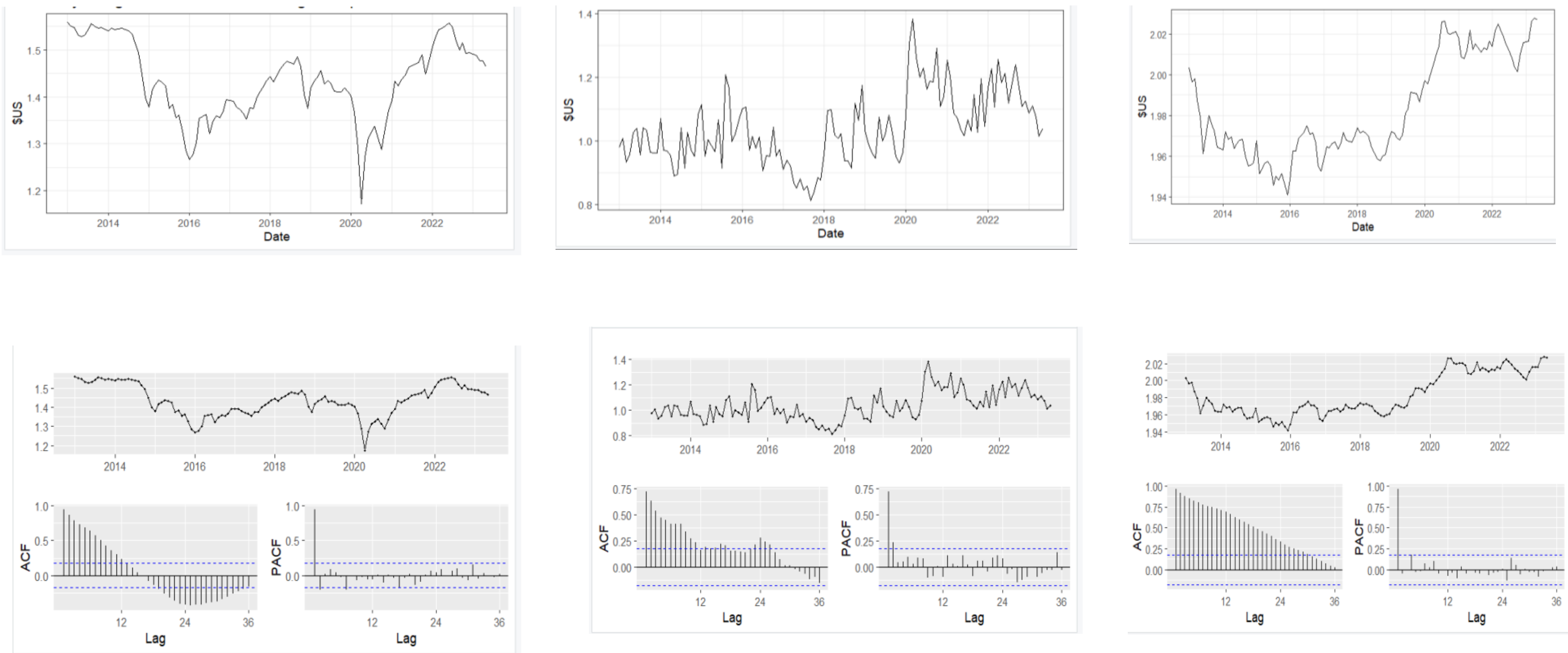
Throughout the decade, the VIX index demonstrated its role as a market sentiment and investor uncertainty barometer. Its fluctuations mirrored key economic events, policy changes, and global health crises, highlighting its responsiveness to shifts in investor sentiment and market conditions. During 2013-2014, the VIX index gradually declined as global markets recovered from the 2008 financial crisis. Improving economic conditions and accommodating monetary policies contributed to a sense of optimism, reflected in lower VIX levels. In 2015-2016, the VIX experienced spikes due to concerns over China's economic slowdown and volatile oil prices. The increased uncertainty about interest rate hikes by the US Federal Reserve and Brexit added to market turbulence.

The most significant and rapid surge in the VIX occurred during the early months of 2020 as the COVID-19 pandemic spread globally. Widespread lockdowns, economic uncertainty, and market sell-offs led to unprecedented volatility, often called the "fear gauge," reaching historical highs.

The VIX gradually subsided as economies adapted to the pandemic, reflecting cautious optimism amid vaccine development and stimulus measures. News related to vaccine efficacy and distribution played a pivotal role in shaping VIX fluctuations during 2020-2021. Discussions around transitioning to a post-pandemic era and concerns about inflation contributed to periodic VIX spikes during 2022-2023.

Gold prices showcased their dual role as a safe haven asset and an inflation hedge. During 2013-2014, gold prices gradually declined after reaching historic highs in previous years; Improved global economic conditions and reduced safe-haven demand contributed to this decline. For 2015-2016, geopolitical tensions and concerns about global economic growth prompted a rebound in gold prices. Investors sought the safety of gold as a hedge against market volatility and economic uncertainties.

In late 2016-2018, with improving economic indicators and a rise in interest rates, gold prices stabilised and showed relative consistency. Positive economic trends reduced the urgency for safe haven assets such as gold. In 2019, escalating trade tensions between major economies fuelled uncertainty and boosted gold demand. Central bank interest rate cuts and accommodative monetary policies further supported gold's appeal. The outbreak of the COVID-19 pandemic led to a rapid surge in gold prices. Investors sought refuge in gold due to heightened uncertainty, economic disruptions, and unprecedented monetary stimulus measures. As vaccine development progressed and economies adapted to the pandemic, gold prices experienced fluctuations in 2020-2021. Positive vaccine news tempered safe haven demand, leading to periods of price correction. In the last two years, 2022-2023, rising inflation concerns, driven by economic recovery and stimulus measures, rekindled interest in gold. Investors turned to gold as an inflation hedge and a store of value against potential currency devaluation.



Monthly changes in Brent closing stock price **Monthly changes in VIX closing stock price** **Monthly changes in gold closing stock price**

Figure 1. The evolutions in the oil price, VIX index, and gold price during the period 2013-2023

Source: Authors' own research.

Literature review

The financial world is a vast network of interconnected indicators, each responding to countless internal and external (global) factors. The price of gold, the VIX index, and oil price are three primary indicators. To understand the complex dance between these indicators beyond their knowledge, we must comprehend the network of interactions and correlations that bind them.

