MASTER'S IN TELECOMMUNICATIONS ENGINEERING

THESIS

THE BUSINESS CYCLE AND THE GOLD MARKET

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Madrid

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The Business Cycle and the Gold Market

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THE BUSINESS CYCLE AND THE GOLD MARKET

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ABSTRACT

This research employs a Vector Autoregressive (VAR) model under a dynamic Markov-Switching regime to conduct a comprehensive empirical analysis under two possible economic states: recession and expansion. Motivated by a detailed exploration of the intricate relationships influencing gold prices, the study begins with a static VAR model, examining Impulse Response Functions (IRFs) and its Historical Decomposition. It is subsequently compared with another MS-VAR model, incorporating the same factors but under the two potential regimes of an economic cycle. The factors and indices under investigation encompass geopolitical volatility (Geopolitical Risk Index Historic - GPRH), monetary policy through interest rates (Federal Funds Rate and Shadow Rate of Interest - SRI), core inflation (Consumer Price Index Core - CPI Core), market sentiment (Consumer Opinion Survey - COS), economic volatility (adaptation of the Volatility Index - VIX through a GARCH model for the MSCI World - VIX_0), portfolio performance (MSCI World Index), oil price (average price in many countries - OIL_AVG), dollar price (U.S. Dollar Index - DXY), and gold price (LBMA Gold Price). This dynamic approach allows for a comprehensive analysis of the influences of these factors on gold prices under different economic contexts.

Key words: VAR, Markov-Switching, LBMA Gold Price, volatility, dollar, interest, inflation, portfolio, regime, recession.

CICLO ECONÓMICO Y MERCADO DEL ORO

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RESUMEN DEL PROYECTO

Esta investigación emplea un modelo Autorregresivo Vectorial (VAR) con un régimen dinámico de Markov-Switching para realizar un análisis exhaustivo bajo dos posibles estados económicos: recesión y expansión. Este enfoque se motiva por una exploración detallada de las complejas relaciones que influyen en los precios del oro. Se inicia con un modelo VAR estático y se examinan las Funciones de Respuesta a Impulsos (IRF) y la Descomposición Histórica. Luego, se compara con otro modelo MS-VAR que incorpora los mismos factores pero bajo los dos posibles regímenes de un ciclo económico. Los factores e índices considerados incluyen volatilidad geopolítica (Índice Histórico de Riesgo Geopolítico - GPRH), política monetaria a través de tasas de interés (Tasa de Fondos Federales y Tasa de Interés Sombras - SRI), inflación subyacente (Índice de Precios al Consumidor Core - IPC Core), sentimiento del mercado (Encuesta de Opinión del Consumidor - COS), volatilidad económica (Índice de Volatilidad - VIX, ajustado mediante modelo GARCH para el MSCI World - VIX_0), rendimiento de cartera (Índice Mundial MSCI), precio del petróleo (Precio Promedio en Muchos Países - OIL_AVG), precio del dólar (Índice del Dólar Estadounidense - DXY), y precio del oro (Precio del Oro LBMA). Este enfoque dinámico permite analizar de manera integral las influencias de estos factores en el precio del oro en diferentes contextos económicos.

Palabras clave: VAR, Markov-Switching, Precio del Oro LBMA, volatilidad, dólar, tasas de interés, inflación, cartera, régimen, recesión.

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Chapter 1. INTRODUCTION

Gold has had various functions throughout history, but its most important and enduring role has been as a store of value. It has been used as currency in its own right on numerous occasions, such as in ancient Mesopotamia, the Roman Empire, and the Middle Ages. It has also been established as a fixed value for many currencies, as seen in the context of the Bretton Woods International Monetary System during the Second Gold Standard from 1944 to 1971. In summary, since then, it has been considered a safe haven against inflation and volatility (Huang, Jia, Xu, & shi, 2019).

Over the past twenty years, gold has undergone a significant shift in its behaviour, transitioning from its traditional role as a commodity to primarily serving as a financial asset for speculation. Investors perceive this fundamental change not only as a store of value but also as a tool for transactions in financial markets. Its value is no longer solely determined by physical supply and demand; instead, financial demand exerts a significant impact on its price, surpassing the demand from jewellery and technology.

After the 2008 housing crisis, gold appreciated significantly, making it a safe haven in times of economic uncertainty. We have witnessed a renewed surge in demand more recently during the COVID-19 crisis and geopolitical tensions such as the war in Ukraine. The perception of gold as a strategic asset in investment portfolios is reinforced by its resilience and ability to maintain appeal during economic crises and conflicts. Its position as a safe haven has further strengthened due to the intersection of economic and geopolitical events, giving it a more nuanced role in the current financial landscape.

Several countries have chosen to acquire gold as a strategic reserve to shield themselves against the growing global uncertainty in the current context. The perception that gold will continue to be a safe haven, and its price will keep rising, has been reinforced by geopolitical tensions, especially between the United States and China over the situation in Taiwan, as well as the recent conflict between Israel and Hamas. However, this positive outlook is accompanied by a persistent concern: the possibility that this upward trend may lead to the creation of a bubble, where the price of gold deviates significantly from its intrinsic value. In times of chaos, there is a worry that gold may behave more like a traditional commodity and be susceptible to significant declines, heightening the sense of caution. In this situation, the trajectory of gold will be influenced not only by geopolitical tensions but also by the market's ability to maintain a sustainable balance between demand as a safe haven and the potential for extreme fluctuations in its value.

As a financial asset, gold possesses a unique duality: it can be utilized both as currency and as a commodity. Despite its impressive status and intrinsic value, it is classified as a commodity due to its tangible presence and importance in industrial sectors. Its corrosion resistance makes it ideal for jewellery and technological applications. However, it is precisely this characteristic that grants it exceptional economic value. The current amount of gold in circulation is equivalent to the sum of all gold ever extracted throughout history due to its inert nature. Furthermore, the amount extracted each year is relatively small compared to the circulating supply, creating a minimal supply that helps maintain its resilience and prevents significant depreciations in value. Additionally, its uniqueness makes it less susceptible to government manipulation, enhancing stability.

In the fields of economics and finance, the analysis of gold prices has become a topic of great interest. The importance of understanding the factors determining the value of gold lies in the metal's exceptional ability to reflect and absorb the complexities of a constantly changing global economy. The allure of gold extends beyond its intrinsic value as a wealth reserve; gold's sensitivity to macroeconomic events provides crucial signals about how markets and the economy as a whole will unfold in the future. As a result, this study not only examines the nature of gold as an asset but also explores the fundamental connections between its behaviour and the forces shaping the global financial landscape.

This article addresses gaps in current knowledge and opportunities to advance the understanding of the determinants of gold prices. Its unique approach focuses on modelling rather than prediction, diverging from the literature's predominant emphasis on predictive strategies. The study prioritizes a profound understanding of the causal relationships among factors and their impact on gold prices through a meticulous modelling process. Additionally, it integrates factors such as interest rates, volatility indicators, consumer sentiment, portfolio performance, and the value of the dollar to validate previous research. Simultaneously, it categorizes and clarifies key indicators to enhance the model's relevance and accuracy. Furthermore, the research explores how the portfolio performance, represented by the MSCI World index, correlates with geopolitics and markets.

Within the scope of this research, the primary objective of this Master's Thesis is to construct a VAR model with Markov-Switching for the purpose of analysing the behaviour of the gold price, specifically represented by the London Bullion Market Association (LBMA) Gold Price. This model will encompass various factors including: geopolitical volatility, as represented by the Geopolitical Risk Index Historic (GPRH); monetary policy through interest, indicated by a combination of the Federal Funds Rate and the Shadow Rate of Interest (SRI); core inflation represented by the Consumer Price Index (CPI) Core; market sentiment, represented by the Consumer Opinion Survey (COS); economic volatility, portrayed by an adapted Volatility Index (VIX) through a GARCH model for the MSCI World (VIX_0); portfolio performance, reflected by the MSCI (Morgan Stanley Capital International) World Index; oil price, indicated by the average price in many countries (OIL_AVG); and dollar price, reflected by the U.S. Dollar Index (DXY).

Chapter 2. LITERATURE REVIEW

Existing literature on the price of gold predominantly centres on prediction rather than modelling. This entails a consequence-oriented approach, prioritizing datasets that offer more accurate forecasts, relegating a genuine understanding of gold's behaviour to a secondary position. Consequently, it is crucial to approach with caution all variables employed in such predictive research, as the purpose may not necessarily align with the objectives pursued in the current project. Nevertheless, these will be utilized as a starting point, coupled with logical reasoning, to fundament the analysis.

A considerable number of studies focus on the financial aspects associated with the demand for gold. This focus on variables linked to demand can be attributed to the distinctive properties of gold, as indicated by O'Connor, Lucey, and Baur (2016). This metal exhibits exceptional resistance to corrosion, leading to a gradual accumulation of its supply over the years. The majority of its supply originates from materials extracted in previous years, diminishing the significance of production figures. Even when considering its global supply, the supply figures are notably low. "The total supply of gold grew marginally by 1% in 2018, supported by increases in mine production to a new record high and recycled gold". (Lakshmanan, Ojaghi, & Gorain, 2019).

According to the demand distribution established by the World Gold Council (2023), the demand for gold can be classified into three sectors: jewellery, technology, and investment. Research conducted by Erb and Harvey (2013), asserts to have identified a high elasticity of demand in the investment sector compared to the other two sectors during the period from 2001 to 2011. This study concludes that a 10% increase in the price of gold resulted in a 9.8% increase in investment demand, representing an elasticity of 0.98. In contrast, the demand elasticity in the jewellery and technology sectors was -0.24 and 0.10, respectively. It is for this reason that in our analysis, we will rely on purely financial or macroeconomic data.

Białkowski, Bohl, Stephan, and Wisniewski (2014) in response to the recent surge in gold prices, investigated whether the accelerated growth in investment activities has led to a new asset price bubble. Drawing on gold's role as a hedge against the dollar, protection against inflation, portfolio diversifier, and safe haven, they calculate fundamental returns and approximate the intrinsic value of gold. Utilizing deviations between the actual price and its adjusted value, to then apply a Markov-Switching ADF test with substantial power to detect explosive behaviours. While empirical results depend on the definition of gold fundamentals, models accounting for the impact of the current European sovereign debt crisis closely capture the actual behaviour of gold prices. Consequently, it is concluded that resorting to explanations of irrational bubbles is not necessary to account for the considerable fluctuations observed in the gold market.

Ismail, Yahya, and Shabri's study (2009) focuses on developing a regression model to predict the price of gold using the London PM Fix as the dependent variable. It identifies eight factors, including the Reuters Commodity Research Bureau (CRB), EUROUSD exchange rate, inflation rate, and monetary supply (M1), the New York Stock Exchange (NYSE) composite index, the Standard and Poor's 500 (S&P 500), treasury bills (T-BILLS), and the US Dollar Index (USDX), as independent variables influencing the gold price. To address issues like multicollinearity and correlated error terms in the regression model, stepwise regression and Prais-Winsten procedures are implemented. Stepwise regression reduces the independent variables to four (CRB, EUROUSD, INF, and M1), while Prais-Winsten procedures prove effective without a significant decrease in explained variance. The resulting forecasting model highlights the importance of considering the CRB index, EUROUSD exchange rate, inflation rate, and monetary supply (M1) when predicting the average gold price for the next month, also incorporating the effects of significant lags in the causal process. It's noteworthy that three of the identified factors are key economic indicators for the United States: the EUROUSD exchange rate, inflation rate, and monetary supply (M1).

Aye, Chang, & Gupta (2016), examine the role of gold as a hedge against inflation using data from 1833 to 2013. A Markov regime-switching regression model is applied to analyse the long-term relationship between the price of gold and inflation. Despite conventional tests not finding evidence of a long-term relationship, interrupted cointegration is discovered, indicating that gold's role as a hedge may be disrupted due to structural changes in the gold market. This suggests that there is no permanent solution to external shocks. The research highlights the need for short-term measures, such as temporary monetary and fiscal policies, but notes that these may introduce uncertainty and increase policy implementation costs. For investors, the importance of monitoring changes in the market and the economy when considering gold investment as wealth protection is emphasized. Additionally, it is suggested that massive accumulations of gold should be approached with caution, as structural changes can erode confidence. The study underscores the importance of considering nonlinearities in future research on the relationship between gold and inflation.

Bilgin, Gozgor, Lau, and Sheng (2018) focus on analysing the determinants of gold prices, with a particular emphasis on four measures of uncertainty (VIX, SKEW, global EPU, PC indices). The empirical model incorporates the real effective exchange rate of the dollar and the price of oil. Nonlinear ARDL estimates reveal that gold prices respond positively to negative changes in oil prices, suggesting a substitution effect between gold and oil. Similarly, a negative reaction is observed to positive changes in the real effective exchange rate, aligning with the theoretical expectation that a weak dollar implies a higher gold price. Furthermore, a positive response to volatility (VIX) is found, indicating that gold is perceived as a safe haven in times of economic uncertainty. These findings provide valuable insights for portfolio diversification and risk management.

