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CASE STUDY **Open Access**

Stock price index analysis of four OPEC members: a Bayesian approach

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Abstract

This study examines the relationship between macroeconomic variables and stock price indices of four prominent OPEC oil-exporting members. Bayesian model averaging (BMA) and regularized linear regression (RLR) are employed to address uncertainties arising from different estimation models and variable selection. Jointness is utilized to determine the nature of relationships among variable pairs. The case study spans macroeconomic variables and stock prices from 1996 to 2018. BMA findings reveal a strong positive association between stock price indices and both consumer price index (CPI) and broad money growth in each analyzed OPEC country. Additionally, the study suggests a weak negative correlation between OPEC oil prices and the stock price index. RLR results align with BMA analysis, offering insights valuable for policymakers and international wealth managers.

Keywords: Equities, Macroeconomics, Bayesian model averaging, Bayesian estimation, Regularized linear regression, OPEC countries

JEL Classification: G10, G15, G19, C11

Introduction

Equity markets play a crucial role in nations' economies and are vital sources of capital and investment platforms. These markets provide a mechanism for companies to raise funds by issuing shares of ownership, which allows them to finance expansion, research and development, and other growth initiatives. Access to equity markets empowers businesses to foster innovation, create jobs, and drive economic growth. In addition, equity markets enable individuals and institutional investors to participate in wealth creation, offering opportunities to increase savings and investment. By facilitating the buying and selling of stocks, equity markets foster liquidity and price discovery, ensure efficient allocation of resources, and enable investors to make informed decisions based on market trends and company performance.

Moreover, equity markets contribute to the overall health and stability of national economies. These serve as indicators of market sentiment and economic conditions, reflecting investor 'confidence in businesses' and the broader economic growth prospects. Equity market performance can influence consumer and business confidence and affect spending patterns and investment decisions. Equity markets play a significant role in corporate governance because public companies are subject to transparency and disclosure requirements, and must ensure accountability to shareholders and the public. Transparency fosters investor trust, attracts capital, and promotes a functional business environment. Continuous monitoring and evaluation of stock prices' and market indices' also provides policymakers, economists, and analysts with valuable insights into the state of the economy, aiding the formulation of effective monetary and fiscal policies. Overall, equity markets are vital components of national economies by fostering growth, facilitating investments, and promoting financial stability.

Thus, it is highly plausible that macroeconomic conditions have a substantial impact on equity returns. According to Merton (1973), asset-pricing models are based on the notion that any factor capable of influencing future investment opportunities or consumption levels can be considered a priced factor in equilibrium. Securities exposed to non-diversifiable risk factors should earn risk premiums in an economy characterized by risk-aversion. Many macroeconomic variables could contribute to equity risk levels, concurrently affecting numerous companies' cash flows and potentially influencing the risk-adjusted discount rate. Furthermore, economic conditions can shape both the quantity and nature of available real investment opportunities.

Researchers attempted to establish a relationship between macroeconomic variables and equity returns. Pioneering studies include those by Nelson (1976), Fama and Schwert (1977), Solnik (1983), Chen et al. (1986), Fama (1981), Geske and Roll (1983), Gultekin (1983), Pearce and Roley (1983, 1985), and Fama (1990). Their studies reveal a negative correlation between equity returns, money supply, and inflation rate growth.

Recently, several researchers investigated the association between equity prices and macroeconomic variables, including Park and Ratti (2008), Nandha and Faff (2008), Humpe and Macmillan (2009), Peiro (2016), Sadorsky (1999), Al-Sharkas (2004), Keho (2010), Zhao (2010), and Chinzara (2011). Interest in developing economies' equity markets has grown over the past few decades because of the improved availability of data, enabling researchers to analyze and derive empirical results more effectively. Furthermore, developing economies, such as China, India, Brazil, and Malaysia experienced rapid economic growth, surpassing the growth rates of developed economies. As equity price growth is closely linked to potential economic growth, wealth managers have shown a keen interest in international equity markets and funds. For instance, Maurya et al. (2023), Zahera and Bansal (2018), Zahera and Bansal (2019), Dixit et al. (2020), Kumar et al. (2020), and Verma et al. (2021) delve into various aspects of equity markets in developing economies, contributing to the rich body of literature in this field.

This study investigates the association between national macroeconomic variables and equity returns in four major OPEC economies: Iran, Saudi Arabia, Kuwait, and Nigeria. These economies were selected because of their prominent original OPEC membership, relative political and social stability, and lack of devastation from conflicts or other geopolitical disasters. Furthermore, no other study examines this specific group of four key OPEC members by employing the unique methodology deployed in the current study. Moreover, the economies of Iran, Saudi Arabia, Nigeria, and Kuwait have been largely overlooked by wealth managers, potentially hindering foreign capital inflows to these regions. Therefore, this study addresses a significant gap in the existing literature.

The findings of this study provide valuable information for domestic policymakers in identifying the strengths and weaknesses of economic and political structures that may require amendments. Improving equity market efficiency and transparency can also enhance the overall efficiency of these economies.

According to data released by the General Authority for Statistics (GASTAT), the Saudi economy achieved remarkable growth in its GDP in 2022, surpassing expectations and outperforming other Group of Twenty (G20) countries. Despite challenging global economic conditions, Saudi Arabia recorded a GDP growth rate of 8.7%, the highest in the last decade.

The report highlighted that Saudi Arabia's GDP exceeded $1 trillion for the first time in 2022, driven by positive growth in various economic sectors. The oil sector played a significant role, with crude oil and natural gas activities contributing to a surge of 32.7% share in GDP. Other sectors that experienced substantial growth included government services (14.2%); manufacturing (except for oil refining) (8.6%); and wholesale and retail trade, restaurants, and hotels (8.2%).

Experts attribute this impressive performance to Saudi Arabia's policies aimed at diversifying the economy and creating a favorable environment for growth. Economic and financial reforms along with vision programs, initiatives, and major projects provided investment opportunities for development funds and the private sector.

The GASTAT report also reveals positive growth in non-oil activities, with transportation, storage, and communications leading the way with a growth rate of 9.1%. Manufacturing activities (except oil refining) followed closely, with a growth rate of 7.7%.

Iran ranks fourth in the world in crude oil reserves and second in natural gas reserves. Iran's economy relies heavily on hydrocarbon, agricultural, and service sectors, with significant state involvement in manufacturing and financial services. Although they are relatively diverse for oil-exporting countries, oil revenues still play a vital role in Iran, making its economy susceptible to external shocks and volatility. A previous development plan focused on economic resilience, scientific progress, and cultural excellence, aiming for 8% annual economic growth. However, a decade of stagnation ensued due to sanctions and commodity price fluctuations, resulting in lower oil exports, increased fiscal pressure, elevated inflation, and diminished purchasing power.

In recent years, Iran's economy has shown signs of recovery, supported by post-pandemic service sector growth, increased oil activity, and accommodating policy measures. The economy adjusted to sanctions through exchange rate depreciation, thus enhancing the competitiveness of domestically produced goods. The decline in oil exports prompted the increased processing of crude oil and hydrocarbons for export as petrochemicals. Trade has shifted toward neighboring countries and China, using alternative payment channels because of restricted access to assets abroad. The government expanded cash transfers and subsidies to mitigate the impact of inflation on welfare; however, these interventions added to fiscal pressure.

Nigeria is expected to become one of the most populous countries in the world and an African growth engine. COVID-19 and the internal turmoil have slowed economic growth in recent years, but the growth rate appears to be rebounding.

Despite the high oil prices in recent years, the Nigerian economy did not see the expected boost in GDP growth. Macroeconomic stability weakened because of several factors, including declining oil production, costly petrol subsidies, exchange rate distortions, fiscal deficit monetization, and high inflation. This deteriorating economic environment has led to an increase in poverty rates, with projections indicating an increase in the number of Nigerians living below the national poverty line.

Between 2023 and 2025, the economy is projected to grow at an average rate of 2.9% per year, which is slightly higher than the estimated population growth rate of 2.4%. The service, trade, and manufacturing sectors are expected to drive growth. However, there are significant risks to this growth outlook, primarily stemming from domestic policies, low oil production, foreign exchange, and currency scarcity.

The findings of this study may provide critical information to policymakers in Nigeria, helping them direct monetary, fiscal, and other policies to foster economic growth and address the challenges faced by the economy.

Kuwait is a key member of OPEC and the GCC. Its economy faces long-term challenges owing to its heavy reliance on oil, domestic consumption as a primary driver of growth, and slow progress in diversification. Despite these challenges, the country's substantial foreign assets held through sovereign wealth funds provide a degree of economic resilience.