Historically, **gold** has held an unwavering position as a foundational store of value. Like those by Baur and Lucey (2010), modern speciality studies provide empirical perspectives on gold's multifunctional utility in financial portfolios. Capie et al. (2005) analysed gold's performance during currency volatility. Sjaastad (2008) offers a methodical analysis of gold's relationship with major exchange rates, highlighting its stabilising attributes. At the same time, Aggarwal and Lucey (2007) investigated potential psychological factors that influence the trajectory of the gold price. Gold has been shown by Akhtaruzzaman et al (2021) to be the best long-term hedge for the US equities market. Gold is more effective at hedging Islamic stock portfolios than conventional ones, according to research by Raza et al. (2019). Gold continuously serves as a hedge and haven for BRICS stocks throughout crises and normal times, as demonstrated by Bekiros et al. (2017). Gold is the strongest safe haven asset in several sophisticated stock markets, according to research by Ali et al. (2020). The theory that during economic downturns, investors flock to gold, causing a negative association between gold yield and stock returns, is unfounded. This was also true for the COVID-19 era and the financial crisis of 2007–2009. The link between the gold price and the stock market, however, is favourable when real rates of return are negative. According to the data, gold is a safe haven during times of stock market turbulence and low interest rates (Drake, 2022).

The VIX, also referred to as the "fear index," is a representative indicator of market mood and predicted swings. Since its creation in 1993, the key US volatility indicator, known as the VIX index, has been keenly watched by foreign investors. It is based on the S&P 500. Investors who evaluate their stakes in underdeveloped countries increasingly follow the VIX index, as opposed to investors from rich countries in the past. Whaley (2000) demonstrates the VIX's ability to forecast impending market changes by building on earlier research. Giot (2002) experimentally examines the association between the VIX and generic stock indices to support this theory. Although Fleming et al. (1995) gave a comparison analysis contrasting the VIX's predictive prowess against other recognised volatility measures, Blair et al. (2001) emphasise the significance of the VIX in anticipating future market volatilities. The VIX index is utilised as a predictor of impending changes in financial markets. The implicit volatility index is another name for it (Sakarya & Akkuş, 2018). Basher and Sadorsky (2016) used daily data between January 4, 2000, and July 31, 2014 for their investigations to evaluate the relationships between the VIX index, gold prices, oil prices, bonds, and stock indices of emerging countries. There was a strong association between stock indexes and oil prices in developing countries, according to the MSCI Emerging Markets Index, which covers 23 developing countries collectively. Additionally, a negative correlation was found between the VIX index, bond prices, emerging market stock indices, and oil prices. The causation association between the VIX index and stock markets from 11 industrialised and developing nations was examined by İskenderoglu, Ö., & Akdağ, S. (2020). Using daily data from January 2015 to December 2017, the Granger Causality and Frequency Analysis was performed. The

VIX index shows a causal association with all indices, with the exception of the US and German indices, according to the study's conclusion.

Oil, an essential commodity in global economic structures, has been the focus of countless academic research. Starting with foundational works like Hamilton (1983), the intricate web of repercussions stemming from oil price disruptions has been dissected. Following this path, Barsky et al (2002) offer a contemporary analysis, emphasising the macroeconomic ramifications of oil price volatility since the 1970s. Further diversifying this discourse, Kilian, L., & Park, C. (2009) distinctly differentiates between various types of oil price shocks, segmenting them into demand and supply-driven paradigms. Complementing this research, Lutz (1999) delivers a comprehensive study illuminating the symbiotic interaction between gold and oil prices during inflationary cycles. The dynamics of crude oil prices exerts a significant influence on global stock markets. Consequently, elucidating the repercussions of oil price fluctuations on stock indices has become a critical focal point in the realm of energy finance Ma, F., et al (2018).As China rises to its status as the world's leading oil importer and the second largest oil consumer, the implications of these price changes become increasingly vital for both Chinese decision makers and the investment community (Zhang, 2017; Ji & Zhang, 2019; Li & Wei, 2018). Recently, a burgeoning literature has been dedicated to studying the interaction between oil prices and stock market performance Roubaud & Arouri, 2018).

The research by Drachal (2021) focuses on predicting real oil prices using a methodology based on time-varying Vector Autoregressive (VAR) models. The study aims to enhance the accuracy of oil price forecasting by considering the dynamic nature of economic relationships and fluctuations in variables over time. The primary contribution of the research lies in its innovative approach to oil price forecasting.

Tuna (2022) investigates how the fluctuations in oil price, gold price, and the VIX index impacted the Turkish BIST 100 stock index during the pandemic period. The Toda-Yamamoto Causality test indicates that there is no causal relationship between oil price, gold price, VIX index, and BIST 100. The results of impulse-response functions and variance decomposition align with this test. They illustrate that the impact of oil price, gold price, and VIX index on BIST 100 diminishes quickly within a short period.

Seyyedi (2017) investigates the interconnections between gold prices, oil prices, and the exchange rate in India. The study is published in the "Global Economic Review," volume 46, issue 1, spanning pages 65 to 79. The research focuses on understanding the dynamic relationships and interactions among these variables within the Indian economic context. The primary objective is to explore whether it is advisable for Indian economic policy makers to separate financial policies from energy policies. By analysing data from January 2004 to April 2015, the study contributes insights into the potential implications of these linkages on economic decision making and policy formulation in India.

Gold and VIX: The correlation between gold and VIX is usually positive during crises. When uncertainty (and therefore, VIX) rises, investors seek refuge in gold, pushing its price up. Conversely, in stable periods, as VIX falls indicating diminished fears, gold may lose its luster in favour of higher-yielding assets. However, this relationship is not always linear, as other factors such as interest rates and currency strength can influence gold prices independently of VIX levels, per Hood and Malik (2013).

Choudhry et al. (2015) found in their research that gold's effectiveness as a safe haven might be diminished during financial crises, attributing this to a two-way relationship between gold returns and stock returns, as well as stock market volatility. Conversely, they observed that, under financially stable conditions, gold appears to function as a hedge against the volatility and returns of the stock market.

Gold and oil: At first glance, gold (a safe haven asset) and oil (a commodity linked to economic activity) might seem unrelated. However, both are priced in US dollars. When the dollar weakens, both oil and gold can become more expensive. Additionally, high oil prices can lead to inflationary pressures, making gold an attractive investment as a hedge against inflation. However, in an economic recession characterised by reduced industrial activity and therefore reduced demand for oil, both the price of oil and gold might decline, although for different reasons Sari et al (2010).