The article conducted by Apergis, Cooray, Khraief, and Apergis (2019), focuses on examining the transmission dynamics between real interest rates and gold prices in G7 countries using a Bayesian Markov-Switching Vector Error-Correction Model (MS-VECM) from 1975 to 2016. The findings indicate a positive association between gold prices and real interest rates, with the relationship being more pronounced in the United States, highlighting the crucial role of U.S. monetary policy at both domestic and global levels. The study concludes that gold prices serve as a hedge against movements in real interest rates during recessionary periods. Robustness checks involve additional variables such as consumer prices, real GDP, exchange rates, oil prices, silver prices, copper prices, and stock prices, confirming the positive association between gold prices and real interest rates across all G7 countries.

The study conducted by Tiwari, Aye, Gupta, and Gkillas (2020) delves into the connection between gold and oil prices, utilizing daily data spanning from 1985 to 2017. The research evaluates the hedging and safe-haven capacities of gold concerning oil, considering the diversity among market participants and geopolitical risks. Copula models are employed, leading to the conclusion that certain models more effectively capture the dependency dynamics. Results exhibit variability based on the investment horizon: gold proves to be a hedge in the short and medium term but not in the long term against oil price increases. Furthermore, the study demonstrates that gold functions as a safe haven for oil in extreme conditions. Implications highlight the need for considering more intricate models and acknowledging market diversity. For investors, the emphasis is on the importance of tailoring risk management and portfolio strategies to their specific characteristics and time horizons. From a policy standpoint, it is recommended to incorporate the interaction between gold and oil into price regulation considerations, emphasizing the significance of effective financial measures to prevent short and medium-term contagion. As a proposal for future research, exploring more intricate moments and their correlation with alternative uncertainty measures is suggested.

Triki & Maatoug (2021) examine the relationship between gold and stock markets in the context of political tensions using the GPR index, originally proposed by Caldaray and Iacoviello (2022). Multivariate GARCH models were employed to analyse correlations and volatility transfers, highlighting a time-varying correlation during turbulent geopolitical periods. A significant volatility transfer from the S&P 500 to gold is observed, indicating the key influence of the stock market on gold, while no significant transfer was found in the opposite direction. The study underscores the necessary active management when including gold in a portfolio, considering its role as a safe haven and its impact on returns during different market conditions. Exploring future extensions with more robust methods to infer causality between variables is recommended.

Huang, Jia, Xu, and shi (2019) explore the relationship between gold prices and consumer sentiment, an area with limited existing literature. In their study, they differentiate between periods before and after the Global Financial Crisis (GFC). A significant threshold effect is identified for both market sentiment and inflation expectations, suggesting that gold serves as a safe haven and hedge against purchasing power loss primarily during periods of high financial turbulence and inflationary expectations. Furthermore, it is observed that the threshold effect of market sentiment is more pronounced in the post-GFC period. These findings provide important guidelines for investors, emphasizing the need to carefully consider the market environment.

The research work that encompasses some of these articles and has served as a starting point for the selection of data series is that of García and Díaz (2023). In this study, a static VAR model is employed to examine the complex relationship between the price of gold and various influencing factors. Through three phases, from initial exploration to detailed analysis of Impulse Response Functions (IRF) and historical decomposition, the model is refined. Refinements are suggested, such as removing inflation as a reference for gold and replacing federal funds rates with the Shadow Rate of Interest (SRI). The exclusion of the Geopolitical Risk Index (GPR) is determined to be detrimental to the model's significance. The final model, integrating Geopolitical Volatility, Monetary Policy, Economic Volatility, Stock Market Performance, and the Dollar Price, provides a robust explanation of gold value. The historical decomposition describes many movements in the price of gold over time, from stable periods to crises such as the dot-com bubble, 9/11, the 2008 financial crisis, and the recent pandemic. This study does not stop there but also suggests opportunities for future research, exploring models with dynamic regression coefficients in response to changing economic conditions, thus enhancing predictive capabilities during different economic contexts. This idea forms the foundation of this project.

With the aim of contributing to the field of this research, we have addressed knowledge gaps in the existing literature. This study provides the following:

- Literature Validation:

  Through the execution of this project, we confirm whether the factors introduced in the model, based on the literature review, are also applicable to a VAR in a dynamic regime or if new discoveries emerge that were previously overlooked.

- Model:

  - Modelling instead of Forecasting:

    Most reviewed research on gold prices focuses on forecasting strategies rather than modelling. The distinction lies in a deliberate approach to variable selection, moving away from a methodology solely seeking the most accurate prediction without exploring causal relationships. Thus, the study is guided by a deeper understanding of each factor and its influence on gold prices. This not only allows for the calculation of future trends but also facilitates comprehension of the hidden nuances generating them.

  - Dynamic Regime:

- If we delve into the historical decomposition by García and Díaz (2023) as depicted in **Fig. 1**, we can observe that specific variables provide a more accurate description of gold during periods of economic recession, while conversely, other variables are more relevant during periods of economic growth. The incorporation of a Markov-Switching dynamic regime into a VAR model is thus both straightforward and essential to elucidate the influence of factors on the price of gold.

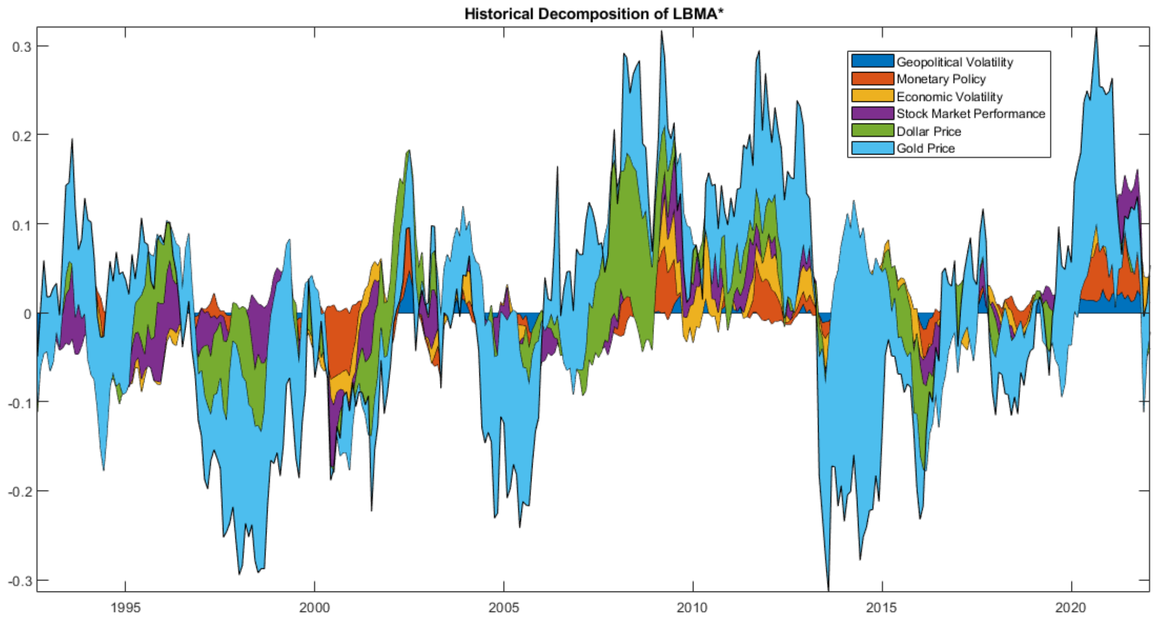

Fig. 1. Historical Decomposition of the LBMA Gold | Source: (García & Díaz, 2023)

- Data:
  - Study Period:

    Our dataset spans from January 1973 to December 2023. Few articles delve into such distant history to analyse gold prices. This is primarily due to limitations in finding variables that extend over such a long timeframe. Many of the more modern indices used for these models do not cover such a period due to the evolving nature of their construction (e.g., the DXY compares the dollar with currencies that hold more weight globally in markets, but this group of currencies changes over time). A thorough review has been conducted to extrapolate and overlap various indices, creating a completely innovative dataset covering the entire study period. This distinction contributes uniquely to the literature as it not only enhances representativeness but also equips the model with better pattern detection owing to reduced variability in the sample.

  - Global Perspective

    One key argument pursued in our study is that in a highly globalized world, and with a precious metal of significant influence and popularity, its price is not conditioned by regional factors but reflects events on a global scale. This premise is supported by an examination of the data series, revealing that the selected indices are specifically chosen to optimally capture the global scale. For instance, to represent overall global economic volatility instead of relying on the VIX, we have created a new indicator based on volatility in the MSCI World Index, utilizing variance derived from a GARCH model (outlined in **0**).

- Selection of indicators that better represent the factors:
  - As previously discussed in this section, some of the reviewed studies utilize the S&P 500 to represent market performance, placing excessive focus on the U.S. economy. In our model, we opt for the MSCI World Index as it provides a broader and more diversified representation of global markets, encompassing companies from various countries and economic sectors.
  - Regarding the representation of the U.S. dollar, the EUR/USD fails to capture the entirety of global monetary information. Therefore, we employ the U.S. Dollar Index in our case. The U.S. Dollar Index is also utilized for "Goods Only" to cover the entire study period comprehensively.
  - To reflect monetary policy, we choose to base our analysis on the Shadow Rate of Interest (SRI) instead of the Federal Funds Rate (FDD). The SRI is capable of capturing unconventional expansionary monetary policies when interest rates are near the Zero Level Bound (ZLB).
- New Factors
  - Economic volatility through the VIX. Many studies conducted before the 2008 real estate crisis do not include it.
  - Geopolitical volatility via the Geopolitical Risk Index (GPR). Although research beyond 2015 starts recommending it, there has been insufficient investigation, especially concerning its relationship with the price of gold. Moreover, little attention has been given to this relatively new index introduced in 2016. Additionally, by introducing this factor alongside market performance, we address the recent belief in their interdependence for the MSCI to be significant (García & Díaz, 2023) (Triki & Maatoug, 2021).
  - Introduction of a new indicator that reflects market sentiment, which is entirely new and understudied despite its logical foundation. This indicator appears to hold considerable significance with the price of gold.

Chapter 3. DATASET DESCRIPTION

After analysing the current state of the literature, it has been determined that the factors influencing the price of gold are optimally reflected in the data series presented in Table 1.

Table 1. Variable Description and Context

Factor	Name	Abbreviation	Description	Source
Gold Price	London Bullion Market Association Gold Price	LMBA	London-based gold price benchmark	(The World Bank, 2024)
Dollar Price	Modified US Dollar Index	DXY_0	Measures USD strength against major world currencies basket	(Federal Reserve Economic Data, 2024)
Oil Price	Crude Oil Average	OIL_AVG	Crude oil, average spot price equally weighed	(The World Bank, 2024)
Stock Market Performance	Morgan Stanley Capital International World Index	MSCI_World	Tracks global stock performance	(Morgan Stanley Capital International, 2024)
Economic Volatility	Modified Volatility Index	VIX_0	Volatility index measuring financial market risk	(Federal Reserve Economic Data, 2024)
Market Sentiment	Consumer Opinion Surveys	COS	Measures market fear and uncertainty	(Federal Reserve Economic Data, 2024)
Inflation	Core Consumer Price Index	CPI_Core	Inflation measure excluding volatile food and energy	(Federal Reserve Economic Data, 2024)
Monetary Policy as interest rate	Federal Funds Effective Rate	DFF	U.S. interest rate set by central bank	(Federal Reserve Economic Data, 2024)
	Shadow Interest Rate	SRI	Virtual interest rate when it is near ZLB	(Wu-Xia, 2024)
Geopolitical Volatility	Geopolitical Risk Historical Index	GPRH	Measures past global political stability trends	(Caldara & Iacoviello, 2024)

The dataset utilized in this project comprises diverse time series with a monthly frequency, spanning the period from January 1974 to December 2023. In comparison to the literature review, this timeframe extends significantly, thereby providing a more comprehensive insight into variability and patterns. From an econometric perspective, this temporal extension suggests lower variability, reducing the risk of biases and enhancing the precision of inferences.

The purpose of this section is to support the inclusion of these factors as determinants in the actual value of gold and to elucidate why the selected data series are suitable for representing them.