Although medium-term projections suggest that elevated oil prices can support economic transformation and promote sustainable and inclusive growth, there are short- and medium-term risks to consider. These include the potential impact of a global economic slowdown, oil price volatility, delays in fiscal and structural reforms, and labor shortages. The findings of this study highlight the significant impact of macroeconomic variables, especially crude oil prices, on Kuwait's equity market and economy.

The research methodology employed in this study is distinctive, showing the pioneering use of Bayesian model averaging (BMA). To the best of our knowledge, this is the first application of BMA in this field. Our methodology relies on a meticulous fusion of data and a Bayesian selection approach to determine the optimal weights for the explanatory variables within the model. Additionally, to mitigate potential issues related to multicollinearity, we incorporated a regularized linear regression (RLR). This comprehensive approach ensures rigorous and robust treatment of the subject matter, setting our research apart from its innovative and effective methodology.

The remainder of this paper is structured as follows. Section II provides the literature review. Section III presents a brief theoretical foundation of the study. Section IV discusses the data and the empirical model. Section V outlines the methodology used in the study. Section VI discusses the empirical findings. The final section contains the summary, conclusions, policy ramifications, and research limitations.

Review of the relevant literature

Numerous studies have explored the associations between equity markets and macroeconomic factors, resulting in an extensive body of literature. The main goal of this section is to derive facts from the past literature that highlight the role of the critical macroeconomic variables to be included in our model.

Examples of commonly used variables are the interest rate, inflation rate, exchange rate, money supply, industrial production, oil price, and gold price.

Verma and Bansal (2021) provide a comprehensive compendium for research on the association between macroeconomic variables and equity market performance. Their systematic review encompassed over 100 research papers covering roughly four decades that explore the role of macroeconomic variables in equity markets. The intensity of interest in this subject has remained high, as their review indicates.

Through an extensive analysis of the literature, Verma and Bansal (2021) reveal numerous facts concerning the relationship between macroeconomic variables and equity prices and returns. For brevity, we only mention and summarize the findings of a few of the studies analyzed by Verma and Bansal (2021), though researchers interested in the topic will find their literature analysis thorough and valuable. Table 3 in their research summarizes some critical statistically significant macroeconomic variables.

Because of the extensive number of existing studies, we organize previous research on the subject of macroeconomics and equity markets into three categories. The first comprises of studies that investigate developed economies. The second category comprises studies focusing on developing economies. The third category, which is more relevant to our study, comprises research on OPEC and Gulf Cooperation Council (GCC) countries' equity markets. However, our review provides only a concise summary of these studies.

Several classical studies investigate the association between macroeconomic variables and equities in developed economies. Flannery and James (1984) examine the impact of changes in nominal interest rates on stock prices. Their findings emphasize that the significance of this association depends on the maturity composition of firms' assets and liabilities. Moreover, they demonstrate a positive relationship between the effect and size of nominal assets and the maturity composition of liabilities.

Asprem (1989) conducts a study across 10 European countries and analyzes the relationships among stock prices, portfolios of different stocks, and macroeconomic variables. This study reveals a negative correlation between interest rates and stock prices.

Similarly, Geske and Roll (1983) and Mukherjee and Naka (1995) identify a negative relationship between changes in interest rates and stock returns in the United States and Japan. Their research further supports the notion that interest rate fluctuations affect stock market performance.

Chen et al. (1986) study the relationship between macroeconomic variables and equity prices in the United States. Their regression analysis, spanning 1958 to 1984, indicates no significant association between consumption expenditure, oil prices, and equity prices. However, they find a positive correlation between US industrial production and stock prices, particularly during periods of market volatility. Additionally, the authors report a negative relationship between the inflation rate and equity prices.

More recent work on this subject is provided by Bulmash and Trivoli (1991); Chen (1991), Sadorsky (1999); Ratanapakorn and Sharma (2007); Kilian and Park (2009); Park and Ratti (2008) Rahman, (2008); Gan et al. (2006); Humpe and Macmillan (2009), Peiro (2016), Celebi and Hönig (2019), and Cheung and Lai (1999). Their methodologies include vector autoregression modeling (VAR), cointegration tests, Granger causality tests, and various GARCH modes. A broad summary of their findings indicates that the association between equity prices or returns is typically positive for industrial production and gross domestic product (GDP) growth and negative for interest rates, the inflation rate, and money supply growth. The relationship between the exchange and unemployment rates is indeterminate.

In a follow-up study, Flannery and Protopapadakis (2002) analyze daily equity returns in the United States, specifically focusing on the value-weighted NYSE-AMEX-NASDAQ market index. The researchers apply a GARCH model to estimate the daily equity returns, where the realized returns and their conditional volatility were dependent on 17 macroeconomic series' announcements.

Flannery and Protopapadakis (2002) identify six variables associated with equity returns. These variables include the consumer price index (CPI), producer price index, and monetary aggregate as nominal variables, and the balance of trade, employment report, and housing starts as real variables. Notably, their model indicates that measures of overall economic activity, such as industrial production or gross national product, do not exhibit a significant association with equity returns in the United States.

Abbas et al. (2019) investigate the relationship between stock market returns, volatility, and macroeconomic factors in Group of Seven (G-7) countries. This study uses monthly data collected from July 1985 to June 2015. Using a generalized VAR model, researchers identify notable connections between stock market returns, volatilities, and various macroeconomic indicators, such as industrial production, money supply, interest rates, inflation, oil prices, and exchange rates. These findings indicate that the dynamics of return and volatility spillovers between these stock markets and the macroeconomic fundamentals changed in the aftermath of the 2008 global financial crisis.

In developing economies, studies by Hu and Li (1998), Ibrahim and Aziz (2003), Wang (2011), Tsai (2012), Sikalao-Lekobane (2014), Kalyanaraman and Tuwajri (2014), Chang et al. (2019), Erol and Aytekin (2019), Kelikume and Muritala (2019), Wang and Li (2020), Kaur and Singla (2021), Asravor and Fonu (2021), and Elangkumaran and Navaratnaseel (2021) examine subsets of macroeconomic variables in research on equity markets in countries such as China, India, Ghana, Turkey, and Sri Lanka. In this section, we summarize these studies.

Ibrahim and Aziz (2003) investigate the relationship between stock prices and Malaysian foreign exchange markets using monthly data on stock prices, exchange rates, and money supply in Malaysia from 1977 to 1998. The authors conclude that the relationship between stocks and foreign exchange markets is negative.

Sikalao-Lekobane (2014) examine the long-term equilibrium relationship between stock market prices in Botswana and various domestic and global macroeconomic variables. The authors highlight the importance of the stock market in accurately reflecting real economic activities, given that it plays a crucial role in the overall health of the financial system, particularly in emerging markets. The study analyzes quarterly data from 1998 to 2012 and considers a range of macroeconomic variables, including GDP, short- and long-term interest rates, money supply, foreign reserves, inflation, the diamond price index, the exchange rate, the US share price index, and the 10-year US government bond yield.

Sikalao-Lekobane (2014) employed a vector error-correction model framework based on Johansen's cointegration technique. The results demonstrate cointegration between the macroeconomic variables and stock market prices, indicating a long-run equilibrium relationship between them. Specifically, the findings reveal that real GDP, short-term interest rates, inflation, and the diamond price index have positive relationships with stock market prices in the long run. Meanwhile, long-term real interest rates, money supply, foreign reserves, exchange rate, US share price index, and US government bond yields have a negative relationship with stock market prices in the long run.

Kelikume and Muritala (2019) examine the influence of oil prices on African stock markets. This study uses quarterly data from five selected oil-producing countries with a stock market presence, covering 2010 to 2018. The analysis was conducted using a dynamic panel analysis that incorporates variables such as stock returns, real GDP growth rate, exchange rate, and OPEC basket prices.

Kelikume and Muritala (2019) reveal that oil prices have an adverse impact on African stock markets, which can be attributed to the fragmented and underdeveloped nature of the capital markets in the region. The real GDP growth rate has a positive effect on African stock markets, indicating that economic growth positively influences stock returns in these markets.

The relationship between stock markets and oil prices has immediate implications for foreign direct investment (FDI) because investments may shift in and away from stock markets in African economies that depend heavily on oil. Based on their empirical results, Kelikume and Muritala (2019) recommend that oil-exporting developing countries devise strategies to ensure stability in their capital markets by implementing pro-growth policies, regardless of shocks in oil prices and other external macroeconomic indicators.

Erol and Aytekin (2019) investigate the relationship between selected macroeconomic variables and the Istanbul Exchange Index (BIST 100). The macroeconomic variables in their regression analysis were the inflation rate, overnight lending interest rate, gold price, industrial production, and GDP growth rate. This study examined data from 2009 to 2018.