Reboredo (2013) conducted an empirical analysis and illustrated a significant positive correlation between gold and oil prices, suggesting that gold might not be an effective hedge against typical oil price fluctuations. However, the research also indicated tail independence between the two markets, proposing that in situations of extreme oil price shifts, gold could function as a reliable safe haven. These insights are pivotal for portfolio risk strategists and policy developers focusing on harnessing gold to maintain or stabilise the purchasing power of oil exporters (Dima & Vasilache, 2009).

VIX and oil: The relationship here is nuanced. Rising oil prices, especially if they are unexpected, can increase market uncertainty. This might lead to a rise in VIX, as investors anticipate greater market volatility. Conversely, a dramatic drop in oil prices might reflect a bleak economic outlook, leading to heightened market fears and a higher VIX. The opposite can also occur: if geopolitical events or financial crises raise the VIX (and therefore uncertainty), this can depress economic activity, impacting oil demand and its price (Kang et al., 2015).

The interaction between these indicators is dynamic, creating feedback loops. For instance: A geopolitical crisis might raise the price of oil due to supply concerns. This increase can elevate production costs, suggesting future inflation. Investors, sensing this, turn to gold, driving its price up. The same geopolitical unrest increases market uncertainty, pushing the VIX higher. Conversely, a global recession might suppress the price of oil due to reduced demand. This economic downturn, reflected in a higher VIX, might also deter investors from riskier assets, making them consider gold. However, reduced industrial activity and potential deflationary pressures of a recession might counteract this effect on gold prices (Bouri et al., (2017).

"Degiannakis et al. (2014) explored the influence of oil price shocks on the volatility of European stock markets, emphasising three distinct volatility measures: conditional, realised, and implied. Their research indicated that supply-side and oil-specific demand shocks appear to have negligible effects on market volatility. In contrast, oil price alterations due to aggregate demand shocks notably diminish stock market volatility. Such aggregate demand-driven oil price shocks hold significant predictive capacity for both current and future volatilities. This observation remains consistent across overall stock market volatility and individual industrial sectors."

To decipher this web of the global economy, the delicate choreography between indicators like gold prices, the VIX index, and oil prices must be appreciated. While each has its own narrative, their collective story paints a comprehensive picture of global economic health and investor sentiment. Understanding these correlations is essential for analysing the volatility of financial markets, especially in times of crisis.

Data and methodology

The research used monthly data covering January 2013-May 2023 using the natural logarithm[1] of three main variables: monthly changes in Brent closing stock price, monthly changes in VIX closing stock price, and monthly changes in gold closing stock price, the source of data being Yahoo Finance.

The choice of variables has been based on a combination of the existing literature, economic theory, empirical evidence, and practical significance. The studies of Echaust and Just (2022), Kumar et al. (2023), Cui et al. (2023), Bhatti et al. (2023), Liu et al. (2023), or Asifulla and Basha (2023) are representative in the field. According to Echaust and Just (2022), gold continues to serve as a safe haven asset during turbulent market periods. The research found that gold exhibits the characteristics of a safe haven asset, particularly during extreme market events when stock markets experience substantial losses. The study of Kumar et al. (2023) proved that there are complex and bidirectional causal relationships among international crude oil prices, gold prices, exchange rates, and stock markets, finding evidence of bidirectional causality between crude oil prices and stock markets, suggesting that fluctuations in oil prices can influence stock market movements, and vice versa. Gold was identified as a hedge against currency depreciation, as there was evidence of unidirectional causality from exchange rates to gold prices. This implies that investors turn to gold as a safe haven when currencies weaken. The study by Cui et al. (2023) investigates the safe haven properties of gold during the COVID-19 period. It assesses the impact of oil price volatility, gold price, and silver price volatility using advanced econometric techniques like ARDL and NARDL, confirming that gold exhibited significant safe haven properties during the COVID-19 era, making it an attractive asset for investors seeking refuge during times of crisis. Bhatti et al. (2023) revealed that fluctuations in gold and oil prices, particularly their implied volatility, have asymmetrical impacts on Pakistan's stock market, emphasising the importance of monitoring commodity market volatility for investors and policymakers in such economies.

The study primarily investigates the intricate relationships among oil prices, the VIX sentiment index, and gold prices through a comprehensive methodology designed in four steps: analysing variables and revealing the integration order, exploring the long-run relationships, testing the Granger causality, capturing the effect on one shock in the system variables using impulse response functions (IRF).

1.Analysing Variables and Integration Order:

The primary objective of this study is to assess the interconnections between three crucial financial indicators: oil prices, the VIX sentiment index, and gold prices. Initially, unit root tests have been conducted, including the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, to determine the appropriate order of integration for these variables. This step is fundamental as it helps us understand whether these variables exhibit stationary or nonstationary behaviour over time. The decision to use the unit root test was driven by the need to confirm the stationarity status of our variables. If the variables were found to be

[1] When dealing with financial data, you often encounter heteroscedasticity, which means that the variance of the data is not constant across all levels. Taking the logarithm can stabilise the variance, making it more homoscedastic, an assumption of many statistical tests. Also, using the natural logarithm of these variables enables working with returns, as this transformation is a common practice in financial and econometric analysis. It's a way to capture the percentage changes in asset prices, making the data more amenable to various analytical techniques.

nonstationary, further differencing or transformation would be necessary to achieve stationarity.

This step is crucial in time series analysis because it ensures that the statistical analyses, such as Granger causality tests and vector autoregressive modelling, produce reliable and meaningful results.

2.Exploring Long-Run Relationships:

Subsequently, the Johansen co-integration approach within a Vector Autoregressive (VAR) model framework has been applied. This approach is vital for investigating the existence of long-run relationships among the variables while ensuring that there is no serial correlation within the model's residuals. We utilised informational criteria AIC and SBC to optimise the model's specifications to determine the optimal lag length. Residual Analysis in VAR modelling involves scrutinising the differences between observed data and model predictions. Key tests under residual analysis include the Serial Correlation Test, which checks for autocorrelation in the residuals, indicating potential omitted variables; the Normality Test, assessing the normal distribution of residuals to detect model misspecification; and the Heteroskedasticity Test, determining if residual variance remains constant over time, crucial for efficient parameter estimates.