GOLD PRICE

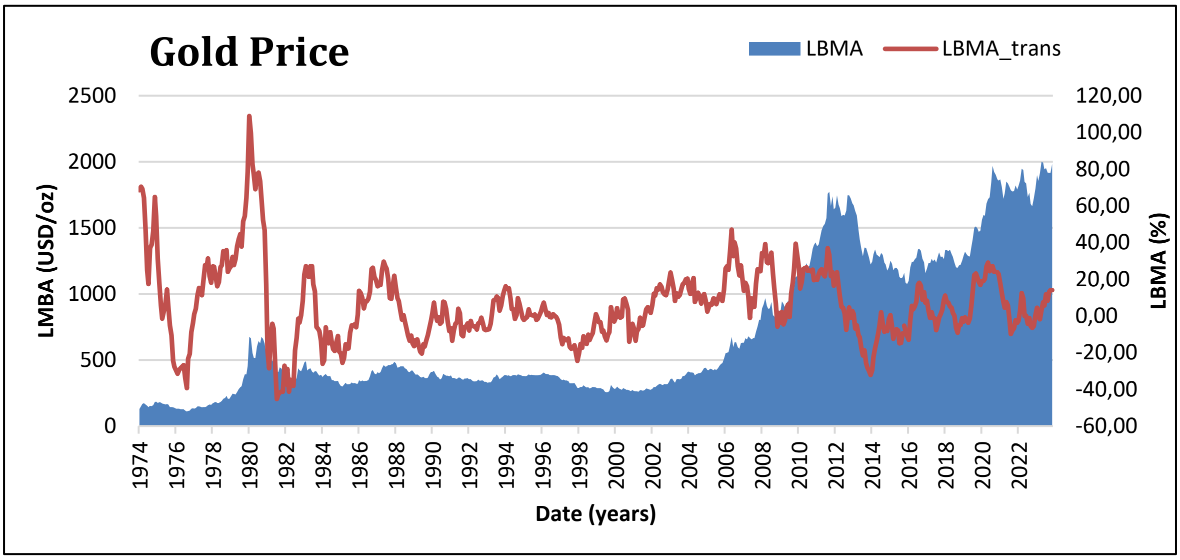

Fig. 2. Comparison between LBMA and LBMA transformed

The valuation of gold is commonly conducted in troy ounces. In this context, there are two predominant alternatives for determining the price of gold: the COMEX (Chicago Mercantile Exchange) and the LBMA (London Bullion Market Association). In this project, the LBMA option has been selected because, while the COMEX relies solely on futures contracts, the LBMA PM Gold Price is based on actual market transactions. This characteristic provides a more accurate representation of the real supply and demand in the gold market at the fixing moment, which is essential for those seeking to model its price accurately.

The LBMA is headquartered in London and stands as one of the oldest and most respected reference markets for precious metals trading. Its long-standing history and international recognition confer substantial credibility within the global financial sphere. The fixing of its gold price index occurs twice daily through an electronic auction involving a diverse range of market participants, including banks, traders, and precious metals manufacturers. It is a transparent and well-established process that contributes to confidence in the integrity of the price.

In **Fig. 2**, the untransformed data series (LBMA) is displayed alongside a transformed version (LBMA_trans) tailored to fit our model. The transformation involves applying **Eq. (2)**, where r_t represents the logarithmic growth rate, V_t the value of the series in the current period, and V_{t-1} is the value of the series in the previous period. In this instance, as annual logarithmic growth was sought, $t = 12$.

$$r_t = \ln\left(\frac{V_t}{V_{t-1}}\right) \qquad \textbf{Eq. (1)}$$

The result of **Eq. (1)** is a percentage variation, which proves highly valuable when anticipating that the growth rate of a variable may not be constant, and there is a desire to more accurately represent percentage changes rather than absolute changes.

DOLLAR PRICE

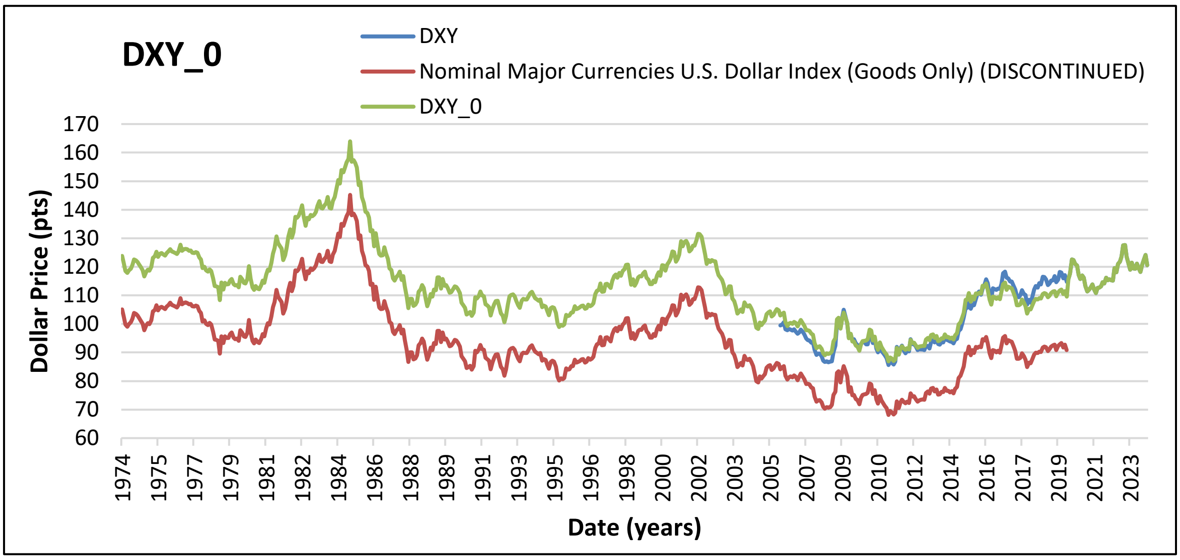

Fig. 3. Comparison between DXY and DXY (Goods Only)

In the majority of the existing models reviewed, there is a consensus that supports the notion that the dollar price is one of the most significant influencing factors on the price of gold. This phenomenon is logical, given that gold is traded in international markets using the dollar as the reference currency.

For this project, the US Dollar Index, DXY, has been chosen instead of the USD/EUR exchange rate used in other studies. This financial index measures the value of the dollar against a weighted basket of other major currencies, providing a much broader perspective on strength or weakness in international markets. As of 2024, the included currencies are the Euro (EUR), Japanese Yen (JPY), British Pound Sterling (GBP), Canadian Dollar (CAD), Swiss Franc (CHF), and Swedish Krona (SEK). The weighting of these currencies within the index is selected based on their importance in international markets and their trade relationship with the United States.

The most logical relationship between the price of gold and the price of the dollar is inverse. This is attributed to the perception of gold as a safe haven during periods of dollar weakness. Additionally, a stronger dollar can make gold more expensive for investors using other currencies, reducing demand (when the dollar appreciates, more currency is needed to exchange for the same amount of gold).

While our study period extends back to 1974, the DXY data retrieved from FRED (Federal Reserve Economic Data) begins in 2006. Therefore, we have utilized a dataset that measures the same but only considers currency exchanges for goods transactions. Both series are depicted in **Fig. 3**. To obtain the final data series (DXY_0) representing the dollar price throughout the entire study period, the DXY (Goods Only) data, incorporated up to 2020 (adjusted by adding the mean difference between the two data series), has been overlaid with the DXY until the end.

Furthermore, due to the nature and scale of the time series, the same transformation as applied to the gold price has been implemented—the logarithmic growth rate from **Eq. (1)**. This approach more accurately captures temporal variations, stabilizes variance, and facilitates interpretation through a comparison of constant changes.

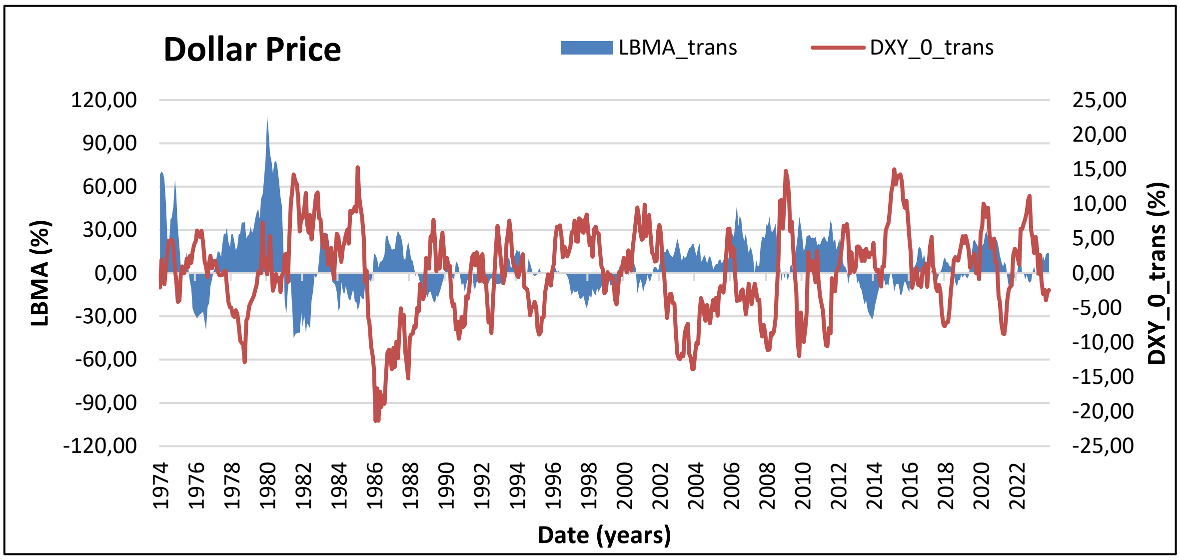

Fig. 4. Comparison between DXY_0_trans and LBMA_trans

OIL PRICE

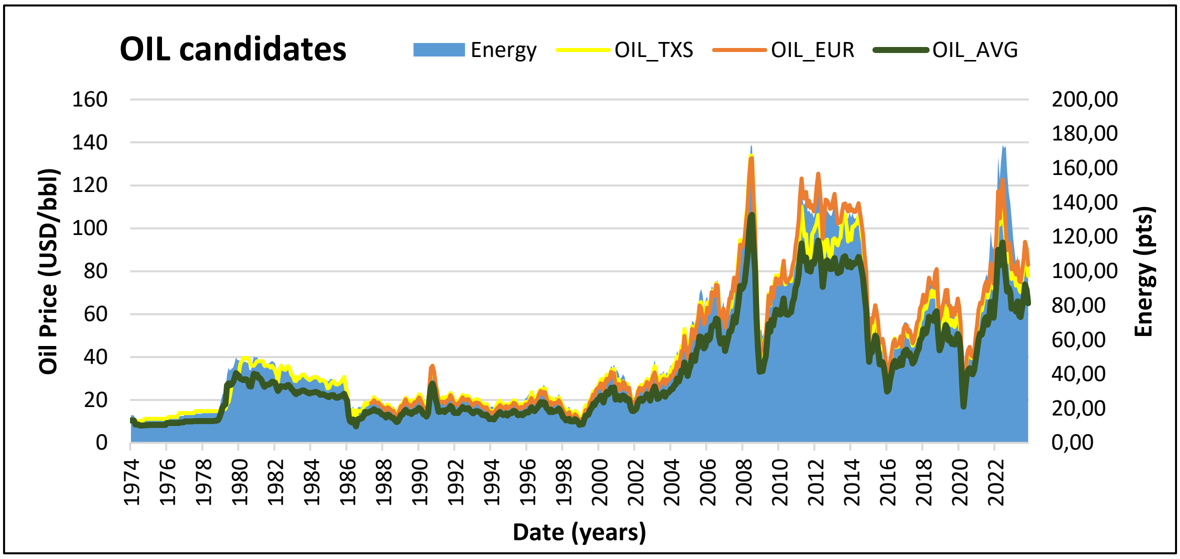

Fig. 5. All oil price data series candidates

The price of gold and the price of oil are interconnected due to various economic and financial factors. Both assets are considered safe havens in times of economic uncertainty, which can lead to a simultaneous increase in their values. They are also seen as protections against inflation and dollar depreciation.

As observed in **Fig. 5** several variables were compared to represent the oil price. The study included the price of a barrel of oil set in Texas and in Europe, even evaluating an energy index. Ultimately, the chosen data series is the average price calculated by the World Bank (World Bank Commodity Markets), OIL_AVG. OIL_AVG. The unit of measurement for oil traded in commodity markets is dollars per barrel of crude oil.

The relationship between gold and oil does not follow a fixed rule; however, throughout history, it has commonly been inverse. In situations of economic uncertainty or geopolitical conflicts, investors tend to seek assets considered safe, such as gold. On the other hand, during periods of greater economic stability and growth, the demand for oil tends to increase, while gold tends to decrease as investors seek more profitable assets.

Similar to the price of gold and the dollar, for the price of oil, due to the nature and scale of the time series, the logarithmic growth rate from **Eq. (1)**. has been applied. This approach more accurately captures temporal variations, stabilizes variance, and facilitates interpretation through a comparison of constant changes.

If we look at **Fig. 6,** where both variables are compared after preparation for model input, we can observe an inverse relationship in general, but a direct one at specific moments such as during the 1970s and the 2000s. This coincides, not coincidentally, with two periods in which crises occurred in the oil sector.