Erol and Aytekin's (2019) empirical findings indicate that the overnight lending interest rate, industrial production, and the inflation rate statistically influence the BIST 100 index. However, they find no statistically significant association between the BIST 100 index and GDP growth rate or gold prices.

Wang and Li (2020) research the relationship between the Chinese stock market and three commonly used macroeconomic variables: industrial production growth, inflation, and the long-term interest rate. They employ continuous wavelet analysis to examine the correlations and lead-lag relationships among these variables in the time–frequency domain, covering 1995–2018.

Wang and Li's (2020) analysis reveals several key findings. First, they observed a positive correlation between stock returns and industrial production growth and between stock returns and inflation. However, they discovered a puzzling relationship between stock returns and long-term interest rates. In the short and medium terms, stock returns and interest rates are negatively correlated, whereas in the long term, they are positively correlated.

These mixed findings and contradictory lead-lag relationships suggest that the Chinese stock market is still relatively underdeveloped. The link between the stock market and the macroeconomy experiences breakdowns, where stock returns cannot serve as reliable leading indicators of the macroeconomy, nor can the real economy accurately predict booms or busts in the Chinese stock market.

Kaur and Singla (2021) study the association between FDI, industrial production, wholesale price index (WPI), currency exchange rate, and oil prices with the performance of the equity market of India. Their empirical results, based on an autoregressive distributed lag model estimation, show that industrial production, WPI, and the exchange rate are significantly associated with the equity market index, but not in the long run. The remaining model variables correlate with the long-run market performance.

Asravor and Fonu (2021) investigate equity prices in Ghana. Their autoregressive distributed lag approach (ARDL) model includes money supply, the inflation rate, FDI, a measure of human capital, and interest rates as factors that potentially influence equity prices in Ghana. Surprisingly, they show that money supply and human capital are negatively associated with equity prices, whereas interest rates are positively associated. The remaining variables behaved as expected in their model.

Zhu et al. (2022) analyze the influence of oil prices and exchange rates on stock market returns in Brazil, Russia, China, India, and South Africa (BRICS) from a time–frequency perspective. Their research covers 2009–2020 and employs a wavelet decomposition series. The authors develop a threshold rolling window quantile regression approach to examine the time–frequency effects across various scales.

Zhu et al.'s (2022) empirical findings are summarized as follows. First, they confirm that the effects of both crude oil prices and exchange rates on BRICS stocks' returns are asymmetric. Positive shocks to crude oil prices have a more pronounced effect in a bull market, whereas negative shocks have such an effect in a bear market.

Second, Zhu et al. (2022) reveal a short-term enhancement effect of both crude oil prices and exchange rates on the BRICS stock markets. Additionally, volatility in the macrofinancial environment exacerbates the impact of oil prices and exchange rates on the stock market, with these effects being heterogeneous across the countries studied.

Overall, Zhu et al. (2022) provide valuable insights for international investors and policymakers, shedding light on asymmetric effects, short-term enhancements, and the role of macro financial volatility in the relationship between oil prices, exchange rates, and stock market returns in BRICS countries.

Regarding the scope of the current study, which focuses on the GCC (i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) and OPEC countries, researchers explored various aspects of the relationship between these countries' economies and their macroeconomic factors. In this section, we present a summary of the relevant papers.

Onour (2007) investigates the determinants of stock market volatility in GCC countries by considering both short- and long-term factors. The research findings suggest that the stock markets of GCC countries are highly responsive to oil price fluctuations. This study indicates that difficult to observe speculative factors mainly influence short-term stock market returns. Conversely, the impact of oil price changes on the GCC stock market returns becomes more apparent over the long term.

Arouri and Fouquau (2009) examine the short-term relationship between oil prices and the GCC stock markets. To examine the linear and nonlinear relationships between these variables, the authors use weekly OPEC crude oil price data and stock indices of GCC member countries from 2005 to 2008. The results show a significant relationship between the two variables in Qatar, Oman, and the United Arab Emirates. The stock markets of these countries react positively to rising oil prices. Oil prices do not affect stock returns in Bahrain, Kuwait, or Saudi Arabia.

Lescaroux and Mignon (2008) examine the connections between oil prices and a range of macroeconomic and financial variables, including GDP, unemployment rate, CPI, and consumption expenditure, across a broad set of oil-importing and oil-exporting countries. This study analyzes both short- and long-term interactions using Granger causality tests, cross-correlation evaluations of cyclical components, and cointegration analysis.

Lescaroux and Mignon's (2008) findings reveal various relationships between oil prices and macroeconomic variables. Particularly noteworthy was the significant link between oil prices and share prices in the short run. In the long run, the study identifies numerous long-term relationships, with Granger causality generally running from oil prices to the other variables. A crucial conclusion from this research is the pivotal and negative role the oil market plays in the stock market.

Arouri and Rault (2012) study the long-term association between oil prices and stock markets in the GCC. Because GCC countries hold considerable importance in the global energy market, it is anticipated that oil price fluctuations will influence their stock markets. The findings of this study reveal the existence of cointegration between oil prices and stock markets in GCC countries. In addition, the seemingly unrelated regression results indicate that rising oil prices positively affect stock prices.

Akoum et al. (2012) investigate the relationship between stock market returns and OPEC crude oil returns in GCC countries as well as two non-oil-producing countries in the region (Egypt and Jordan) using data from 2002 to 2011.

Akoum et al.'s (2012) empirical findings obtained using the wavelet coherency methodology indicate no strong correlation between oil and stock returns in the short term. However, they find evidence of comovement between oil and stock market returns over the long term. They also reports an increase in the strength of market dependencies after 2007, suggesting that investors may experience greater diversification benefits in the short term than in the long term.

Naifar and Dohaiman (2013) examine the impact of oil price variables, including changes and volatility, on stock market returns in GCC countries. The analysis incorporates the regime-shift concept and uses Markov switching regression models.

Naifar and Dohaiman (2013) demonstrate that the relationship between stock market returns in GCC countries and OPEC oil market volatility varies depending on the prevailing regime. However, Oman exhibits different behaviors in the low-volatility state compared with other countries.

Samontaray et al. (2014) study the influence of macroeconomic variables on the Saudi Stock Exchange index (TASI). They examine three independent variables: the

WTI crude oil price, Saudi exports, and the PE ratio. The results indicate a statistically significant relationship between these variables and the TASI.

Furthermore, Samontaray et al.'s (2014) findings reveal that the three independent variables explain approximately 93% of the variation observed in the TASI Last Price. This result suggests that a substantial portion of the fluctuations in TASI can be attributed to changes in oil WTI, Saudi exports, and the PE ratio.

Okere and Ndubuisi (2017) study the link between crude oil prices, stock market development, and economic growth in Nigeria and OPEC countries from 1981 to 2014 using ARDL and cointegration analysis. Using inflation and trade openness as moderators of economic activities in Nigeria, this study did not find a significant role for crude oil prices in driving economic growth, indicating poor financial sector performance. These findings highlight the dominant role of crude oil prices and the weakness of the stock market in stimulating economic growth through resource mobilization and allocation in Nigeria. The authors suggest that the government enact policies that stimulate financial markets to achieve sustainable economic development and maximize stock market performance. Furthermore, they conclude that policymakers in oil-exporting countries should monitor the movement in crude oil prices.

Alam (2020) investigates the relationship between inflation, short-term interest rates, money supply, crude oil prices, and oil price shocks in the capital markets of Saudi Arabia. His findings indicate a long-term balanced relationship between the Saudi stock market and the selected variables. Furthermore, his findings show that the stock market is positively associated with money supply and negatively associated with other macroeconomic factors.

Abakah et al. (2023) examine the effects of pre- and post-global financial crisis shocks on the relationship and systemic risk between the return series of OPEC oil prices and GCC stock markets. They use nonparametric conditional value-at-risk (NCoVaR), quantile cross-spectral coherency, Diebold and Yilmaz connectedness, and spillover models as estimation techniques.

The results from Abakah et al.'s (2023) full-sample analysis indicate that Bahrain was the only stock market to exhibit a dynamic volatility spillover to OPEC oil prices. Conversely, all GCC stock markets, except Saudi Arabia, experienced dynamic volatility from OPEC oil prices. Except for Bahrain, they observe a two-way NCoVaR relationship between OPEC oil prices and the GCC markets. During the pre-financial crisis period, GCC stock markets did not transfer dynamic volatility spillovers to OPEC oil prices. However, all GCC stock markets except Oman experienced dynamic volatility in OPEC oil prices.