In the general VAR system with n variables, using an unrestricted VAR in levels is appropriate if all variables are nonstationary. The Johansen Co-integration Approach employs a system of equations to test for co-integration among the variables. It assesses whether linear combinations of these variables are stationary, examining whether oil prices, the VIX index, and gold prices share long-term relationships. Johansen's methodology has been implemented via two key tests: the Trace Test and the Maximum Eigenvalue Test. These tests help determine the number of co-integrating relationships in the system. If the Trace Test and/or the Maximum Eigenvalue Test show statistical significance, it suggests the presence of co-integration. Suppose that the variables are found to be co-integrated. In that case, error-correction terms must be included in the VAR model, and the model becomes ECM, analysing both short-term and long-term perspectives of the relationships among oil prices, the VIX index, and gold prices.

If instead of this, the variables are nonstationary (integrated of order one, I(1)), but collectively not co-integrated, the VAR model in the first difference can be employed. This is because the VAR in differences contains only information on short-run relationships between variables.

Therefore, a first-difference Vector Autoregression (VAR) model with p lags for the natural logarithm of oil price (ln(oil)), gold price (ln(gold)), and the VIX index (ln(VIX)) can be represented as follows:

1.Equation for In(Oil):

$$\Delta \ln\,(Oil)_t = \alpha_{0,O} + \sum_{i=1}^{p} \alpha_{i,O} \Delta \ln\left(O_{il_{t-i}}\right) + \sum_{i=1}^{p} \beta_{i,OG} \Delta \ln\,(\text{ Gold }_{t-i}) + \sum_{i=1}^{p} \gamma_{i,OV} \Delta \ln\,(VIX_{t-i}) + \epsilon_{t,O}$$

2.Equation for In(Gold):

$$\Delta\ln(\text{ Gold })_t=\alpha_{0,G}+\sum_{i=1}^{p}\alpha_{i,G}\Delta\ln(\text{ Gold }_{t-i})+\sum_{i=1}^{p}\beta_{i,GO}\Delta\ln(\text{ Oil }_{t-i})+\sum_{i=1}^{p}\gamma_{i,GV}\Delta\ln(VIX_{t-i})+\epsilon_{t,G}$$

3. Equation for In(VIX):

$$\Delta\ln(VIX)_t=\alpha_{0,V}+\sum_{i=1}^{p}\alpha_{i,V}\Delta\ln(VIX_{t-i})+\sum_{i=1}^{p}\beta_{i,VO}\Delta\ln(Oil_{t-i})+\sum_{i=1}^{p}\gamma_{i,VG}\Delta\ln(\text{ Gold }_{t-i})+\epsilon_{t,V}$$

Where:

- ✓ ***Δ*** represents the first difference operator.
- ✓ t represents the current time.
- ✓ α, β and γ are coefficients to be estimated.
- ✓ ϵ represents the error term.

The model captures how changes in the current values of ln(Oil), ln(Gold), and ln(VIX) are influenced by their past values and the past values of the other two variables. The number of lags, p, determines how many past periods are considered in the model.

Furthermore, under the VAR framework, the Granger causality (Granger, 2001) can be tested by exploring the potential causality between oil prices, the VIX index, and gold prices.

3.Granger Causality from Δln(Oil) to Other Variables:

1.Null Hypothesis (H0): Past values of Δln(Oil) do not Granger cause past values of Δln(Gold) and Δln(Vix).

Granger Causality Equation (Δln(Oil)-> Δln(Gold)):

$$\Delta\ln(\text{ Gold })_t=\alpha_1+\sum_{i=1}^{p}\beta_1\Delta\ln(\text{ Gold })_{t-i}+\sum_{i=1}^{p}\gamma_1\Delta\ln(\text{ Oil })_{t-i}+\epsilon_1$$

Granger Causality Equation (Δln(Oil)-> Δln(Vix)):

$$\Delta \ln\,(VIX)_t = \alpha_2 + \sum_{i=1}^{p} \beta_2 \Delta \ln\,(VIX)_{t-i} + \sum_{i=1}^{p} \gamma_2 \Delta \ln\,(Oil)_{t-i} + \epsilon_2$$

2.Alternative Hypothesis (H1): Past values of Δln(Oil) Granger cause past values of Δln(Gold) and Δln(Vix).

Granger Causality from Δln(Gold) to Other Variables:

1.Null Hypothesis(H0): Past values of Δln(Gold) do not Granger cause past values of Δln(Oil) and Δln(Vix).

Granger Causality Equation (Δln(Gold)-> Δln(Oil)):

$$\Delta \ln\,(\mathrm{Oil})_t = \alpha_3 + \sum_{i=1}^{p} \beta_3 \Delta \ln\,(\mathrm{Oil})_{t-i} + \sum_{i=1}^{p} \gamma_3 \Delta \ln\,(\text{ Gold })_{t-i} + \epsilon_3$$

Granger Causality Equation (Δln(Gold)-> Δln(Vix)):

$$\Delta \ln\,(VIX)_t = \alpha_4 + \sum_{i=1}^{p} \beta_4 \Delta \ln\,(VIX)_{t-i} + \sum_{i=1}^{p} \gamma_4 \Delta \ln\,(\text{ Gold })_{t-i} + \epsilon_4$$

2.Alternative Hypothesis (H1): Past values of Δln(Gold) Granger cause past values of Δln(Oil) and Δln(Vix).

Granger Causality from Δln(VIX) to Other Variables:

1.Null Hypothesis (H0): Past values of Δln(VIX) do not Granger cause past values of Δln(Oil) and Δln(Gold).

Granger Causality Equation (Δln(VIX)-> Δln(Oil)):

$$\Delta ln(\mathrm{Oil})_t = \alpha_5 + \sum_{i=1}^{p} \beta_5 \Delta \ln\,(\mathrm{Oil})_{t-i} + \sum_{i=1}^{p} \gamma_5 \Delta \ln\,(\mathrm{VIX})_{t-i} + \epsilon_5$$

Granger Causality Equation (Δln(VIX)-> Δln(Gold)):

$$\Delta\ln(\text{ Gold })_t = \alpha_6 + \sum_{i=1}^{p} \beta_6 \Delta\ln(\text{ Gold })_{t-i} + \sum_{i=1}^{p} \gamma_6 \Delta\ln(VIX)_{t-i} + \epsilon_6$$

2.Alternative Hypothesis (H1): Past values of Δln(VIX) Granger cause past values of Δln(Oil) and Δln(Gold).