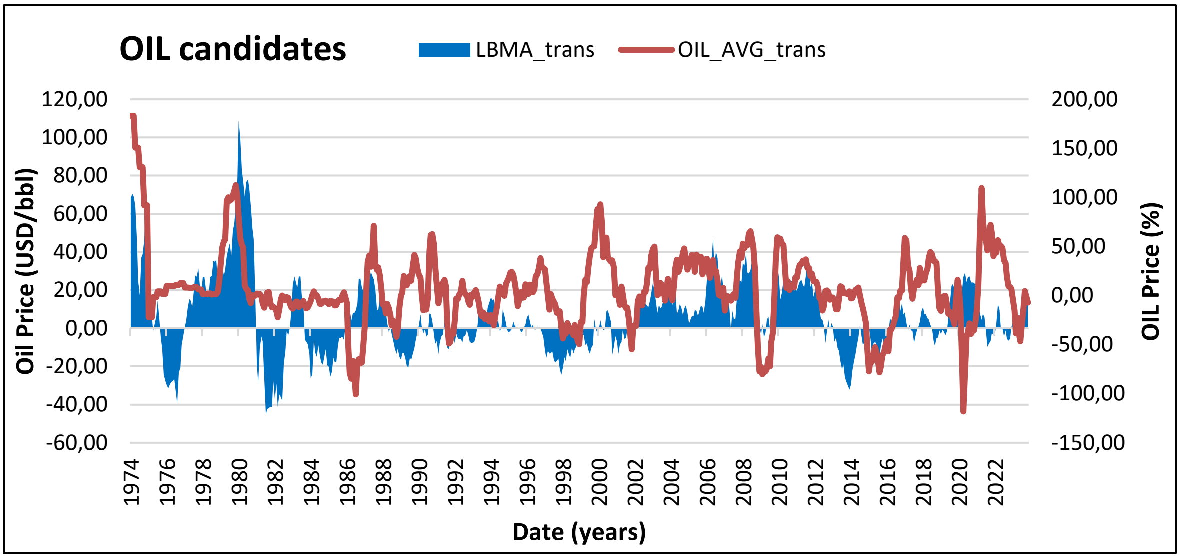

Fig. 6. Comparison between OIL_AVG_trans and LBMA_trans

STOCK MARKET PERFORMANCE

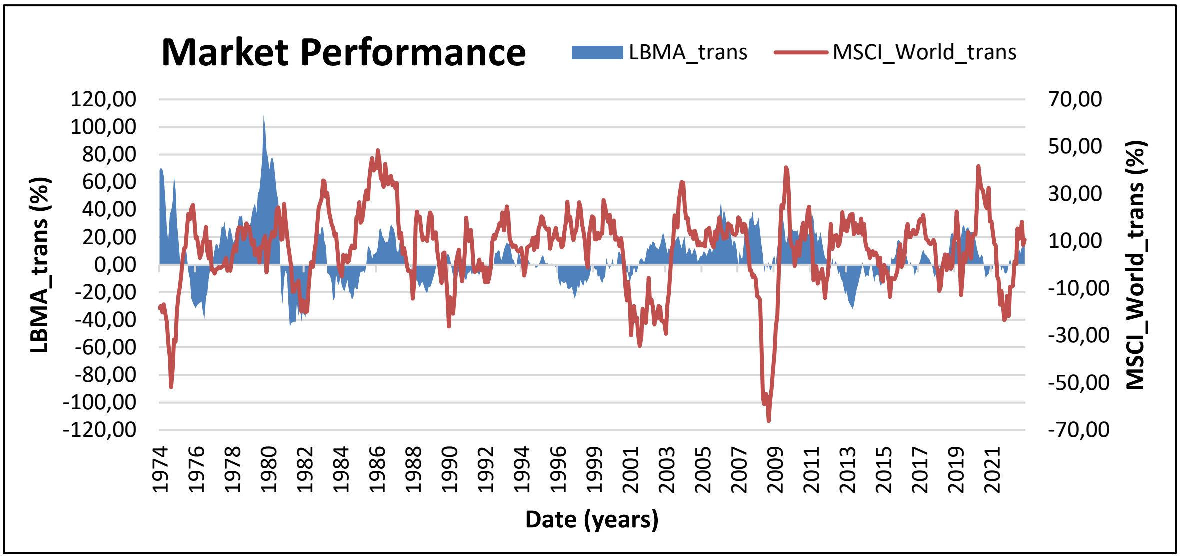

Fig. 7. Comparison between MSCI_World_trans and LBMA_trans

The inclusion of gold in portfolios provides diversification, as its behaviour does not always follow the same trends as other financial assets, thus reducing overall volatility. During market tensions or recessions, gold can exhibit movements opposite to other assets, providing additional balance in portfolios. Clearly, these gold movements in portfolios have consequences, showing a clear relationship with their performance and, therefore, market trends.

In contrast to other options such as the performance of the S&P 500, used in other studies, for this project, the MSCI World Index has been considered as an indicator of portfolio performance. This is a market capitalization-weighted index reflecting the performance of large and mid-cap stocks in developed markets worldwide, offering a global and diversified representation for investors. By spanning multiple countries and sectors, it provides balanced exposure, reducing the risk associated with concentration in specific areas. Its tracking through investment funds makes it easy for investors to seek performance aligned with the global market, making it a valuable tool for evaluating the relative success of investments in an international context—meeting all the requirements sought by our model.

Similar to the price of the dollar, gold, and oil, due to the nature and scale of the MSCI World time series, the logarithmic growth rate from **Eq. (1)** has been applied. This approach more accurately captures temporal variations, stabilizes variance, and facilitates interpretation through a comparison of constant changes.

In **Fig. 7**, the LBMA and the MSCI World are displayed with their corresponding transformations, clearly showing an inverse relationship.

ECONOMIC VOLATILITY

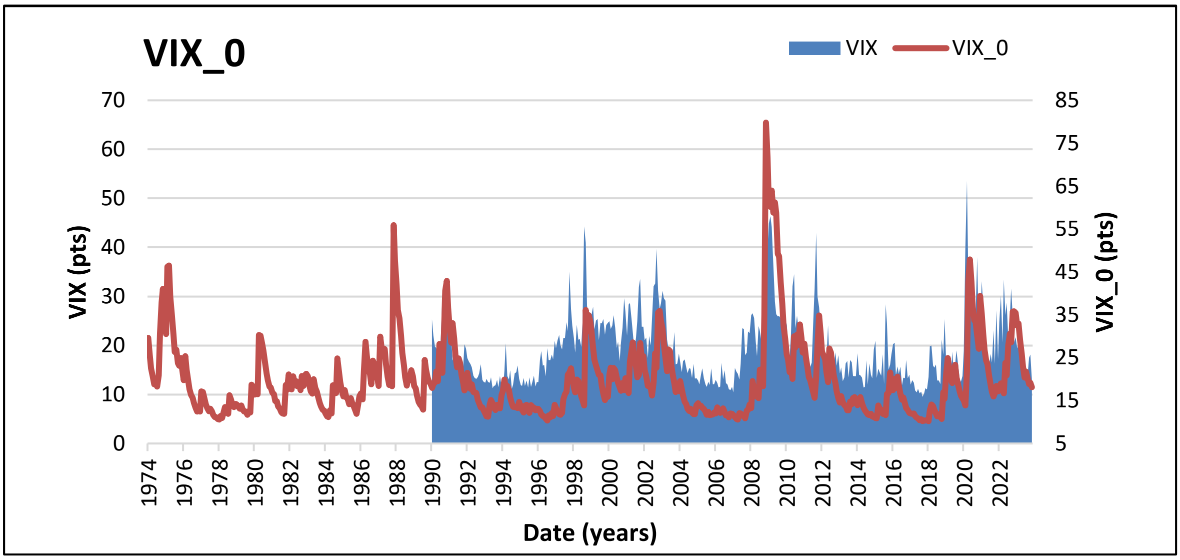

Fig. 8. Comparison between VIX_0 and VIX

The relationship between economic volatility and the price of gold stems from the perception of gold as a safe haven asset in times of uncertainty, as mentioned earlier. When economic volatility increases, whether due to financial crises, geopolitical tensions, or significant changes in monetary policy, investors tend to seek the stability offered by gold.

Initially, and as evident across the literature on gold prices, the widely recognized indicator for representing economic volatility is the VIX. Developed by the Chicago Board Options Exchange (CBOE), the VIX reflects the expected volatility in the U.S. stock market for the next 30 days. Known as the "Fear Index," the VIX is calculated from S&P 500 index options and is used as an indicator of risk perception among investors. A high VIX suggests expectations of increased volatility, indicating potential downward movements in the market, while a low VIX signals anticipation of lower volatility and a more stable market. This inverse indicator is linked to risk management and is considered useful for assessing market sentiment, employed by investors and portfolio managers as part of their market condition analysis.

Attempting to incorporate this variable into our model presents two challenges. Firstly, the index in question has a start date in 1990, limiting its temporal coverage and not spanning the entire study period. Secondly, by focusing on the volatility of U.S. companies, it does not encompass the global representation of all relevant variables for the research, given the global nature of gold in this study. For this reason, a GARCH model (explained in section **0**) was chosen to extract the volatility from the performance of global portfolios (VIX_0), i.e., from the aforementioned MSCI World. This approach achieves a representation of economic volatility that covers both the temporal and geographical aspects. Furthermore, by observing **Fig. 8** where both data series representing economic instability are compared, it is evident that, in the period with available data for both, they align in shape, indicating that the created data series appropriately represents economic volatility.

Through **Fig. 9** the economic volatility calculated by us is compared with the price of gold, illustrating how their relationship evolves throughout history.

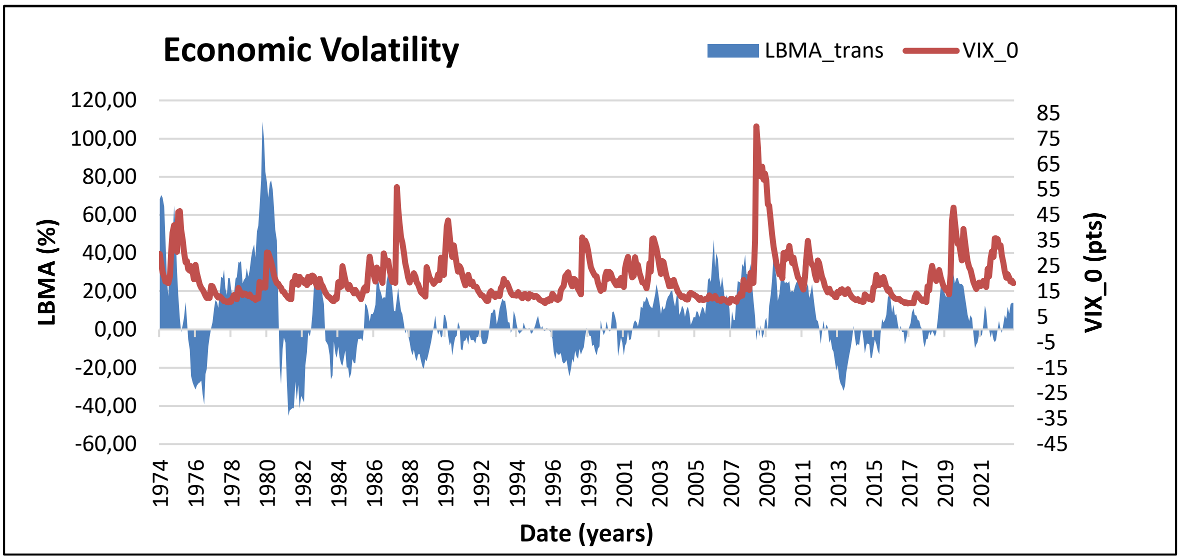

Fig. 9. Comparizon between VIX_0 and LBMA_trans

MARKET SENTIMENT

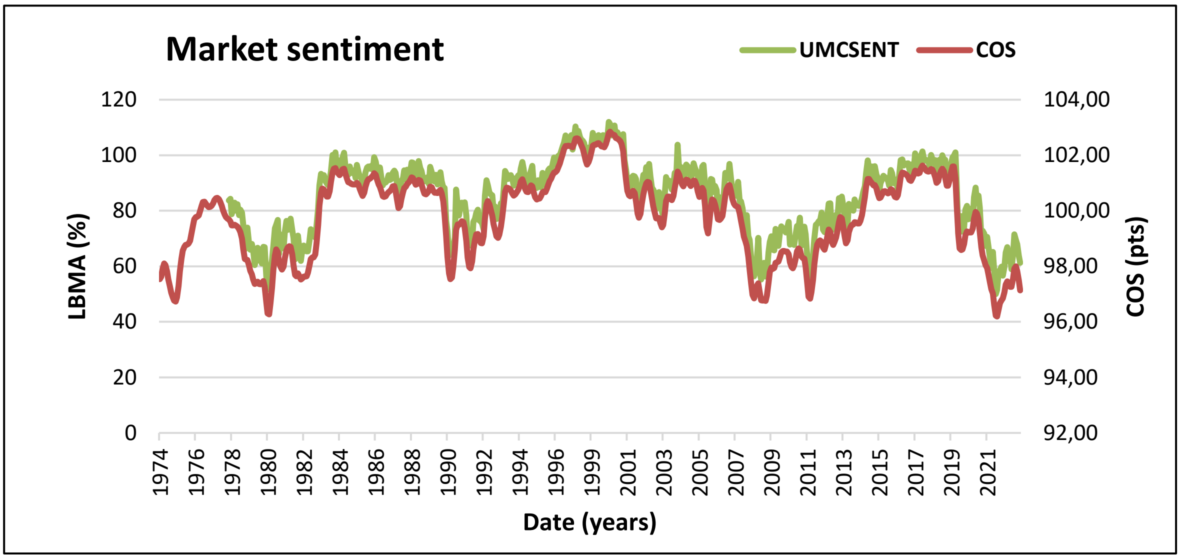

Fig. 10. Comparison between UMCSent and COS

This factor is not quite common in all the reviewed studies, probably due to its potential correlation with other indices such as economic or geopolitical volatility. However, in this study, we believe that even though consumer sentiment is often influenced by these two factors, there may be times when sentiment is negative without volatility appearing in the other two (**Fig. 12**). For this reason, including this factor may enable us to capture movements in the economy that affect the price of gold that other variables in the model may not be able to capture.