Abakah et al.'s (2023) findings support the notion that the oil and stock markets behave as a unified entity, particularly following global commodity financialization. The study also demonstrated evidence of contagion between the OPEC oil and GCC stock markets. These results highlight the importance of understanding the dependence between OPEC oil prices and the GCC equity markets, providing valuable information for investors to make risk management decisions and develop investment strategies. Policymakers can benefit from this knowledge when pursuing effective energy and macroeconomic policies.

Summarizing the recent findings from studies that concentrate on the equity markets of OPEC and GCC countries, it is evident that most studies incorporate some stylized facts. This review reveals that these markets have been studied through diverse lenses, with each study focusing on a set of related critical issues.

Our research takes a broad approach to examine the association of widely quoted factors that influence equity markets. Specifically, we focus on a selected group of OPEC economies that lack sufficient attention in previous studies.

The following section presents a concise theoretical model. It incorporates the macroeconomic variables that the literature suggests are associated with equity prices into an equity evaluation model.

Theoretical model

Theoretically, the association between equity prices and macroeconomic variables can be established using various models, such as the standard stock valuation model, monetary and portfolio allocation models, and the standard aggregate demand and supply (AD-AS) model. In the following, we use a standard equity valuation model to elucidate the connection between the macroeconomy and equity prices.

To understand the influence of macroeconomic variables on the stock price index, it is essential to examine the discounting of future cash flows. The stock price is contingent on both the expected dividend payment flow and market discount rate. Consequently, any macroeconomic variable that affects future dividends or discount rates can influence stock prices (Humpe and Macmillan 2009).

The present value of future cash flows; that is, the price of a share, is given by Eq. (1).

$$P_t = \frac{E_t(d_{t+1})}{1+E_t r} + \frac{E_t(P_{t+1})}{1+E_t r}, \tag{1}$$

where E_0 represents the conditional expectations of the operator for all available information at time t, P_t is the real price of the stock at time t, $E_t(d_{t+1})$ is the expected real dividend per share at the end of the first year, E_t (P_{t+1}) is the expected (real) price of the share at the end of the first year, and $E_t r$ is the expected (constant) market-determined (real) discount rate or cost of capital. Based on these definitions, we obtain Eqs. (2) and (3) as follows:

$$E_t P_{t+i} = \frac{E_t(d_{t+1})}{1+E_t r} + \frac{E_t(P_{t+1+i})}{1+E_t r}, \tag{2}$$

$$P_t = \sum_{i=1}^{n} \frac{E_t(d_{t+i})}{(1+E_t r)^i} + \frac{E_t(P_{t+n})}{(1+E_t r)^n}. \tag{3}$$

As the time horizon approaches infinity, that is, $T \to \infty$, Eq. (3) results in Eq. (4).

$$P_t = \sum_{i=1}^{n} \frac{E_t(d_{t+i})}{(1+E_t r)^i}. \tag{4}$$

Therefore, stock prices depend on the expected stream of dividend payments and market discount rate.

The market discount rate is sensitive to several macroeconomic variables. For instance, it is associated with general price levels, as represented by the CPI and with the percentage change in the CPI, which represents the rate of inflation. The payment of dividend corporations is related to exchange rates through the costs of imports and revenues from exports. Other variables that may influence equity prices, especially in developing OPEC countries, include gold and oil prices. Gold is considered an investment alternative to other asset classes including equities and real estate. During periods of high inflation, investment in gold may be perceived as a safe haven, diverting savings away from equities. Capital shortages can cause corporations to borrow funds at high interest rates. The result may be lower future cash flows and higher discount rates, and thus, lower equity prices.

Oil prices are also critical in OPEC countries because crude oil is their largest export source and the most critical source of export income. For instance, by 2022, oil exports are estimated to account for one-third of Iran's annual budget. Crude oil exports are expected to constitute 79% of Saudi Arabia's total exports by 2022. Oil is the primary source of government revenue in all countries. In 2014, the share of oil revenue in the total revenue ranged from 47% in Yemen to 94% in Iraq, averaging 77% across the group under study. Similarly, in all countries except the United Arab Emirates, oil is the main export good. Oil accounts for more than 80% of the total exports in half of the countries in the group and more than 60% in all countries, except the United Arab Emirates. In that country (as In Bahrain), non-oil exports comprise a large share of reexports.

Empirical model and data

This section presents the empirical model, model variables, and data sources for these variables. We employ Bayesian model averaging methodology to investigate the interactions among various macroeconomic variables, including the CPI, inflation, economic growth, exchange rates, exports, imports, gold prices, OPEC oil prices, and broad money growth (MG), in relation to the stock price index of a group of OPEC oil-exporting countries (Iran, Kuwait, Saudi Arabia, and Nigeria).

The first three variables (CPI, inflation, and economic growth) are common real economy indicators. The inclusion of exchange rates, exports, and imports in the analysis is crucial, because the selected countries rely heavily on oil, making their total exports and economic stability highly dependent on international trade. The MG is representative of the monetary sector in this study.

In addition, the prices of oil (OPEC) and gold are variables beyond the control of each country. Fluctuations in the prices of these two commodities can significantly affect the economies of oil-exporting countries.

However, the literature does not investigate the weight of the impact of these variables on equity price fluctuations. Using the BMA, we rank the size of the influence of each variable on the stock price or index.

Equation (5) is the basis for the empirical tests conducted in this study. Based on the literature, there is no definitive or unanimously supported set of macroeconomic variables that influences equity prices or indices. However, most of the reviewed studies pointed to the combination of variables included in Eq. (5). In parentheses, we state the direction of association of each variable with equity indices as positive or negative, based on evidence from the literature. Table 3 in Verma and Bansal (2021) offers an excellent summary of the macroeconomic variables in over 100 studies, their statistical significance, and the direction of their association with equity prices or indices.

$$\mathrm{SPI} = \mathrm{f}(\mathrm{CPI}, \mathrm{INF}, \mathrm{EG}, \mathrm{EXP}, \mathrm{IMP}, \mathrm{OP}, \mathrm{EG}, \mathrm{MG}, \mathrm{GP}) \tag{5}$$

The model variables are defined below. The positive or negative signs in parentheses indicate the direction of the association of a variable with equity prices or indices.

SPI: Stock price index.

CPI: Consumer price index (+ or −).

INF: Inflation (−).

EXR: Exchange rates (+ or −).

EXP: Exports (+).

IMP: Import (− or insignificant).

OP: Oil price (OPEC) (+ for exporting and importing economies).

EG: Economic growth (+).

MG: Broad money growth (+ or −).

GP: Gold price (−).

The sources of annual data for these variables are the World Bank and International Monetary Fund. The study period was 1996–2018 based on data availability. We excluded the years 2020–2022 to avoid the influence of the COVID-19 pandemic shock.

The equity price indices of the four countries under study were obtained from the websites of each country's exchange in the capital city. The BMA methodology, which is described next, requires the study sample to come from a relatively homogeneous population. In this study, we consider the four OPEC economies to be homogenous.

Methodology

In this section, we briefly describe the proposed methodology. We begin with the BMA as our methodology's primary focus, and we follow this with an explanation of RLR and jointness tests.

BMA

Leamer (1978) introduced the BMA, which has gained significant attention in the field of statistics (George and McCulloch 1997; Raftery et al. 1997; Wasserman 2000; Montgomery and Nyhan 2010; Faust et al. 2013; Blazejowski and Kwiatkowski 2015; Fragoso et al. 2018).

Choosing and estimating a single model can lead to overconfident inferences and riskier decision-making because it disregards existing uncertainty in favor of specific distributions and assumptions for the chosen model. In practice, it is highly probable that several models sufficiently describe the distributions that generate the observed data. The BMA addresses this issue by combining multiple alternative models into a single unified framework, providing a flexible approach for model selection and estimation that accounts for the uncertainty in selecting the "best" model.

The BMA methodology begins by specifying a set of candidate models, each representing a different set of explanatory variables or functional forms. These models are often derived from prior knowledge, theoretical considerations, and empirical studies. The estimation process updates prior beliefs using the available data to obtain the posterior probabilities for each model.

After obtaining the posterior probabilities, the BMA computes the model-averaged estimates for the parameters of interest. This was achieved by combining the parameter estimates from each candidate model, weighted by their respective posterior probabilities (Chow 1981). The resulting model-averaged estimates provide a comprehensive summary of the parameter values that consider the uncertainties associated with the model selection.

Overall, the BMA is a powerful econometric tool that allows us to address model uncertainty, enhance the comprehensiveness of inferences, and improve the reliability of predictions by integrating multiple models into a coherent framework (Draper 1995; Fernandez et al. 2001a, b).

BMA methodology does not necessarily rely on the assumption of normality for variables or residuals. Although the underlying models within the BMA can make different assumptions about the distributions of variables and residuals, the methodology does not mandate a specific distributional assumption. The BMA can be applied to models that assume non-normal distributions or include nonlinear relationships as long as appropriate prior distributions and likelihood functions are specified. In this sense, the BMA is a general framework similar to nonparametric methodologies that can accommodate different types of models and data distributions.