These equations represent the Granger causality tests between the first differences of the variables. The coefficients (β's and γ's) are estimated from the data to determine the significance and direction of the causality. If the coefficients are statistically significant, it suggests Granger causality from one variable to another in the first differences.

4. Impulse Response functions:

After establishing Granger causality relationships, we examined the impact of shocks on gold prices, oil prices, and the VIX index. To achieve this, we employed generalised impulse response functions, a technique pioneered by Pesaran and Shin (1998). These functions allow us to trace the dynamic responses of the variables following a shock in one of them, providing insights into the short-term and long-term effects of such shocks.

Empirical results

Over the decade spanning from 2013 to 2023, the common evolution of oil prices, the VIX index, and gold prices reflects a complex interplay of economic, geopolitical, and financial market dynamics. In the earlier years of this period, particularly from 2013 to 2015, oil prices exhibited a downward trajectory. This decline was driven by a confluence of factors, including a global oversupply of oil, a slowing demand from emerging markets, and the emergence of shale oil production in the United States. This drop in oil prices had a ripple effect on the VIX index, which measures market volatility, causing it to remain relatively subdued during this period, as market participants anticipated a stable environment with lower oil prices. Gold prices, on the other hand, experienced a degree of stagnation during this phase, as the decline in oil prices and low market volatility reduced the demand for gold as a safe-haven asset. Toward the mid-2010s and approaching the latter half of the decade, the dynamics shift significantly. Geopolitical tensions, particularly in the Middle East, began to impact oil markets, leading to supply disruptions and a rebound in oil prices. This uptick in oil prices, coupled with broader economic and geopolitical uncertainties, contributed to a rise in market volatility, as reflected in the VIX index. Investors turned to gold once again as a hedge against uncertainty, driving up its prices. This pattern continued into the late 2010s when events such as the COVID-19 pandemic and global economic turmoil further intensified these trends. Oil prices plummeted due to reduced demand caused by lockdowns and travel restrictions, resulting in extreme volatility in the VIX index. Gold, characterised by its historical role as a safe haven, reached record highs during this period as investors sought refuge in the precious metal (Figure 2).

Figure 2. The evolution of oil price, VIX index, and gold price during 2013-2023

Source: Authors' own research.

Exploring the interdependencies between oil prices, the VIX index, and gold prices is essential for comprehending the complex web of factors that influence financial markets, assessing risk, and making informed investment and policy decisions in an increasingly volatile and interconnected world. When exploring the dynamic interconnections among the natural logarithms of oil price, gold price, and the VIX index, the initial phase involves the investigation of the integration order of each series. This examination aims to determine whether all variables exhibit integration of the same order, thereby allowing for the consideration of co-integration. By conducting the ADF and PP tests under various intercept and deterministic trend scenarios, it was established that all series possess an integration order of I (1), aligning them harmoniously and satisfying the first co-integration criterion. Moreover, the Johansen approach has been applied to investigate the existence of a long-run equilibrium relationship between variables. Based on Akaike and Schwartz's criteria, the optimal lag number is 1, and the main hypotheses on the residuals have been validated (Table 1).

Table 1. The optimal lag length

AIC(n)	HQ(n)	SC(n)	FPE(n)
1	1	1	1

Source: Authors' own research.

The empirical results of the Johansen approach invalidated any long-run relationship between the variables analysed since the computed values of both the trace test and the maximum eigenvalues are smaller than the critical ones (Table 2).

Table 2. The empirical results of the Johansen co-integration test

Test type: trace statistic
Values of test statistic and critical values of test:
Test 10pct 5pct 1pct
r <= 2 | 1.71 7.52 9.24 12.97
r <= 1 | 11.89 17.85 19.96 24.60
r = 0 | 33.92 32.00 34.91 41.07
Test type: maximal eigenvalue statistic
Values of test statistic and critical values of test:
test 10pct 5pct 1pct
r <= 2 | 1.71 7.52 9.24 12.97
r <= 1 | 10.18 13.75 15.67 20.20
r = 0 | 22.03 19.77 22.00 26.81

Source: Authors' own research.

Therefore, the potential interdependencies between Brent crude oil price, gold price, and VIX index have been captured through a VAR model in the first differences.
The empirical results are displayed in Table 3.

Table 3. The empirical results of the VAR model

	Dependent variable:		
	y		
	(1)	(2)	(3)
Oil.price.l1	0.209**	-0.027	-0.017
	(0.089)	(0.224)	(0.037)
VIX.index.l1	-0.069*	-0.332***	0.007
	(0.035)	(0.088)	(0.015)
Gold.price.l1	0.170	-0.424	0.082
	(0.219)	(0.550)	(0.091)
const	-0.003	0.001	0.002
	(0.009)	(0.022)	(0.004)
Observations	123	123	123
R2	0.094	0.113	0.011
Adjusted R2	0.071	0.091	-0.014
Residual Std. Error (df = 119)	0.096	0.240	0.040
F Statistic (df = 3; 119)	4.099***	5.069***	0.448
Note:	*p<0.1; **p<0.05; ***p<0.01		

Source: Authors' own research.

The estimated VAR model has the following specification:

- $\Delta oil_t = 0,209 * \Delta oil_{t-1} - 0,069 * \Delta VIX_{t-1} + 0,17 * \Delta gold_{t-1} - 0,003$
- $\Delta VIX_t = -0,027 * \Delta oil_{t-1} - 0,332 * \Delta VIX_{t-1} - 0,424 * \Delta gold_{t-1} + 0,001$
- $\Delta gold_t = -0,017 * \Delta oil_{t-1} + 0,007 * \Delta VIX_{t-1} + 0,082 * \Delta gold_{t-1} + 0,002$

Analysing the empirical results, it can be highlighted that the oil price from the current period is positively influenced by that of the previous period and negatively influenced by the VIX index from the previous period.

Specifically, it can be emphasised that the current oil price is positively impacted by the oil price observed in the previous period. This implies a degree of continuity or persistence in oil prices over time, where a previous period's oil price positively affects the current period's price.

Furthermore, the empirical results also reveal a negative influence of the VIX index from the previous period on the current oil price. This suggests that heightened market volatility, as indicated by a higher VIX index in the previous period, tends to lead to a decrease in the oil price in the subsequent period.