To represent this factor, two options were considered: the Consumer Sentiment published by the University of Michigan every month (Consumer Sentiment) or the index derived from the consumer opinion survey conducted by the OECD every month (Consumer Opinion Surveys: Confidence Indicators: Composite Indicators). Because UMCSENT does not go back as far as we can observe in **Fig. 10** the COS was chosen. The COS is an indicator commonly used in the financial world to anticipate turning points in economic activity. It combines several indicators into one that reflects the future direction of economic activity.

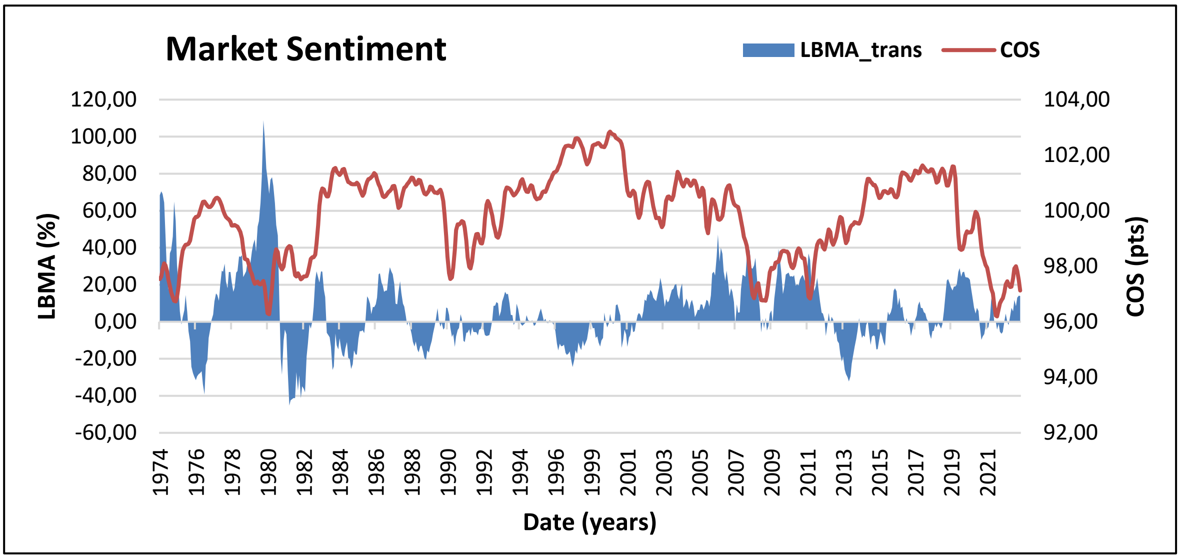

Fig. 12. Comparison between COS and LBMA_trans

INFLATION CORE

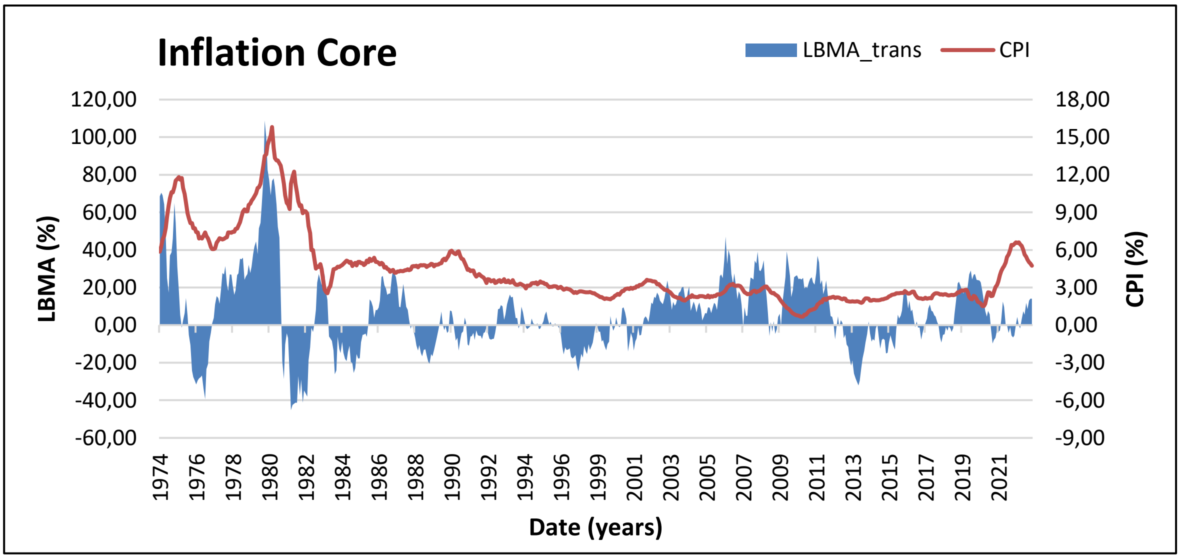

Fig. 11. Comparison between CPI and LBMA_trans

Historically, before the 2000s, gold was commonly recognized as a hedge against inflation. This association made sense as gold, being a physical asset and commodity, tends to maintain a relatively stable monetary value. However, since the early 2000s, possibly due to the increase in commodity prices during that period, the value of gold has experienced a notable increase and has lost some of its link to inflation **Fig. 11**. Despite this, the discussion on this topic remains complex, and many investors continue to use gold as a means to preserve their purchasing power over time.

The study conducted by Erb and Harvey (2013) delves into the possible correlation between gold and inflation, offering several notable conclusions. In stable economic conditions, gold does not seem to be an effective short-term hedge against inflation, as its movements in such situations are mainly influenced by immediate economic factors. However, in the long term, these dynamics could prove more effective. It is crucial to highlight that this "long term" extends beyond the typical investment horizon of individual investors, often spanning decades or even a century.

When choosing the data series that best represents inflation, two options were considered: the Consumer Price Index (CPI) overall and the Core CPI. The difference between these indicators lies in the components included in their calculations. While the overall CPI reflects price changes that incorporate all components within the basket of goods and services, the Core CPI excludes food and energy. This exclusion is due to the higher volatility of these two components, making them more susceptible to temporary variations influenced by external factors such as weather conditions, geopolitical events, and other fluctuations. The Core CPI provides a more stable and underlying measure of long-term inflationary trends.

This work specifically aims to discover whether the effect of inflation on the price of gold changes depending on whether we are in an expansion or a recession. The inflation we have used has also been subjected to the formulas of the logarithmic growth rate from **Eq. (1)**. This approach captures temporal variations more accurately, stabilizes variance, and facilitates interpretation through a comparison of constant changes.

MONETARY POLICY AS INTEREST RATE

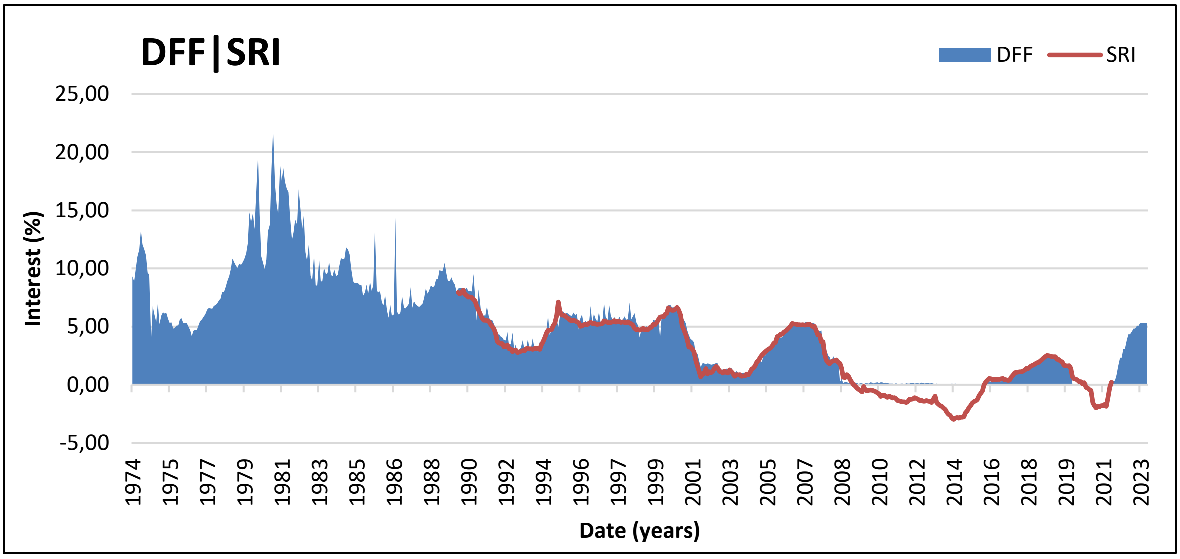

Fig. 13. Comparison between DFF and SRI

The most effective way to represent the monetary policy implemented by central banks worldwide is through interest rates—a parameter they control to increase or decrease the amount of currency freely moving in markets. While some research resorts to the M2 money supply, it does not have a direct impact on investors' credit costs, which they can use to purchase and increase demand for gold.

The federal funds rate, representing the interest at which banks in the United States lend money to each other in the short term, plays a crucial role as a tool used by the Federal Reserve to influence monetary conditions and its macroeconomic objectives. However, a challenge arises when the Federal Reserve seeks to stimulate spending and investment to boost economic growth. In situations where the federal funds rate approaches the zero lower bound (ZLB), the Federal Reserve turns to unconventional measures, such as massive asset purchases known as quantitative easing. This strategy involves acquiring financial assets, such as government bonds and mortgage-backed securities, with the aim of increasing the money supply and reducing long-term interest rates. While this tactic can stimulate the economy, it has sparked debates about its long-term effects, including concerns about the formation of asset bubbles and the uneven distribution of economic benefits. These extraordinary policies, implemented during periods of extremely low interest rates, affect the effectiveness of the federal funds rate in accurately reflecting monetary policy.

On the other hand, the Shadow Rate has gained importance in econometric and statistical modelling. Operating as a hypothetical interest rate, the Shadow Rate is meticulously constructed to mimic the dynamics of effective monetary policy, especially when official interest rates are at the Zero Lower Bound, unable to fully capture the impact of unconventional monetary measures.

In **Fig. 13** both are depicted throughout history, showing their alignment until interest rates reach zero. Additionally, the SRI does not cover the entire study period, so it was decided to use the DFF for the moments when the SRI lacks data. If we observe, during those moments, interest rates are positive, so we extrapolate what the SRI would have been, solving all our problems. The new data series is called DFF|SRI.

Looking at **Fig. 14**, we can see how the relationship between interest rates and gold changes over time, suggesting that there may be significant distinctions depending on the phase of the economic cycle.