In summary, the BMA is an extension of the usual Bayesian inference method in which both parameter uncertainty and model uncertainty are handled through a prior distribution.

Formally, as in Hoeting et al. (1999) and Zeugner (2015), the BMA begins with Bayes' law, as in Eq. (6):

$$\Pr(\theta|\mathrm{Y}) = \frac{\Pr(\mathrm{Y}|\theta)\Pr(\theta)}{\Pr(Y)}, \tag{6}$$

where $\Pr(\mathrm{Y}|\theta)$ represents the prior density of the data on the model parameters' vector θ, and $\Pr(\theta|\mathrm{Y})$ is the posterior function derived from the prior distribution and the likelihood function. $\Pr(\mathrm{Y}|\theta)$ is the likelihood function with a normal-gamma distribution and a normal density likelihood function given by Eq. (7).

$$\mathrm{PR}\left(\mathrm{Y},\mathrm{X}|\beta,\delta^2,\lambda\right) = \mathrm{pr}\left(\mathrm{Y}|\mathrm{X},\beta,\delta^2\right)\mathrm{pr}(\mathrm{X}|\lambda) \tag{7}$$

In Eq. (7), X denotes the matrix of all the independent variables theorized to be predictors of outcome Y, and δ^2 is the variance of the parameter estimates, λ, a vector of parameters that do not include β, δ^2. Prior distribution of the model parameters, Pr $(\mathrm{Y}|\mathrm{X},\beta,\delta^2)$, is the parameters' probability distribution function before examining the data.

The mean of the posterior density function is a point estimator for the coefficients of the model-independent variables given by Eq. (8).

$$E\left(\theta_i|\mathrm{y}\right) = \int \theta_i \mathrm{pr}\left(\theta|\mathrm{y}\right)\mathrm{d}\theta \tag{8}$$

The model selected in this study is linear with a dependent variable (the stock price index of countries). α_y is a constant coefficient for the model; β is the model coefficient output; ε is a disturbance term with variance σ^2; and X is a matrix of potential K explanatory variables.

$$Y = \alpha_y + \beta_y \mathrm{X} + \delta \tag{9}$$

If Δ in Eq. (10) is the quantity of interest, like parameters in a regression or a future observation (here α_y and β_y). Its posterior distribution given dataset D (Eq. 10) also has K different models based on a mixture of posterior distributions, as shown in Eq. (10).

$$\Pr(\Delta|\mathrm{D}) = \sum_{k=1}^{K} \mathrm{pr}\left(\Delta|\mathrm{M}_k,\ \mathrm{D}\right) pr(\mathrm{M}_k|D) \tag{10}$$

Equation (10) provides the averages of the posterior distributions based on their weight probabilities. The weighting scheme for the average is defined by the probabilities of the posterior model derived from Bayes' theorem. The posterior probability is given by (11):

$$pr(\mathrm{M}_k|D) = \frac{pr(D|M_k)\, pr(M_k)}{\sum_{k=1}^{K} pr(D|M_1) pr(M_1)}. \tag{11}$$

In Eq. (11), $pr(D|M_k) = \int pr(D|\theta_k, M_k)\, pr(\theta_k|M_k) d\theta_k$,
and the mean of posterior distribution Δ is given by Eq. (12).

$$\mathrm{E}(\Delta|D) = \sum_{k=0}^{k} \hat{\Delta}_k\, pr(\mathrm{M}_k|D) \tag{12}$$

In Eq. (12), $\hat{\Delta}_k = \mathrm{E}(\Delta\ |D, \mathrm{M}_k)$ and $pr(\mathrm{M}_k|D)$ is the probability distribution of coefficients in the prior model.

Given that the sum of all the probabilities of occurrence of the posterior functions of the models is equal to one, the probability of occurrence of each model can be obtained. However, as the number of models increases, this method becomes extremely time-consuming and computationally complex. In Bayesian econometrics, many algorithms perform model averaging without considering all models. A common algorithm for solving these problems is the MC^3 (Markov chain Monte Carlo model composition) method. This was a specific case of the Metropolis–Hastings (MH) algorithm. The main idea behind the MH algorithm is to establish an irreducible and alternating Markov chain such that the equilibrium distribution is the desired posterior distribution.

This method selects from among all possible models based on the probability of the posterior performance of each model, leading to a superior model choice.

The MH algorithm simulates a chain sequence of M^s models, where M^s represents a model obtained by repeating the model "s" times (M^s is one of the M_1 to M_j models). To create this chain, model M_0 is selected as the current model M^*. The probability of accepting the updated model is given by Eq. (13).

$$\alpha(M^s, M^*) = Min\left(\frac{pr(Y|M^s)pr(M^s)}{pr(Y|M^*)pr(M^*)}, 1\right) \tag{13}$$

The most updated model replaces the previous model as the current model (M^*) if and only if $\alpha \geq 50$; otherwise, M_0 remains the current model. This process was repeated s times. Thus, a chain of models is created based on the highest posterior probability. With the updated model (M^*) in each step, the mean and variance of the model are estimated using the updated model (M^*) at each step. Finally, the grand mean, that is, the Bayesian average, was computed from the sum of this chain. According to Kass and Raftery (1995), any variable with a posterior inclusion probability (PIP) less than 0.5 is considered statistically insignificant.

The specific expressions for the marginal likelihoods and posterior distributions depend on the chosen estimation framework. The most common prior in the Bayesian linear regression model is "Zellner's g prior." It is common to assume a conservative prior mean of zero for the coefficients, to reflect that little is known about them.

Zellner (1986) suggested the coefficient variance given by

$$g = \delta^2\left(\frac{1}{g}X_{\lambda}\prime X_{\lambda}\right)^{-1}.$$

Therefore, the coefficients' probability distribution for the model M_k is

$$\pi(\beta_{\lambda}|M_k\delta^2) \sim N_{p\lambda}\left[0, g\,\delta^2\left(\frac{1}{g}X_{\lambda}'\,X_{\lambda}\right)^{-1}\right].$$

Thus, the mean of the coefficients is zero and the covariance structure is broadly consistent with the X data. The confidence level of the expected coefficient was determined using g. A small g indicates confidence that the coefficient is zero and vice versa for a large magnitude of g.

In the Bayesian literature, there are different forms for g, and the choice of different types can greatly change the final answer. For instance, Zeugner (2015) suggests the unit information prior. Following other papers in the literature, we opt for the prior structure that Fernandez et al. (2001a) proposed.

In the next section, we address the potential problem of overfitting in BMA and the need for regularized linear regressions.

RLR

RLR is a technique used to address the problem of overfitting in linear regression models. Overfitting occurs when a model becomes too complex and begins to fit noise in the training data rather than the underlying patterns. This can lead to poor performance when the model is applied to new unseen data.

RLRs balance between fitting the training data well and avoiding overfitting. By controlling the regularization parameter, we can control the trade-off between the goodness of fit and complexity of the model, leading to more robust and reliable predictions.

The rationale behind RLR is to introduce a regularization term that adds a penalty to the loss function. This penalty discourages the model from assigning excessively large weights to features, effectively reducing the coefficients to zero. Thus, the model becomes less sensitive to noise in the training data and can better generalize to new data.

Two common types of regularization are used in linear regression: ridge regression (L2 regularization; see Hoerl and Kennard 1970a, b; Cessie and Houwelingen 1992) and lasso regression (L1 regularization; see Park and Casella 2008). The L1 penalty used by lasso restricts some of the coefficient estimates to zero. The LASSO methodology was used in this study.

Following Tibshirani (1996), dimensionality reduction of variables was used, and the modified sum of squares was minimized. Thus, the number of parameters was controlled using a penalty function on the absolute sum of the coefficients of the regression model.

The sum of squares of the lasso regression error is given by Eq. (14).

$$\sum_{i=1}^{n}\left(y_i-\beta_0-\sum_{j=1}^{p}x_{ij}\beta_j\right)^2-\lambda\sum_{j}|\beta_j| \tag{14}$$

In Eq. (14), λ is the adjusting parameter. If λ = 0, Eq. (14) will collapse to the sum of squared errors in ordinary least squares, and all variables will be present in the model. As λ increases, the number of independent variables in the model will decrease. Therefore, by choosing infinity (∞) for λ, there is virtually no variable in the model. The value of this parameter is typically determined using a cross-validation method. James et al. (2013) stated that the L1 penalty used in lasso achieves both variable selection and shrinkage. Finally, the association between the explanatory variables of the models was tested by examining their jointness.