In summary, the analysis demonstrates that historical oil prices positively correlate with current oil prices, reflecting a certain momentum or trend continuity level. Additionally, the negative impact of the previous period's VIX index on the current oil price signifies the inverse relationship between market volatility and oil prices.

Within the equation representing the VIX index, a noteworthy observation emerges of a statistically significant and negative influence exerted by the VIX value from the preceding period upon the current period's VIX level. This notable finding signifies a crucial dynamic, an inverse relationship between the VIX index of the previous period and the VIX index of the current period. Such an outcome underscores the notion that elevated market volatility in the past tends to correspond with a lower VIX index in the subsequent period, implying a potential dampening effect on volatility levels over time.

Notably, the analysis revealed a lack of discernible impact stemming from the previous period's gold prices on either oil prices or the VIX index. In other words, the empirical results suggest that fluctuations in gold prices from one period to another do not significantly influence the subsequent period's oil prices or the VIX index. This absence of a significant relationship underscores the distinct nature of gold prices compared to the dynamics of oil prices and market volatility, as captured by the VIX index.

Interestingly, the analysis indicates a lack of significant impact from oil prices and the VIX index on gold prices. In other words, the empirical results suggest that fluctuations in oil prices and market volatility, as represented by the VIX index, do not appear to have a discernible influence on subsequent changes in gold prices. This finding underscores the distinct nature of gold's behaviour compared to the dynamics of oil prices and market volatility, suggesting that gold may respond to different factors within the market environment.

The diagnostics on residuals revealed that the residuals have been not serially autocorrelated, but not normally distributed and heteroskedastic, since the probabilities of the tests are very small (Table 4).

Table 4. The empirical results of residual tests

Portmanteau Test (asymptotic)
data: Residuals of VAR object model_1
Chi-squared = 107.91, df = 99, p-value = 0.2539
ARCH (multivariate)
data: Residuals of VAR object model_1
Chi-squared = 287.74, df = 216, p-value = 0.0007855
JB-Test (multivariate)
data: Residuals of VAR object model_1
Chi-squared = 55.686, df = 6, p-value = 3.369e-10

Source: Authors' own research.

The empirical results of the CUSUM test revealed the stability of the results.

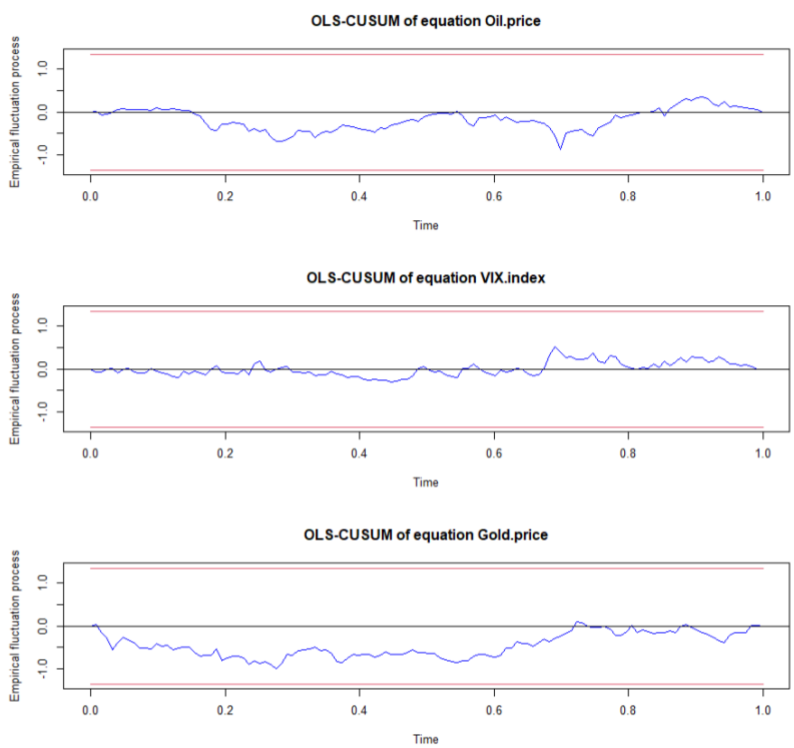


Figure 3. The empirical results of the CUSUM test

Source: Authors' own research.

The empirical results of Granger causality revealed the existence of causality running from the VIX index to oil and gold prices, since the probability is smaller than 10%. In contrast, any other direction of causality has been invalidated.

Table 5. The empirical results of the Granger causality test

Granger causality Ho: Oil price does not Granger cause VIX index and gold price F-test=0.121, df=2, df2=357, p-value=0.885
Granger causality Ho: VIX index does not Granger cause oil and gold prices F-test=2.26, df1=2, df2=357, p-value=0.105
Granger causality Ho: Gold price does not Granger cause Oil price and VIX index F-test=0.456, df1=2, df2=357, p-value=0.639

Source: Authors' own research.

The empirical findings from the Granger causality analysis indicate the presence of a Granger causality relationship running from the VIX index to both oil and gold prices. This implies that past variations in the VIX index can provide valuable predictive information for explaining subsequent changes in both oil and gold prices. Such a relationship underscores the significance of market volatility, as captured by the VIX index, in influencing the price movements of oil and gold. Therefore, using the generalised Pesaran impulse response function, the impact of a shock on the VIX index has been quantified in the Brent crude oil price and gold prices.

The reaction of oil prices to a shock in the VIX sentiment index displayed a decline during the second quarter following the shock, followed by a subsequent oscillating pattern in their evolution. This response suggests that an initial decrease in oil prices occurred immediately after the shock in the VIX sentiment index, followed by subsequent fluctuations in oil price movements in the following periods.

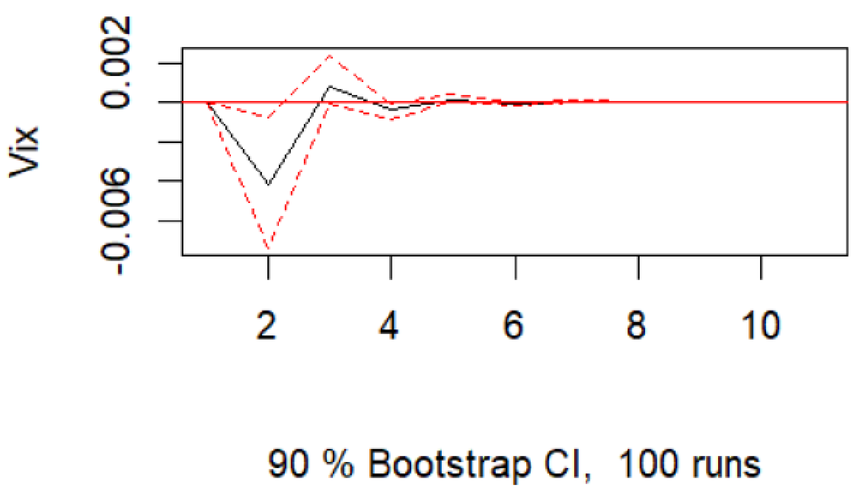


Figure 4. The response of oil price to a shock in the VIX index

Source: Authors' own research.