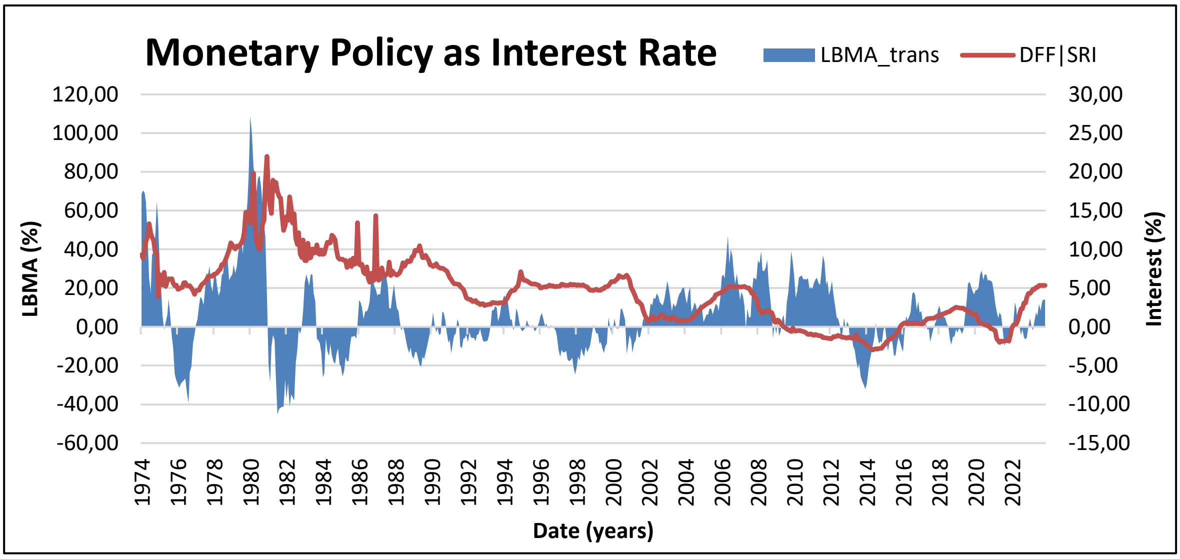

Fig. 14. Comparison between DFF|SRI and LBMA_trans

GEOPOLITICAL VOLATILITY

Geopolitical tensions typically increase demand as a result of investors seeking safe-haven assets. As explained in **Section** Impulse Response Functions (IRFs), the order in which we introduce variables is not arbitrary. It is necessary to include this factor, whether or not it is significant in the model, to capture all geopolitical events that may have involvement in other variables such as interest rates, inflation, economic volatility, etc. This way, the rest of the variables will be related to gold in the model due to their own causes. An example would be a war affecting economic volatility; in this case, the model would find the relationship with geopolitical volatility and not economic volatility, even though the latter may have undergone changes in that period.

The Geopolitical Risk Index (GPR) will be used to represent this factor, following the suggestion of Triki and Maatoug (2021). This index (Caldara & Iacoviello, 2022) assesses the probability that political, social, or geopolitical factors impact the business environment. Since the GPR does not cover the entire study period, the Geopolitical Risk Index Historic (GPRH) has been used instead, which is an adaptation of this index that goes further back in time. Through **Fig. 15** we can see its development in relation to gold throughout history.

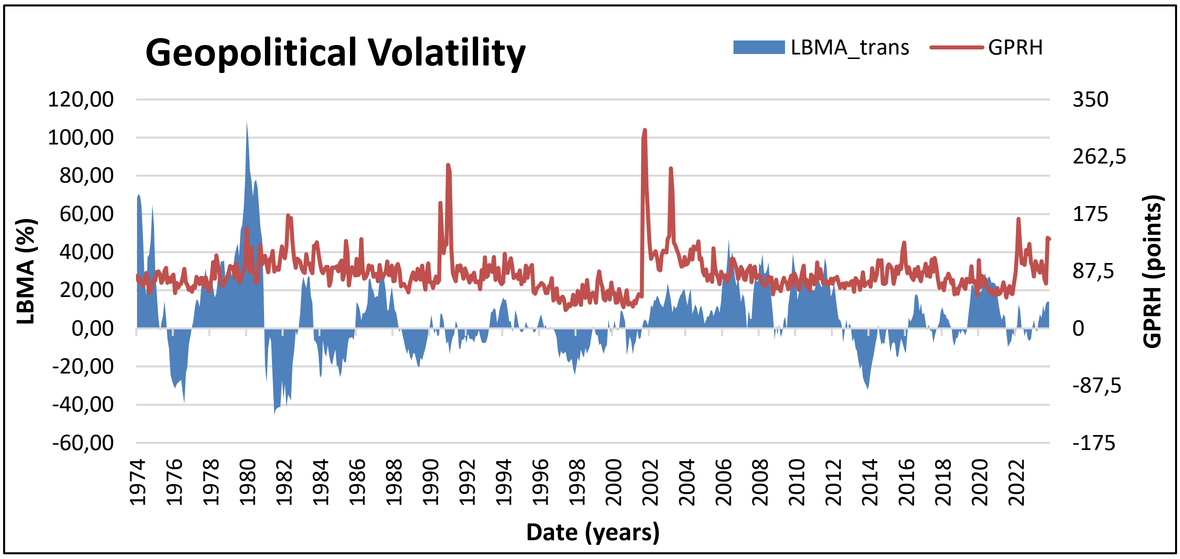

Fig. 15. Comparison between GPRH and LBMA_trans

METHODOLOGY[1]

VAR MODEL

The model used as the foundation for this project is a Vector Autoregressive (VAR) model, widely employed in time series analysis to study the relationship between various variables evolving over time. A VAR involves a system of multiple regression equations in which each variable depends on its own past values (lags) and the past values of other variables (Kilian & Lütkepohl, 2016).

The system of equations for a Vector Autoregressive model is represented as shown in **Eq. (2)**.

$$y_{it} = a_{0i} + \sum_{j=1}^{K} \sum_{l=1}^{L} a_{ij,l} y_{j,t-l} + \mu_{it}, \forall i \in \mathbb{N}, 1 \leq i \leq K \qquad \textbf{Eq. (2)}$$

Where K is the number of variables, and hence the number of equations, and L is the number of lags.

The system of equations in matrix form is represented as shown in **Eq. (3)**.

$$Y_t = A_0 + \sum_{l=1}^{L} A_l Y_{t-l} + \mu_t \qquad \textbf{Eq. (3)}$$

Where: $Y_t \equiv \begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Kt} \end{pmatrix}; A_0 \equiv \begin{pmatrix} A_{01} \\ A_{02} \\ \vdots \\ A_{03} \end{pmatrix}; A_l \equiv \begin{pmatrix} a_{11,l} & a_{12,l} & \cdots & a_{1K,l} \\ a_{21,l} & a_{22,l} & \cdots & a_{2K,l} \\ \vdots & \vdots & \ddots & \vdots \\ a_{K1,l} & a_{K2,l} & \cdots & a_{KK,l} \end{pmatrix}; \mu_t \equiv \begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_K \end{pmatrix}$

In other words, Y_t represents the column vector of all variables in the model, A_0 is the mean parameters, A_l is the coefficient matrix at lag l, and μ_t is the column vector of errors, also known as the linearly unpredictable component of Y_t.

[1] The explanation of the model before introducing the Markov-Switching dynamic regime is based on the work by García and Díaz (2023).

IMPULSE RESPONSE FUNCTIONS (IRFS)

The model can also be represented in a structural way, such as in **Eq. (4)**.

$$B_0 Y_t = \sum_{l=1}^{L} B_l Y_{t-l} + \omega_t \qquad \textbf{Eq. (4)}$$

Where: $A_l \equiv B_0^{-1} B_i$, $\mu_t \equiv B_0^{-1} \omega_t$. In other words, B_0^{-1} is the matrix of instantaneous response, and w_t is the column vector of shocks corresponding to each variable.

This way, we can organize the variables in such a manner that it can be asserted that the error derived from a variable depends solely on the impacts generated within it and the variables that precede it, without being affected by those that follow it. This arrangement is commonly referred to as the decreasing order of exogeneity and shapes the B_0^{-1} matrix as a triangular matrix. This can be observed in **Eq. (5)**.

$$\mu_t \equiv \begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_K \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 \\ b_{21} & b_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ b_{K1} & b_{K2} & \cdots & b_{KK} \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_K \end{pmatrix} \qquad \textbf{Eq. (5)}$$

Based on these assumptions, if we introduce a shock equivalent to one standard deviation in a specific variable, we can subsequently estimate the Impulse Response Function (IRF) by applying the Cholesky decomposition of the variance-covariance matrix of the errors. Then, the error is estimated for the Impulse Response Functions as shown in **Eq. (6)**.

$$\mu_t \equiv \begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_i \\ \vdots \\ \mu_K \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 & \cdots & 0 \\ b_{21} & b_{22} & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{i1} & b_{i2} & \cdots & b_{ii} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{K1} & b_{K2} & \cdots & b_{Ki} & \cdots & b_{KK} \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_i \\ \vdots \\ \omega_K \end{pmatrix} \equiv \begin{matrix} \mu_1 = b_{11} w_1 \\ \mu_2 = b_{21} w_1 + b_{22} w_2 \\ \vdots \\ \mu_i = \sum_{j=1}^{i} b_{ji} \omega_j \\ \vdots \\ \mu_K = \sum_{j=1}^{K} b_{ji} \omega_j \end{matrix} \qquad \textbf{Eq. (6)}$$

It is at this point that one realizes that the error of each variable in the Impulse Response Function is affected by the variable itself and those that precede it. By doing so, we can discard from the error of the function whose impulse is variable i all the error contributed by the variables that precede it. This ensures the independence of the previous variables in the instantaneous response matrix. Therefore, it is imperative to organize the variables in decreasing order of exogeneity to justify the zeros within this matrix. Failing to do so would compromise the functionality of the model.

IMPULSE RESPONSE FUNCTIONS (IRFS) INTERPRETATION

Understanding how an Impulse Response Function (IRF) is calculated, it is interesting to explore its application as a key tool for analysing complex interactions between variables in a time series model, such as VAR. These functions prove particularly powerful in assessing the consequences of economic policies or unexpected events on a set of interconnected variables, facilitating the identification of cause-and-effect relationships, propagation effects, and feedback mechanisms.

In this context, the concept of an 'impulse' comes to life as an external disturbance, like a sudden change in a variable, equivalent to a standard deviation in the corresponding data series. A practical example would be a rapid increase in interest rates triggered by a change in monetary policy. The 'response' refers to the behaviour of another specific variable (or even the same variable) over time. Taking the above example, we might observe a subsequent decrease in inflation a few months after this impact on monetary policy.

The process of estimating IRFs begins with the statistical representation of how variables interact over time through the estimation of model coefficients. Then, the impact of an impulse on one variable is simulated, keeping all others constant, to observe the evolution of the system over multiple periods. In this matrix, each column represents the response of an endogenous variable to each of the shocks (rows). In each IRF, the horizontal axis denotes periods after the impulse, while the vertical axis indicates the magnitude of the response. It is essential to note that the horizontal axis is not restricted to the influence period, i.e., the L lags, but can extend as needed, depending on what is being investigated.

In our project, we have enriched each IRF with contour plots. These curves surround the estimated response and represent a 95% confidence interval, indicating where we could expect the real response to a similar disturbance based on our historical data or sample. This feature becomes particularly relevant by providing information about the strength of relationships between variables. If, after the impulse, the zero value falls within the contours, we cannot confidently assert that any significant change in the endogenous variable has occurred with a 95% confidence.

MARKOV-SWITCHING[2]

Hamilton (1996) introduces the Markov regime-switching method. His research suggests that economic systems under different mechanical states exhibit diverse characteristics, which are reflected in the model parameters. The relationship between variables may change due to economic impacts. In this context, Krolzig (1997) merges the vector autoregressive

[2] The incorporation of the Markov-Switching regime into a VAR model is based on the work conducted by Gong et al. (2021) similar to this study but focused on oil prices.

model with the Markov regime-switching to obtain the Markov-switching VAR model. This assumes that the parameters vary with the transition of the regional economic system, allowing for a more effective capture of the nonlinear dynamic characteristics of macroeconomic variables.

Despite the inherent limitation of predefining the number of regimes, empirical studies adopting the regime-switching approach significantly overcome several potential shortcomings (Cheng, Gao, & Yan, 2018). First, it addresses the theoretical foundation related to economic principles involving multiple equilibriums and nonlinearities in financial market interactions. Second, it takes into account various characteristics of time series related to the price of gold, such as non-normality, fat tails, time-varying volatility, and heteroskedasticity. Third, it is noteworthy that this model does not require the prior decomposition of sample data into periods of high and low fluctuation; on the contrary, economic cycles are determined endogenously. This feature provides greater flexibility and adaptability to the model, avoiding the rigidity associated with the anticipated segmentation of data. Finally, it is worth highlighting that the approach explicitly allows for measuring the probability associated with each regime, enabling precise calculation of the transition probability between different economic cycles and estimation of the duration of regime changes. This aspect provides a valuable analytical tool for understanding and anticipating economic dynamics in an environment characterized by variability and complexity.

Given that this article focuses on analysing driving factors under different economic cycles, the MS-VAR model provides an effective tool to endogenously define different economic states during the sample period.