Jointness measure

In the last step of our empirical analysis, we address the jointness of the explanatory variables. The degree of dependence between the explanatory variables of the model is measured using a joint metric.

We followed the methodology of Doppelhofer and Weeks (2009). Only the joint relationships between pairs of variables are discussed in the following sections. However, it is also feasible to investigate the associations between triplets or even larger collections of data.

For the model Mj, posterior probabilities are

$$\left(M_j|\mathrm{y}\right)=\mathrm{P}\left(\varphi_1=w_1,\varphi_2=w_2,\ldots,\varphi_k=w_k|y,M_j\right),$$

where we can assume that w_k has a value of 1 if a variable is present in the model and 0 otherwise. The combined posterior probability of adding the two model variables x_i and x_h, is as follows:

$$\mathrm{P}\left(i\cap h|\mathrm{y}\right)=\sum_{j=1}^{2^k}1\left(\varphi_i=1\cap\varphi_2=1|\mathrm{y},\ M_j\right)*\mathrm{P}\left(M_j|\mathrm{y}\right),$$

where P $(i\cap \mathrm{h}|y)$ is the sum of the posterior probability of the models that include the variables denoted by x_i and x_h. By comparing estimates of the posterior joint probability,

Table 1 Points of probability mass defined on space $\{0, 1\}^2$ for uniform distribution $P(\varphi_i, \varphi_j|y)$

$P(\varphi_i, \varphi_j|y)$	$\varphi_h = 1$	$\varphi_h = 0$	Sum
$\varphi_i=1$	$P(i \cap h|y)$	$P(i \cap h'|y)$	$P(i|y)$
$\varphi_i=0$	$P(i' \cap h|y)$	$P(i' \cap h'|y)$	$P(i'|y)$
Sum	$P(h|y)$	$P(h'|y)$	1

$p(i \cap h|y)$, with marginal estimates p(i|y) and p(h|y), we may determine whether x_i and x_h are independent over the model space or if jointness occurs in terms of a complementary or substitution relationship between x_i and x_h, as in Doppelhofer and Weeks (2009). Table 1 defines the probability mass points.

We quantify the degree of dependence between the two variables by calculating the statistics presented in Eq. (15).

$$j_{ih} = \ln\left[\frac{P\left(i \cap h|y\right)}{P\left(i' \cap h|y\right)} \cdot \frac{P\left(i' \cap h'|y\right)}{P\left(i \cap h'|y\right)}\right] = \ln\left[PO_{i|h} . PO_{i'|h'}\right] \tag{15}$$

In Eq. (15), $PO_{i|h}$ and $PO_{i'|h'}$ represent the posterior odds of including x_i conditional on x_h being included, and the posterior odds of excluding x_i conditional on x_h being excluded, respectively. In Eq. (15), the jointness between two variables is commonly known as JDW (or J_{DW} for Doppelhofer and Weeks (2009)) in the Bayesian literature. Table 2 presents the classification of jointness based on the JDW.

Empirical results and discussion

In this section, we present the probability of the association of the nine variables in models 2–9 with the stock price indices of the four OPEC countries. As we have 512 estimated parameters, it is essential to select a method that evaluates the impact of all variables on the dependent variable in all models.

We employed a BMA to accomplish this objective. BMA calculates the PIP for potential explanatory variables. The estimated model parameters were highly reliable because they were obtained from the weighted average of the estimates in 2048 repetitions of the sampling models. The weighted average of the coefficients is.

$$\hat{\alpha}_1 = \sum_{t=1}^{i} \eta_i \hat{\alpha}_{1i},$$

where η_i are the non-negative random weights given to each model, and $\hat{\alpha}_{1i}$ is an estimate of $\hat{\alpha}_1$, conditional on the M_K model.

Table 3 displays the empirical findings, with the variables entered in descending order of PIP. The third column reports the posterior probability distribution derived from the Bayesian estimation. The fourth column shows the standard deviation of the posterior distribution (Post SD). In the fifth column, the conditional posterior sign (CPS) indicates the "sign certainty" for each variable. In some models, a variable may have a positive sign, whereas in others, it may have a negative sign. The CPS value ranges from 0 to 1, where a value closer to one suggests that the posterior mean of the estimated coefficient is more likely to be positive in most models. Conversely, a value closer to zero indicates

Table 2 Classification of relationship between variables based on jointness measure

$j_{ih}> +2$	Strong complements
$+1 < j_{ih}< +2$	Significant complements
$-1 < j_{ih}< +1$	Not significantly related
$-2 < j_{ih}< -1$	Strong substitutes
$< j_{ih}< -2$	Significant substitutes

j_{ih} signifies JDW posterior odds of inclusion defined by Eq. (15)

Table 3 Estimation results of coefficients

Variable	PIP	Post Mean	Post SD	CPS
CPI	0.97	1.60	0.67	1.00
Money growth	0.90	2.48	1.17	1.00
Gold price	0.42	− 4.83	0.07	0.01
Econ. growth	0.36	1.29	2.12	1.00
Import	0.16	5.63	0.39	0.73
Export	0.16	− 2.73	0.25	0.41
Oil price	0.14	− 7.35	0.25	0.52
Exchange rate	0.14	− 4.68	0.00	0.23
Inflation	0.11	-0.08	1.01	0.42

PIP indicates the probability of the presence of a variable in the model. All variables are sorted accordingly in a descending order of PIP. CPS is the conditional posterior sign

that the posterior mean of the estimated coefficient is more likely to be negative in most models.

Based on the PIP computed in Table 3, only CPI and broad MG are statistically significant with PIP > 0.5, assuming a uniform prior distribution, whereas the remaining variables are not.

The magnitudes of the CPS in Table 3 reveal that the CPI, broad MG, economic growth, and imports are most likely positively associated with the equity indices under study, whereas the other variables are most likely negatively associated. These findings are qualitatively identical to those of two groups of economies: a subset of the G-7 and a group of developing markets. For brevity, we do not present these results.

The graph in Fig. 1 confirms that only the CPI, broad MG, and economic growth are positively associated with stock indices. However, the signs of the other variables, such as crude oil prices, behave erratically. Figure 2 further reinforces the consistent positive association of the CPI and broad MG (blue) with the studied stock indices.

The top 100 models are shown in Fig. 1. Blue indicates a positive correlation between the variable and the stock price, red indicates a negative correlation between the variable and the stock price, and white indicates that the variable is not present in the model. It can be observed that oil prices exhibit different behaviors concerning their relationship with stock prices. However, as Table 3 shows, they have a weak negative relationship with stock prices on average.

In Fig. 1, the vertical axis (y-axis) represents the explanatory variables, whereas the horizontal axis represents the posterior model probability (PMP) mass of the models (i.e., the number of models in which the variable is included). Each column in the figure represents a specific model. Additionally, blue indicates a positive relationship between

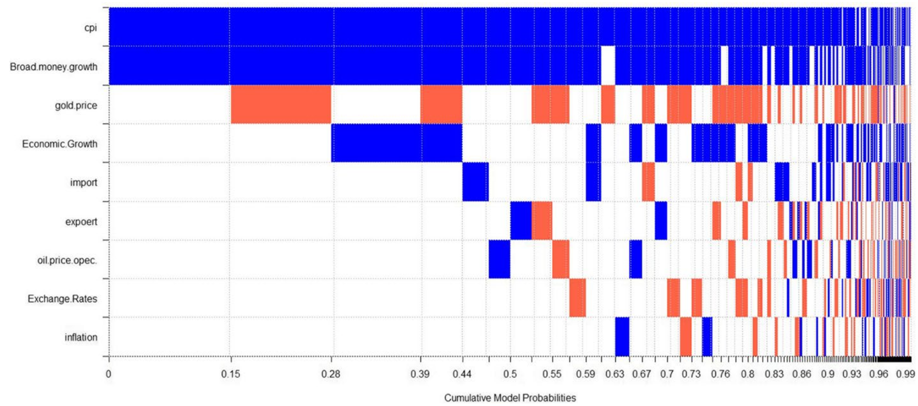

Fig. 1 Best- performing 100 models: Model inclusion based on the best 100 models of uniform model priors: red indicates negative coefficient, blue indicates positive coefficient and white indicates non-inclusion

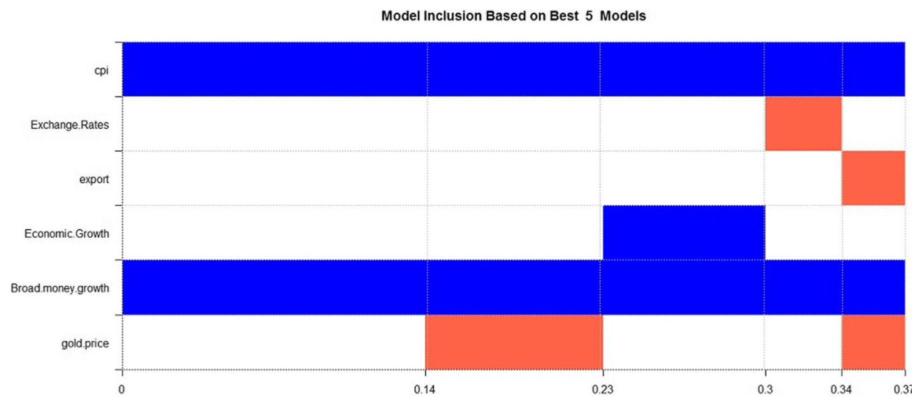

Fig. 2 The 5 best-performing models and included variables. The color blue represents the positive, and red the negative estimated coefficient signs

the variable and the stock price index, whereas red indicates a negative relationship between the variable and the stock price index. White indicates the absence of variables in the estimated model.