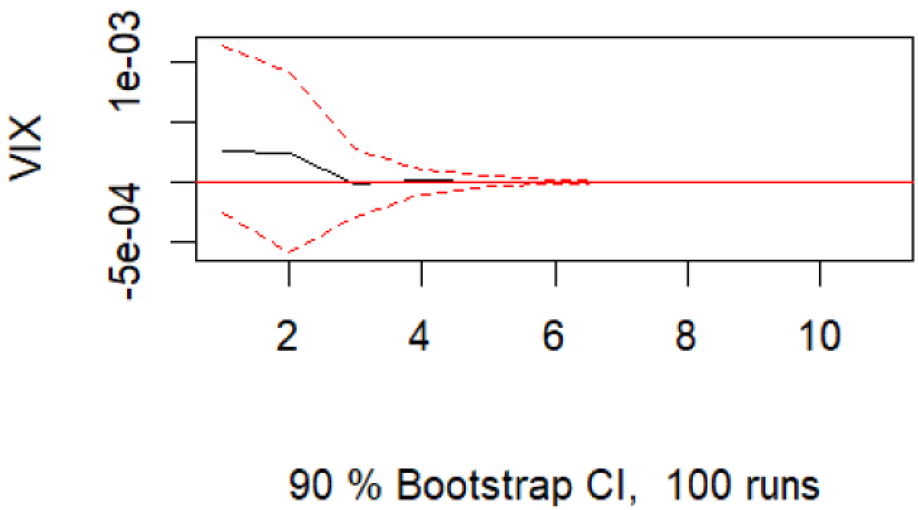


Figure 5. The response of gold price to a shock in the VIX index

Source: Authors' own research.

The response of gold prices to a shock in the VIX index refers to how the price of gold reacts when there is a sudden and significant change in the VIX index, which measures market volatility. It involves analysing how the shock impacts gold prices in the immediate aftermath and over subsequent periods. This analysis provides insights into the relationship between gold prices and market volatility, shedding light on whether gold serves as a safe haven asset during increased market uncertainty captured by higher VIX values.

The impulse response function suggests that if there is a sudden and substantial increase in the volatility index (VIX), which indicates market uncertainty, the effect on the price of gold would not be very pronounced. Instead, the impact on gold prices would be minimal, with only a slight decrease observed in the early part of the analysed period. In other words, the analysis indicates that changes in market volatility, as represented by the VIX index, do not strongly influence the price of gold. While a surge in market uncertainty might lead to a slight dip in gold prices initially, this effect is not substantial, and the price of gold seems to be relatively resilient to short-term fluctuations in market volatility.

The observed high probability values of the Fisher test indicate the absence of a Granger causality relationship flowing from the oil price to the VIX index and the gold price. Similarly, the probabilities suggest the absence of a Granger causality relationship flowing from the gold price to the oil price and the VIX index. These findings imply that past variations in oil and gold prices do not provide significant predictive power for explaining subsequent changes in the VIX index and vice versa. This lack of causality suggests that other factors or variables might play a more dominant role in influencing the relationships between these financial indicators.

Discussions

The positive influence of past oil prices on current oil prices suggests a form of momentum or trend continuity in the oil market. This implies that the oil market exhibits a certain degree of persistence, where higher oil prices in the previous period tend to translate into elevated prices in the present. This momentum could be driven by factors like supply-demand dynamics, production trends, geopolitical events, and broader economic conditions. Investors and market participants may find this insight valuable for making short-term price predictions and investment decisions.

On the other hand, the observed negative impact of the VIX index on oil prices presents an intriguing dynamic. Higher market volatility, as measured by an elevated VIX index, appears to coincide with lower oil prices in the subsequent period. This finding underscores the inverse relationship between oil prices and market uncertainty. It suggests that during periods of elevated volatility, investors might perceive greater risk in oil markets, leading to cautious trading behaviours that result in lower prices. This insight could inform strategies for risk management and portfolio diversification.

The Granger causality relationship that originated from the VIX index and extended to both oil and gold prices is a significant discovery. It highlights that past variations in the VIX index contain predictive information for subsequent changes in both commodity prices. This underscores the importance of market sentiment and volatility as leading indicators of oil and gold price movements. Understanding this relationship could empower investors to use the VIX index to anticipate trends in the oil and gold markets.

The response of oil prices to a shock in the VIX index, characterised by an initial decrease and subsequent oscillations, provides valuable information for market participants. This pattern suggests that a sudden increase in market volatility could lead to a short-term drop in oil prices, potentially due to heightened investor caution and increased selling pressure. However, the subsequent oscillations could indicate market participants gradually adjusting to the new volatility levels.

Similarly, the impact of a VIX shock on gold prices is relatively muted, with a slight initial decrease and no significant long-term effects. This result aligns with gold's historical role as a safe-haven asset. While market volatility may initially prompt some investors to liquidate gold holdings, the absence of significant long-term effects suggests that gold's appeal as a hedge against uncertainty remains intact.

The results are in line with other similar studies of Tursoy and Faisal (2018), Gharib et al. (2021), and Tuna (2022).

The study by Tursoy and Faisal (2018) demonstrates the impact of gold and crude oil prices on the stock market in Turkey. Through the application of an ARDL bounds test and combined co-integration methodology, the research reveals significant empirical evidence of interconnections between these financial variables. The empirical results proved the existence of a long-run relationship between stock prices, gold prices, and oil prices; gold prices cause stock prices, but oil prices do not cause stock prices.

The study by Gharib et al. (2021) investigates the impact of the COVID-19 outbreak on crude oil and gold markets, focusing on the potential bubble contagion effect caused by the pandemic. The study employs empirical evidence to explore how the outbreak influenced these two key markets, shedding light on the interconnectedness between COVID-19 and the dynamics of crude oil and gold prices. The study establishes bilateral contagion effects between the oil and gold markets through time-varying Granger causality tests.