Suppose there are $M = 2$ regimes in the Markov-switching VAR model ($s_t \in \{1, \cdots, M\}$), $y_t = y_{t1}, \cdots, y_{tk}$, $t = 1, \cdots, T$, for the autoregression of order L of a KK-dimensional time series vector, the expression in its constant term evolution from **Eq. (3)**, is **Eq. (7)**.

$$Y_t = A_0(s_t) + \sum_{l=1}^{L} A_l(s_t) Y_{t-l} + \mu_t \qquad \textbf{Eq. (7)}$$

where: $\mu_t \sim NID[0, \sum s_t]$

The expression, therefore, of the mean shift is that of **Eq. (8)**.

$$Y_t - A_0(s_t) = \sum_{l=1}^{L} A_l(s_t)\big(Y_{t-l} - A_0(s_{t-l})\big) + C(s_t) z_t + \mu_t \qquad \textbf{Eq. (8)}$$

Where $A_0(s_{t-l})$ are the mean parameters related to the state variable. The probability of transitioning from one regime to another is: $P_{ij} = P_r(\, s_{t+1} = j \mid s_t = i\,), \sum_{j=1}^{M} P_{ij} = 1\,, \forall i, j \in \{1, \cdots, M\}$. Therefore, the probability matrix can be written as shown in **Eq. (9)**

$$P = \begin{pmatrix} P_{11} & \cdots & P_{1M} \\ \vdots & \ddots & \vdots \\ P_{M1} & \cdots & P_{MM} \end{pmatrix} \qquad \textbf{Eq. (9)}$$

Where: $\forall i \in (1, \cdots, M), P_{i1} + P_{i2} + \cdots + P_{iM} = 1.$

The Markov-switching VAR model does not assume that all parameters are related to the regime variables in practical applications. For simplicity, specific parameter configurations are often associated with regime variables. For example, different Markov-switching VAR models can be obtained when the mean, intercept, coefficient, and variance of the equation vary with the regime variable s_t.

Maximizing the likelihood function of the Markov-switching VAR model requires an iterative estimation method to obtain autoregressive parameters and control the estimated value of the transition probability of the unobservable state of the Markov chain. Let's denote the parameter vector as λ, which satisfies the likelihood function for a given observation. For a specific estimation, we can use the Expectation-Maximization (EM) algorithm. Each iteration of the EM algorithm consists of two steps: the first is the expectation process, which includes filtering and smoothing, using the last step's estimation from the maximization process to obtain the parameter vector instead of the unknown true parameter vector. The second step is the maximization process, estimating the parameter value and then replacing the conditional probability.

GARCH[3]

To characterize economic volatility, following previous research such as Caporale et al. (2015), Aye et al. (2014), Elyasani et al. (2011) and Chen and Hsu (2012), the application of a univariate GARCH (1,1) model to the MSCI World Index has been considered. The key in applying this model to this index is that by estimating the change from one period to another in market returns, it yields a normal distribution with a non-constant variance, considered as changing volatility. This becomes our new data series representing economic volatility. The equations of a GARCH (1,1) model applied to the MSCI are shown in **Eq. (9).**

$$\begin{gathered} MSCI_t = MSCI_{t-1} + u_t \\ u_t | MSCI_1, \cdots, MSCI_{t-1} \sim N(0, h_t) \\ h_t = \gamma_0 + \gamma_1 u_{t-1}^2 + \gamma_2 h_{t-1} \end{gathered} \qquad \textbf{Eq. (10)}$$

[3] The inclusion of the GARCH model in the study to calculate global economic volatility is based on the work conducted by Diaz, Molero, and Gracia (2016) similar to this study but focused on the volatility of oil prices.

Where: $MSCI_t$ represents the market performance in period t and u_t denotes the change in market performance in each period, following a normal distribution with mean zero and variable volatility h_t. In this formulation, the parameter γ_0 reflects the long-term average variance rate of market performance. On the other hand, γ_1 is interpreted as a parameter quantifying the sensitivity of oil price volatility. **Eq. (9)** establishes that γ_0 is a real number, $\gamma_1 \geq 0$, $\gamma_2 \geq 0$ y $\gamma_1 + \gamma_2 < 1$, thus ensuring covariance stationarity in the GARCH model. The estimation of the time series of conditional volatility of market performance for each specification is conducted through the maximum likelihood method.

Chapter 4. EMPIRICAL ANALYSIS

In the context of this project, a VAR model will first be constructed to assess its influence on gold in a static manner throughout the entire study period. The results of the IRFs and a historical decomposition will be analysed. Subsequently, the dynamic model (VAR with Markov Switching regime) will be run, and the IRFs will be compared with those of the static model and the historical decomposition.

VAR

The model contains 9 variables introduced in the following order: geopolitical volatility, represented by the Geopolitical Risk Index Historic (GPRH); monetary policy through interest, represented by a concatenation of the Federal Funds Rate and the Shadow Rate of Interest (SRI); core inflation represented by the Consumer Price Index (CPI) Core; market sentiment, represented by the Consumer Opinion Survey (COS); economic volatility, represented by an adaptation of the Volatility Index (VIX) through a GARCH model for the MSCI World (VIX_0); portfolio performance, represented by the MSCI (Morgan Stanley Capital International) World Index; oil price, represented by the average price in many countries (OIL_AVG); dollar price represented by the U.S. Dollar Index (DXY); and gold price, represented by the LBMA (London Bullion Market Association) Gold Price.

The sequence in which factors affecting gold prices are introduced into the model is not arbitrary. The noise generated in the gold response to the impulse in variable i has had the noise contributed by variable j discarded, which was introduced earlier ($i > j$). This sequence follows an order in which the initial variables are considered more independent of disturbances from later variables, as explained in **Chapter 0**. From another perspective, this order finds its rationale in that if a variable is unable to explain the movement that gold has had at a given moment, the later variables may still be able to explain it. Hence, the following assumptions have been made[4]:

- The gold price and oil price are the variables that will be most capable of capturing movements in the gold price. After all, oil functions as a reflection in its price as a commodity with financial speculative incentives. Additionally, the dollar has the strongest relationship with gold, as it is the currency with which gold is purchased.
- Geopolitical factors are expected to exert the most significant influence on the other variables. In the face of any conflict, all macroeconomic or financial variables

[4] These assumptions aim to clarify the sequence in which variables are introduced to the model. The chosen order has been validated through robustness checks exploring various alternatives. The findings affirm that this specific arrangement holds the most significance in influencing the gold price. Robustness checks have been omitted for the sake of prioritization and avoiding redundancy.

experience instability due to uncertainty about the altercation. Therefore, geopolitical factors are positioned as the first.

- Macroeconomic factors such as monetary policy and inflation precede financial factors such as COS, VIX, and MSCI World because they act as barometers of economic health, shaping expectations and investor behavior.

As parameters defining the VAR model in **Eq. (2)**, $K = 9$, has been introduced, as it is the number of variables included in it, and $L = 12$, as it is a dataset with monthly frequency, and we want the influence period between the data series to be one year.

The response of the gold price over the next 20 months to an impulse equal to one standard deviation of the different factors studied, according to the data from our sample (January 1974 to November 2023) and our VAR model ($L = 12$), is shown in **Fig. 16**. The standard deviations of the model residuals according to the variables' introduction order are presented in **Code 1**. In addition to the response, the 95% confidence interval limits of the gold response are displayed. The nuanced conclusions for each of the represented IRFs are as follows:

- Geopolitical Volatility: An impulse of 17.80 points in GPR does not cause any significant change in the gold price over the next 20 months. Although not significant, it plays a special role in the model as the first introduced variable, capturing all events affecting gold prices that could also be affecting other variables, reducing their significance in their IRFs.

- Monetary Policy: An impulse of 0.72% in interest does generate significant changes in the gold price. Specifically, during the same instant it occurs and in the second month, it causes a decrease of at least 0.25% in LBMA Gold Price. Its inverse relationship may be justified by the fact that when central banks raise interest rates, the cost of borrowing increases, leading investors to abandon high-yield assets for assets that diversify their portfolio and reduce risk, increasing gold demand and hence its price.

- Inflation: An impulse of a year-on-year increase of 6.07% in inflation does generate significant changes in the gold price. Specifically, in the third month, it causes an increase of at least 0.56% in the gold price. Its positive relationship may be justified by the widespread belief that gold is a good store of value. When investors see inflation increasing, they demand more gold, increasing its price.

- Market Sentiment: An impulse of 0.09 points in COS does generate significant changes in the gold price. Specifically, over the entire study period of 20 months, reaching its peak in the 7th month, it decreases the gold price by at least 5.06%. Its inverse relationship may be justified by the fact that when the average consumer sentiment is positive towards the market, there is a greater willingness to take risks and invest in assets with higher returns than gold, decreasing its demand and hence its price.

- Economic Volatility: An impulse of 3.26 points in VIX does not cause any significant change in the gold price over the next 20 months. This may be because the relationship between LBMA and economic volatility depends on whether we are in a recession or a growth stage. Therefore, although not significant in the static model, we do not consider its removal from the model, as it may be significant in the dynamic model.

- Portfolio Performance: An impulse of a year-on-year increase of 4.90% in market performance does generate significant changes in the gold price. Specifically, in the fourth month, it causes an increase of at least 2.12% in the gold price. Its positive relationship is surprising, as it is expected that the demand for assets when the market is not bullish will move towards safer metals such as gold. This is probably due to the fact that this interrelation only occurs in the short term, as seen in the figure, where the gold response eventually becomes negative.
- Oil Price: An impulse of a year-on-year increase of 10.42% in oil prices does generate significant changes in the gold price. Specifically, during the first 11 months with real significance in the first 3 and the 11th month, it causes an increase of at least 0.96% in the gold price. Both are commodities used as safe-haven assets during periods of instability, so they will follow the same trend. This makes it a very good addition to the model, as if none of the variables can capture the movement of gold, oil prices may capture it. This is why it has been added as the penultimate variable.
- Dollar Price: An impulse of a year-on-year increase of 2.04% in the dollar price does generate significant changes in the gold price. Specifically, during the first 4 months, with its peak significance in the first month, it causes a decrease of at least 4.90% in the gold price. This is because precious metals are quoted in the same currency, and a stronger dollar can make gold relatively more expensive for investors using other currencies.

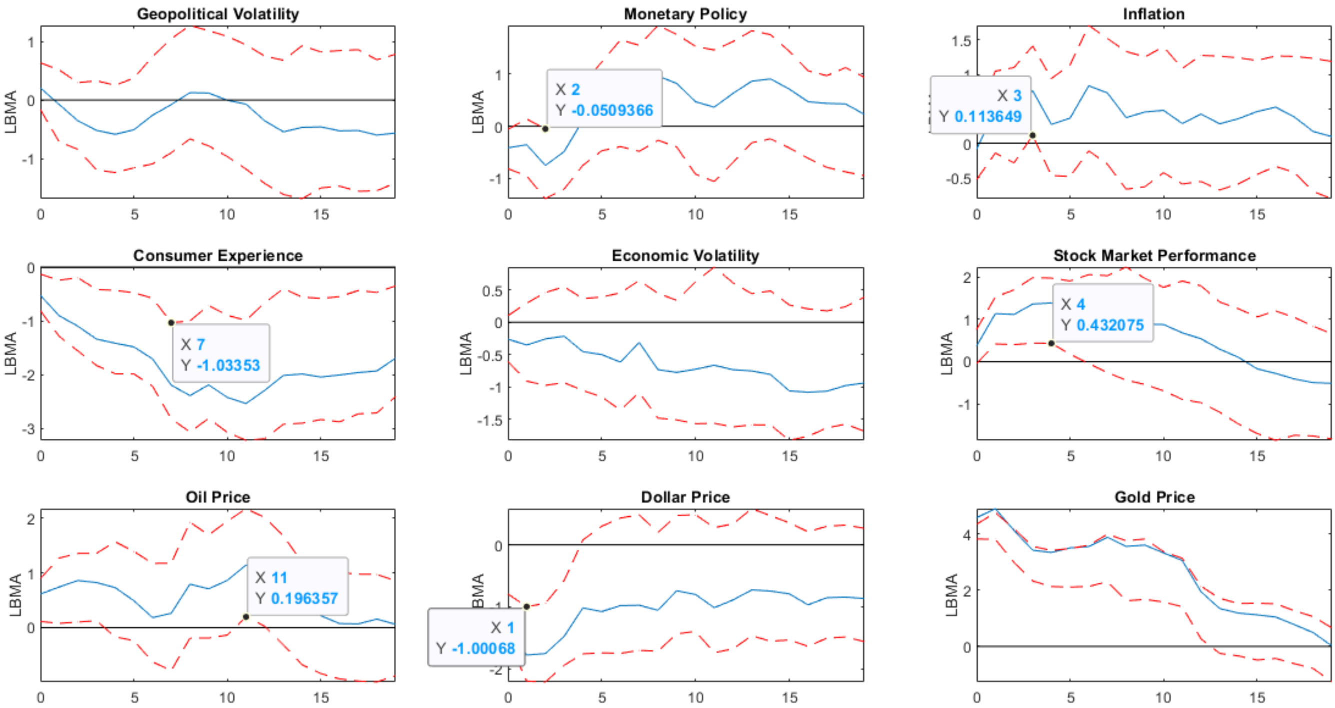

Fig. 16. IRFs VAR Model

```
>> std=sqrt(diag(EstMdl.Covariance))'

std =

  17.7956    0.7242    6.0656    0.0949    3.2634    4.9010   10.4242    2.0388    4.8951
```

Code 1. Standard Deviation VAR Model

The historical decomposition of the gold price in relation to the other factors is illustrated in **Fig. 17**. As observed, the majority of gold price movements are explained by at least one of the introduced factors. Furthermore, when compared to **Fig. 1**, corresponding to the historical decomposition of another study using the same VAR but with different variables, it can be asserted that the model in this present work is much more accurate. The analysis for each period is as follows:

- 1974-1984: If we focus on **Fig. 2** the gold price before 1980 experiences a considerable increase. This is likely due to a combination of macroeconomic and geopolitical factors. Events such as the Soviet invasion of Afghanistan and the Iran hostage crisis generated uncertainty, leading investors to seek safe assets like gold. Other factors, such as increasing inflation and the devaluation of the dollar against other currencies, may also have played a significant role. The return to normalcy of these factors explains the reversion of the gold price to its previous equilibrium by 1984.