Figure 1 contains 100 columns, each representing a selected model. The models with the highest explanatory power are shown on the left side of Fig. 1. Starting from the origin on the x-axis (left), the first blue column represents the best model, which possesses the highest PMP mass and includes the CPI and broad MG variables.

For instance, the first model, encompassing the CPI and broad MG rate, exhibits the highest explanatory value, accounting for 15% of the PMP, as displayed on the x-axis. The second-best model involves the CPI, broad MG, and gold prices with a negative association with equity indices (shown in red), resulting in a PMP of 13% (28% minus 15%). The third model incorporates economic growth in addition to the two variables present in the first model, contributing a PMP of 24% (39% minus 15%). The remaining models were similarly ranked based on their PMP values.

The top five models, represented by the first five columns in Fig. 1, account for approximately 37% of the PMP mass shown on the x-axis. The models are shown in Fig. 2. Notably, gold prices, exchange rates, and exports entered the top models with a negative association with equity indices. Considering that the two largest economies in the

Table 4 Coefficients of the five best-performing models

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
CPI	1.35	1.85	1.37	1.80	1.12
Inflation	0.00	0.00	0.00	0.00	0.00
Exr	0.00	0.00	0.00	0.00	0.00
Exp	0.00	0.00	0.00	0.00	0.00
Imp	0.00	0.00	0.00	0.00	0.29
EG	0.00	0.00	0.00	0.00	0.00
MG	3.17	2.54	2.79	2.39	2.85
OP	0.00	0.00	0.00	0.00	0.00
Gold Price	0.00	− 0.09	0.00	− 0.07	0.00

The top five models based on PMP

sample suffer from high inflation rates, this observation is not surprising. Gold acts as a hedge against inflation. It is a safe haven investment that is a substitute for equity.

Table 4 displays the estimated coefficients of the top five models and the association of the explanatory variables included in each model with the equity indices according to the color of each variable. For instance, the coefficients of CPI and broad MG are consistently positive, whereas those of gold prices are either negative or not included in most models.

A critical conclusion from this analysis is that models that include only the CPI and broad MG as their explanatory variables represent only 15% of the PMP. This result indicates that even the best models may lead to unwise economic and financial policies because they may not capture exogenous, political, and other immeasurable factors, such as employment policies and corruption, that influence the overall performance of the equity indices.

With 2^{k} combinations of possible variables, the prior uniform model results in a common prior model probability of 2^{-k}. This result implies a prior expected model size of 4.5 (approximately between four and five, because the density function is flat). Figure 3 depicts the prior and posterior density functions of the estimated models, along with the analytical PMP (red line) and their Markov chain Monte Carlo (MCMC)-simulated probabilities (blue line) for both the top 2000 models (top) and the 100 best models (bottom).

The red line represents the probability density function of the posterior analytical model, and the blue line indicates the number of MCMC iterations. The PMP is proportional to the final probability of the model, meaning that it reflects the likelihood of model selection based on available data. The accuracy of MCMCs in simulating prior distributions relies on the number of draws through which the MCMC sampler passes. Initially, models with low PMP, which are considered inadequate, may be drawn. However, the sampling process gradually moves toward models with the highest marginal likelihoods, resulting in better approximations.

To achieve the best model approximation, the first set of iterations ("burn") is excluded from the calculation of the results. The PMP number in Fig. 3 indicates that the convergence reached an acceptable level, that is 0.9996. Additionally, "Corr PMP" defines the correlation between iteration counts and analytical PMPs for the top 100 models.

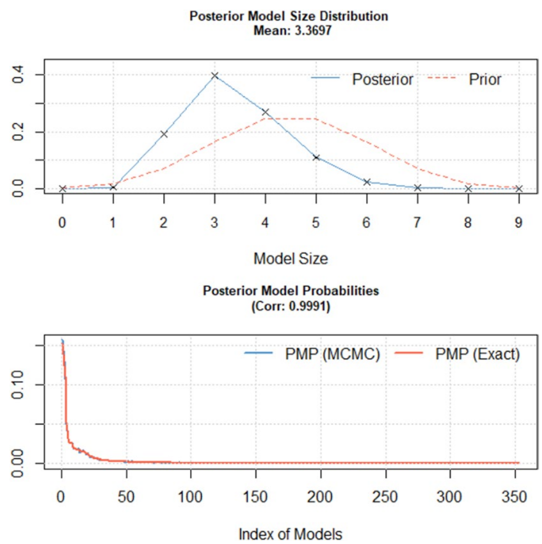

Fig. 3 Posterior model size distribution and posterior model probabilities

Figure 4 shows the marginal posterior distributions of the significant regression coefficients of the CPI and broad MG, as well as the PIP and expected value of the estimated coefficients.

The red line in Fig. 4 represents the conditional expected values. The green line indicates the median, and the red dotted line represents the 90% confidence interval of the estimated coefficients. For instance, the conditional expected value of the estimated CPI coefficient was approximately one, with a 95% confidence interval of 0, and approximately 2.

Table 5 reports the empirical findings from the RLR. Table 5 confirms that the two variables, CPI and broad MG, have the highest statistically significant estimated coefficients (0.85 and 0.31, respectively), reaffirming their strong association with equity indices. The inflation rate, exchange rate, imports, and economic growth have a relatively lower association, as the magnitude of their estimated coefficients in Table 5 indicate. The direction of the association of explanatory variables with equity indices shown by RLR corroborates those shown by BMA, further lending support for the empirical results derived from BMA. Table 5 also reports the Durbin–Wu–Hausman (DWH) test of the exogeneity of the final two model variables (CPI and broad MG). The insignificance of the difference in J-statistics confirms that the final model variables do not pose any endogeneity issues.

The jointness test results regarding the behavior of the explanatory variables and their associations with each other are discussed below. Table 6 presents the findings of the jointness tests, in which the JDW criterion is used to determine whether the two variables are substitutes, strong substitutes, complements, or strong complements. For instance, the results indicate that the CPI is a strong substitute for imports, as indicated by a negative JDW value greater than the absolute value of one. At the same time, CPI is a strong complementary variable for the MG rate based on a positive and greater-than-one JDW.

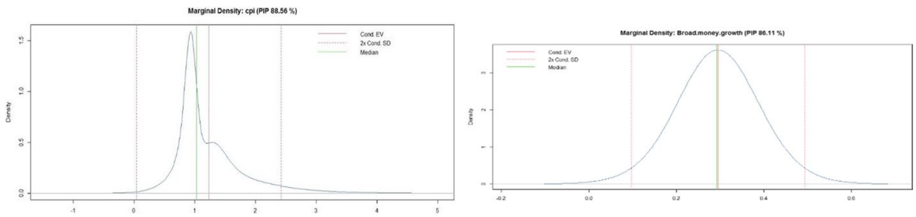

Fig. 4 Marginal density distributions for 2 important variables (CPI and Broad Money growth) in the model

Table 5 Regularized linear regression results

Penalty	λ	Validation MSE	Test MSE	R^2
L1 (Lasso)	0.014	0.185	0.162	0.95
Variables	Coefficients (β)			
CPI	0.85			
Inflation	− 0.03			
Exchange Rates	− 0.09			
Export	0.00			
Import	0.09			
Economic growth	0.09			
Broad money growth	0.31			
Oil price (OPEC)	0.00			
Gold price	0.00			
Difference in J-statistic			3.43	

Durbin–Wu–Hausman (DWH) tests the null of exogeneity by comparing the difference in J-statistics from restricted and unrestricted models based on critical values of chi-squared distribution. Insignificant test statistic means that the null hypothesis is not rejected

Table 7 summarizes the findings of Table 6, which are based on Table 2. It classifies all the model variables into pairs of substitute and complementary variables. For instance, it identifies the CPI and MG as substitutes for imports. Consequently, the empirical models do not need to include imports because the CPI already serves as one of the explanatory variables. The coefficient on imports is statistically insignificant. However, the CPI and MG act as complementary variables, necessitating their inclusion as explanatory variables in the regressions. Furthermore, the coefficients consistently exhibit statistical significance.