Tuna (2022) research investigates how oil prices, gold prices, and volatility of the VIX index affect Turkey's BIST 100 stock index during the pandemic. The Toda-Yamamoto test results suggest that there is no causal relationship between oil price, gold price, VIX index, and BIST100. Impulse response and variance decomposition analyses corroborate these findings, demonstrating a swift, short-term reduction in the impact of the oil price, the gold price, and the VIX index on BIST 100.

In conclusion, these results provide valuable insights into the complex interactions between oil prices, the VIX index, and gold prices. They offer actionable information for investors seeking to navigate the ever-changing landscape of financial markets. Understanding the relationships and responses between these variables is crucial for making informed decisions, managing risks, and formulating effective investment strategies.

The theoretical contributions and managerial implications of the study's findings are significant, aligning with up-to-date and recent literature on capital market volatility, financial risk management, and investment strategies.

The study empirically establishes gold as a significant safe haven asset during crisis periods, corroborating recent research (Cui et al., 2023). This finding contributes to the ongoing discussion on the role of gold as a hedge against market turmoil. By examining the interdependencies between oil prices, the VIX index, and gold prices, the study deepens our understanding of how these key financial indicators respond to economic turbulence. The findings provide insights into the intricate dynamics that exist within and between these variables, offering a nuanced perspective consistent with the research of Liu et al. (2023). The identification of Granger causality relationships running from the VIX index to oil and gold prices adds to the body of literature investigating causal linkages in financial markets (Asifulla & Basha, 2023). This contributes to a better comprehension of how market sentiment can influence commodity prices.

From a managerial perspective, the study's confirmation of gold's safe haven properties suggests that investors and portfolio managers should consider allocating a portion of their portfolios to gold during times of heightened market volatility. This aligns with the findings of Bhatti et al. (2023) and can serve as a risk mitigation strategy. For businesses exposed to oil price fluctuations, the study's revelation of the significant impact of oil price volatility on stock markets underscores the need for robust risk management practices. Firms should monitor and adjust their strategies in response to changing oil market conditions. Understanding the Granger causality relationship between the VIX index and commodity prices, as highlighted in this study, can empower market participants to anticipate and react to shifts in market sentiment. Traders, investors, and policy makers should incorporate sentiment analysis into their decision-making processes.

The study emphasises the importance of diversification in investment portfolios. Diversifying across asset classes, including safe havens like gold, can help mitigate risks associated with market volatility and reduce exposure to negative shocks.

Policymakers can draw on these findings to inform economic policies during crisis periods. The study suggests that changes in the VIX index can have a cascading effect on commodity prices and, consequently, on economic stability. Policy makers should be prepared to implement measures to mitigate potential adverse impacts.

Conclusions

The study reveals a positive influence of past oil prices on current oil prices, indicating a momentum or trend continuity in the oil market. Higher oil prices from the previous period tend to lead to elevated prices in the present, implying persistence in oil price movements.

An elevated VIX index indicates that market volatility negatively impacts current oil prices. This inverse relationship suggests that the higher market uncertainty corresponds to lower oil prices in the subsequent period. This connection underscores the cautious trading behaviours during volatile market conditions.

The empirical results demonstrate a significant Granger causality relationship between the VIX index to oil and gold prices. Past variations in the VIX index provide predictive insights into subsequent changes in commodity prices, highlighting the role of market volatility in influencing and forecasting price movements.

Impulse response functions indicate that a shock in the VIX index prompts a notable decrease in oil prices during the second quarter following the shock, followed by oscillations. Gold prices, however, show a minor initial decrease in response to a VIX shock, with no significant long-term effects observed.

These conclusions offer a comprehensive understanding of how oil and gold prices interact with changes in the VIX index, shedding light on short-term fluctuations, the impact of market volatility, and the predictive potential of the VIX index for both commodities.

The main future directions of research concern how the relationships between oil prices, the VIX index, and gold prices evolve over longer time frames, providing insights into sustained patterns and changes, expanding the analysis by including a wider range of variables such as macroeconomic indicators, geopolitical events, and market sentiment to uncover more comprehensive insights into market interactions, incorporating behavioural factors, such as investor sentiment and psychological aspects, to provide a more holistic understanding of market movements, as well as testing the robustness of the results using alternative econometric models and methodologies to ensure the findings are not heavily dependent on specific model assumptions.

The main limitations of the research emphasise the market specificity, the timeframe selection, data frequency, external events, or market behaviour changes. The study focuses on a specific set of financial indicators (oil prices, the VIX index, and gold prices) and their relationship to capital market volatility. While these variables are essential, financial markets are highly complex, and other factors like interest rates, economic policies, and corporate earnings can also influence volatility.

The study's chosen time frame of 2013-2023 encompasses various economic phases, including periods of growth and recession. The impact of the chosen variables on capital market volatility can vary significantly during these phases. The study uses monthly data, which may not capture rapid market movements or intraday events. A higher frequency dataset (e.g., daily or intraday) could provide a more accurate assessment of short-term volatility dynamics.

Also, the study does not explicitly account for external events that occurred during the study period, such as major geopolitical events or policy changes, which could have had a substantial impact on capital markets. Furthermore, financial markets are dynamic and the behaviour of investors, institutions, and market participants can change over time. The study assumes stable market behaviour, which may not always hold true.

Building on the study's confirmation of gold's safe haven status, future research can delve into the dynamics of gold as a safe haven asset during different types of crises. This research can explore how gold's performance as a safe haven varies during financial, geopolitical, and health-related crises. Additionally, examining how different factors, such as inflation expectations, interest rates, and global economic conditions, influence gold's safe haven properties can provide deeper insights for investors and policymakers. Given the study's use of econometric techniques to investigate causal relationships and impulse response patterns, future research can focus on developing predictive models. Machine learning and artificial intelligence methods, such as deep learning algorithms or hybrid models, can be employed to forecast market volatility and asset price movements during crises. Researchers can integrate a broader range of economic, financial, and sentiment data to enhance predictive accuracy. These models could help investors in making more informed decisions and risk management strategies during turbulent times. These research directions offer opportunities to expand our understanding of safe haven assets like gold and provide practical tools for investors and financial professionals to navigate volatile markets effectively.

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