Although numerous studies examine this subject, their findings are rarely consistent. Verma and Bansal (2021) confirm that the results can vary based on factors such as the study's sample period, the combination of explanatory variables, and the specific economy under investigation.

The BMA methodology used in this research relies on a data-determined model and variable selection. Table 3 indicates that the CPI, MG, economic growth, and gold prices are the most critical market variables in this study. Among these variables, only the CPI, MG, and gold prices show statistically significant associations with equity prices in the top-selected models.

These findings are consistent with those of Arouri and Fouquau (2009), Lescaroux and Mignon (2008), Giri and Joshi (2017), Chang et al. (2019), El Abed and Zardoub (2019),

Table 6 Jointness based on JDW criterion

Variable	CPI	INF	EXR	EXP	IMP	EG	MG	OP	GP
CPI	0	− 0.847	− 3.439	− 1.229	− 4.603	0.440	2.312	− 1.191	− 0.834
INF	− 0.847	0.00	0.299	0.228	0.420	− 0.099	− 0.208	0.249	0.090
EXR	− 3.439	0.299	0.00	0.150	2.103	− 0.052	− 0.656	0.1649	− 0.350
EXP	− 1.229	0.228	0.150	0.00	− 0.308	− 0.226	− 0.881	− 0.699	− 0.146
IMP	− 4.603	0.420	2.103	− 0.308	0.00	− 0.185	− 1.060	− 0.033	− 0.325
EG	0.440	− 0.099	− 0.052	− 0.226	− 0.185	0.00	− 0.385	− 0.108	− 0.469
MG	2.312	− 0.208	− 0.656	− 0.883	− 1.060	− 0.385 0.00	− 0.790	− 1.174	
OP	− 1.191	0.249	0.165	− 0.699	− 0.033	− 0.108	− 0.790	0.00	− 0.349
GP	− 0.834	0.091	− 0.350	− 0.146	− 0.325	− 0.469	− 1.174	− 0.349	0.00

JDW > 1 indicates strong or significant Complements, JDW < − 1 means strong or significant substitute. Also see Table 2

Table 7 Summary variable jointness based JDW criterion

Variables	JDW	Association
CPI, money growth	3.060	Strong complements
inflation, import	1.361	Significant complements
CPI, inflation	− 1.384	Significant substitutes
CPI,OP	− 1.004	Significant substitutes
CPI, import	− 6.095	Strong substitutes
import, money growth	− 2.659	Strong substitutes

See Table 2

Celebi and Hönig (2019), and Alam (2020). Hence, the money supply and CPI influence equity price indices in both developed and developing economies. However, our findings contradict those of Akoum et al. (2012) and Arouri and Rault (2012).

The OPEC oil price consistently appears to be an insignificant factor for the equity indices of the studied markets. Tusiime and Wang (2020) report a similar finding for the US equity markets. However, Gupta and Kumar (2020), Nasar and Rashid (2018), and Giri and Joshi (2017) find that crude oil prices negatively influence equity prices in India and Brazil and positively influence equity prices in China. These contradictory findings point to the complexity of the subject and the influence of immeasurable factors such as market competitiveness, political systems, transparency, and securities market regulations.

Our findings are also in line with the quantity theory of money, suggesting that increased money supply may be responsible for inflated asset prices, including equities. This is particularly evident when the real GDP cannot respond adequately to money supply changes because of institutional inefficiencies, inefficient labor laws, political and economic corruption, and other structural constraints.

The consistently high inflation rates and asset appreciation in Iran and Nigeria can be attributed to the monetization of government budget deficits. This practice distorts economic activities, leading to elevated inflation and interest rates, which in turn, discourage new investments and trigger social costs such as protests and unrest.

A comparison of our findings with those in the existing literature reveals that the economies under study are not open, competitive market-oriented economies. The expectation was that oil exports and prices would play a significant role in these economies;

however, our findings indicate otherwise. Instead, they suggest that the overall government budget, which appears to consist of significant monetized budget deficits in Iran and possibly Nigeria, is a more crucial variable than OPEC oil prices.

The government is the largest employer in all four economies examined in this study. Therefore, it is not surprising that money supply, being a significant component of the government budget in two of the four economies, is a significant factor behind equity index movements.

The policy implications of this study indirectly emphasize the urgency of implementing structural changes in social security systems, labor market laws, and retirement plans. These changes should discourage early retirement and reduce reliance on a balanced government budget while also eliminating deficit monetization. Investing in economies with government fiscal mismanagement, high inflation, and inefficient equity markets may pose significant risks for wealth managers and international investors.

As a final note, it is important to clarify that the findings of the BMA methodology do not directly imply causality. Instead, the method focuses on establishing associations between equity indices and a set of explanatory variables. Building on the results of this study, the analysis can be extended by employing a typical causality test, such as Granger causality, to investigate relationships through a causal lens.

Summary and conclusions

This study examines the relationships between macroeconomic variables and equity indices in four major OPEC countries: Iran, Kuwait, Nigeria, and Saudi Arabia. These economies were chosen because they are long-standing OPEC members and have demonstrated resilience against various geopolitical challenges. However, uncertainty and occasional equity market crashes can lead to wealth loss, decreased consumer confidence, and disruptions in capital resource allocation. Thus, understanding the behavior of equity prices and their association with other asset classes remains a focus in financial economics, driven by the desire for more information among investors and policymakers.

The empirical investigation primarily employs the BMA method, which is robust in the presence of models and variable uncertainties. The dataset covers 1996–2018 and is sourced from the World Bank and IMF. This study excludes 1999–2022 to avoid extreme economic events during the pandemic era.

The research findings indicate that among the explanatory variables considered, the CPI and broad MG have the most significant positive impact on stock prices. Additionally, three variables–CPI, broad MG, and economic growth–consistently demonstrate a positive relationship with the stock price indices in the sample countries. Surprisingly, oil prices show a weak and negative relationship with equity price indices in these countries.

We employed RLR to validate the BMA results, confirming the importance and signs of the explanatory variables. The jointness method was used to identify relationships between pairs of independent variables, revealing their complementarity and substitution effects.

These findings align with those of previous studies and are consistent with the quantity theory of money, indicating that increased money supply can raise prices, especially when real GDP remains unresponsive.

This study's policy implications underscore the urgency of implementing structural changes in the social security system, labor market laws, and retirement plans. These changes should aim to discourage early retirement and reduce reliance on government debt monetization. Wealth managers and international investors must be aware that investing in economies plagued by government fiscal mismanagement, high inflation, and inefficient equity markets may involve significant risks.

One notable limitation of this research is the lack of available data on the sample economies compared with developed economies. This creates a vicious cycle that hinders empirical research and reliable economic data, ultimately affecting the efficiency of economic policies and their potential to promote growth.

Abbreviations

OPEC	Organization of petroleum exporting countries
BMA	Bayesian model averaging
RLR	Regularized linear regression
CPI	Consumer price index
GASTAT	General Authority for Statistics
GDP	Gross domestic product
G20	Group of Twenty
GCC	Gulf Cooperation Council
G-7	Group of Seven
FDI	Foreign direct investment
WPI	Wholesale price index
ARDL	Autoregressive distributed lag approach
BRICS	Brazil, Russia, China, India, and South Africa
AD-AS	Aggregate demand and supply
MG	Broad money growth
INF	Inflation
EXR	Exchange rates
EXP	Exports
IMP	Import
OP	OPEC oil price
EG	Economic growth
GP	Gold price
MC^3	Markov chain Monte Carlo model composition
MH	Metropolis–Hastings algorithm
PIP	Posterior inclusion probability
CPS	Conditional posterior sign
PMP	Posterior model probability
MCMC	Markov chain Monte Carlo
JDW or J_{DW}	Jointness as in Doppelhofer and Weeks (2009)

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Author contributions
SH proposed the initial idea, developed the methodology, and outlined the rough draft. All authors (HA, JH, SH, and BA) collaborated on data collection, data cleaning, and formatting. All authors collectively participated in finalizing the data set, conducting estimations, interpreting empirical findings, and contributing to various segments of the manuscript. All authors were actively engaged in organizing, drafting, and refining both the initial drafts and the final version of the manuscript. Furthermore, each author made significant and equal contributions to the extensive revisions requested by the three reviewers. All authors read and approved the final manuscript.

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Competing interests
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