- 1984-1992: The easing of tensions between East and West could have reduced the demand for gold as a safe haven, contributing to some stability or price decrease. However, events like the 1987 financial crisis or the 1990 recession had the opposite effect. The dollar strengthened, negatively impacting gold, only to weaken later. Interest rates dropped, and inflationary pressures increased. In summary, the evolution of the gold price during these years can be largely explained by the introduced data series, but through a complex interaction in which the situation of gold, though relatively stable, was highly dynamic.
- 1992-1996: During this period, gold remained relatively stable. The early 1990s were characterized by economic stability and some growth due to the end of the Cold War, although uncertainties stemming from revolutions in Eastern Europe and the Gulf War persisted.
- 1996-2001: In this period, gold experienced a decline compared to its behaviour in the previous decades. This phenomenon is attributed to the rise of the Internet and the exponential growth of technology companies, leading investors to shift from gold to dot-com companies. This change is reflected in the historical decomposition primarily by consumer sentiment. However, many of these companies lacked sustainable profitability and were overvalued, resulting in the burst of the dot-com bubble at the end of the century, revaluing gold once again.
- 2001-2005: In 2001, after the events of September 11, the world experienced significant instability, driving up the price of gold. Geopolitical volatility, reflected in the GPR, captured this event, affecting other variables. In 2003, despite relative calm, the GPR indicated a slight uptick, possibly related to the invasion of Iraq. Between 2003 and 2005, economic growth slowed but continued its course.
- 2005-2013: During this period, gold underwent significant changes. Between 2005 and 2008, a shift in the upward trend of gold was observed, slowing down prior to the 2008 crisis. Our historical decomposition only identifies relevance in portfolio performance during this period. Subsequently, from 2008 to 2013, with the onset of the housing crisis, our variables, including the initial price of the dollar and later monetary policy, economic instability, portfolio returns, and consumer expectations, prominently explain the behaviour of the gold price.
- 2013-2020: During the period from 2013 to 2016, after a crisis, economic recovery is evident, reflected in a decrease in the price of gold. Although the model does not provide a complete explanation for the abrupt fall in 2013, it can be interpreted as a possible bubble during the crisis, where investors sought refuge in gold for stability. From 2016, the model begins to explain gold movements, especially in relation to the price of oil caused by OPEC's (Organization of the Petroleum Exporting Countries) attempts to coordinate oil production reductions to balance excess supply in the global market. The subsequent stage, from 2016 to 2020, is characterized as a

transition phase, also reflected in the behaviour of LBMA Gold, returning to its upward trend.

- 2020-2024: This stage is distinguished by high volatility in all aspects. The COVID-19 pandemic created significant uncertainty in the markets. This was followed by government stimulus policies, the shutdown of many businesses, the digitization of many others, bottlenecks in international distribution networks lasting for years, and escalating conflicts worldwide, such as the war between Russia and Ukraine or the more recent one between Israel and the Gaza Strip controlled by Hamas. Despite this instability, gold has not experienced a strong appreciation. This research suggests several reasons, such as gold losing its role as a safe haven in periods of extreme instability and behaving like other commodities. However, our model finds the answer in the significant strengthening of the dollar, which has thwarted gold's potential rise.

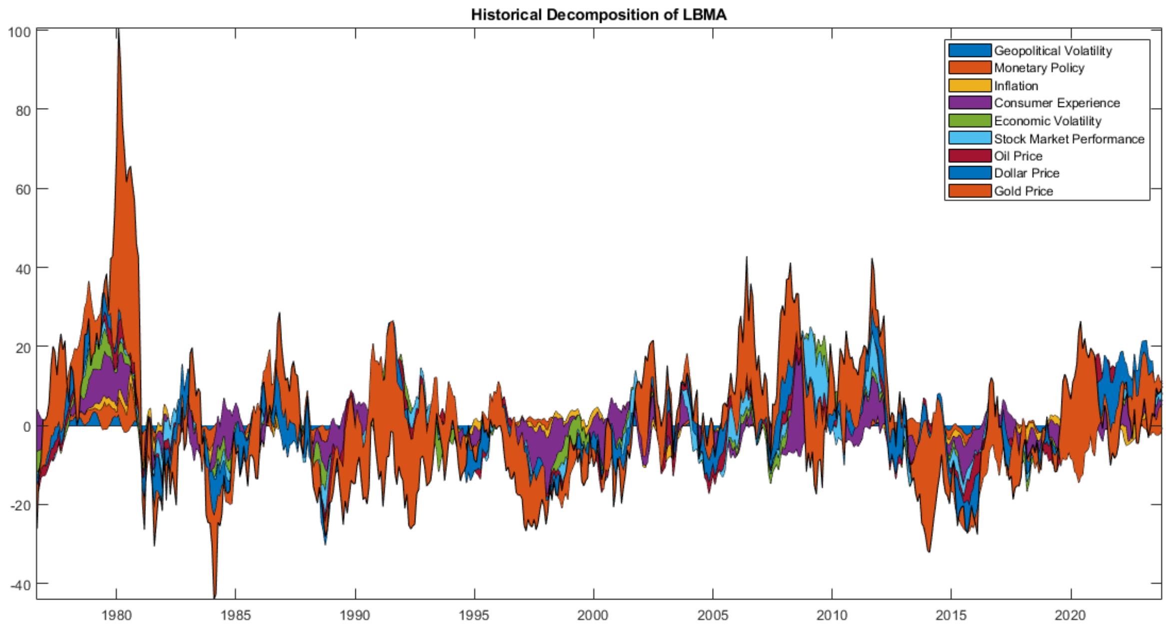

Fig. 17. Historical Decomposition

The varying influence that certain variables exert during periods of expansion versus periods of recession, and vice versa, is what leads this research to develop a dynamic model in which regression coefficients change based on the state in which we find ourselves.

MARKOV-SWITCHING

One of the advantages of Markov-Switching is that it detects the state throughout the entire sample period independently. This allows us to determine if the model is capturing the complexity of the entire reality of our dataset. Confirming that the model places recessionary periods when actual recessions have occurred throughout history ensures that the regression coefficients are changing when they should. In our case, the probability map of the regime in which we find ourselves is shown in **Fig. 18**. Our model is capable of detecting major crises that have occurred in the last 50 years. These include:

- 2020-2024: COVID-19.
- 2008-2013: Housing financial crisis.
- 2001-2003: Recession after 9/11 and the dot-com crash.
- 1997: Asian financial crisis.
- 1994-1995: Tequila crisis.
- 1990: Collapse of the Soviet Union.
- 1980-1987: Global recession in the early 80s, until the Black Monday of '87. During this period, there were not as many crises, but the model marks it as such because factors such as interest rates and inflation were very high at that time. This situation has not occurred in recent years. The good thing about Markov-Switching is that it has detected it as a period in which gold does not behave like in the recent expansion periods. Thus, we have realized this and will take it into account.
- 1973: Oil crisis.

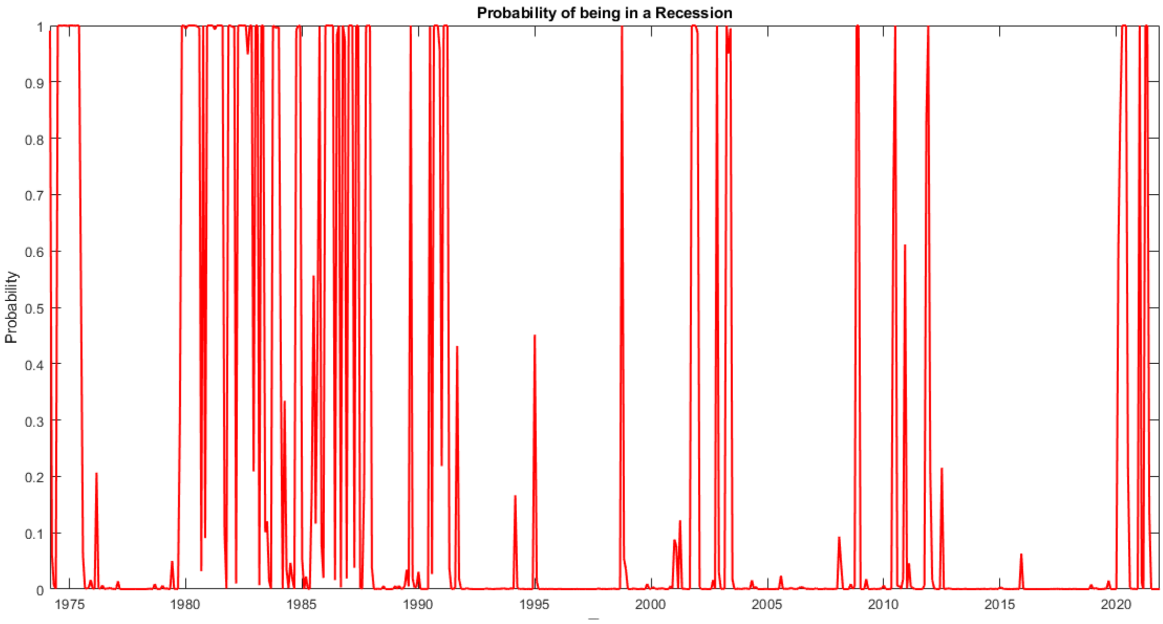

Fig. 18. Recession Regime Probability Map

Now that we know the model accurately captures the reality of our sample, we can delve into the analysis of gold responses to impulses in the rest of the variables. In **Fig. 19** is represented the expansion and the recession regime, respectively. The standard deviations of the residuals for both models are shown in **Code 2**. A direct analysis of the figures yields the following insights:

- Geopolitical Volatility: In the expansion regime, an impulse of 12.92 points in GPR does not generate any significant change in the gold price. In the recession regime, an impulse of 32.81 points in GPR generates an impact on the gold price starting from month 12, with a peak of significance in month 16, indicating a decrease of at least 4.08%.

- Monetary Policy: In the expansion regime, an impulse of 0.27% in interest does not generate any significant change in the gold price. In the recession regime, an impulse of 1.94% in interest generates an impact on the gold price for the next 20 months, with a peak of significance in month 14, indicating a decrease of at least 9.05%.
- Inflation: In the expansion regime, an impulse of a year-over-year increase in inflation of 7.16% does not generate any significant change in the gold price. In the recession regime, an impulse of a year-over-year increase in inflation of 9.77% generates an impact on the gold price for the next 3 months, with a peak of significance at the same instant of the impulse, indicating a decrease of at least 12.32%.
- Market Sentiment: In the recession regime, an impulse of 0.19 points in COS generates an impact on the gold price for the next 20 months, with a peak of significance in month 16, indicating a decrease of at least 2.23%. In the expansion regime, an impulse of 0.27 points in COS generates an impact on the gold price from month 2 to 6, with a peak of significance in month 4, indicating an increase of at least 1.06%.
- Economic Volatility: In the expansion regime, an impulse of 1.87 points in VIX_0 does not generate any significant change in the gold price. In the recession regime, an impulse of 6.18 points in VIX_0 generates an impact on the gold price starting from month 7, with a peak of significance in month 13, indicating an increase of at least 10.24 %.
- Portfolio Returns: In the expansion regime, an impulse of a year-over-year increase in MSCI World of 5.43% does not generate any significant change in the gold price. In the recession regime, an impulse of a year-over-year increase in MSCI World of 6.67% generates an impact on the gold price until month 13, with a peak of significance in month 5, indicating an increase of at least 10.86%.
- Oil Price: In the expansion regime, an impulse of a year-over-year increase in OIL_AVG of 10.09% generates an impact on the gold price for the next 2 months, with a peak of significance in month 1, indicating an increase of at least 0.90%. In the recession regime, an impulse of a year-over-year increase in OIL_AVG of 18.67% generates an impact on the gold price for the next 16 months, with a peak of significance in month 6, indicating an increase of at least 24.63%.
- Dollar Price: In the expansion regime, an impulse of a year-over-year increase in DXY of 4.96% generates an impact on the gold price for the next 20 months, with a peak of significance in month 1, indicating a decrease of at least 6.87%. In the recession regime, an impulse of a year-over-year increase in DXY of 2.96% does not generate any significant change in the gold price.

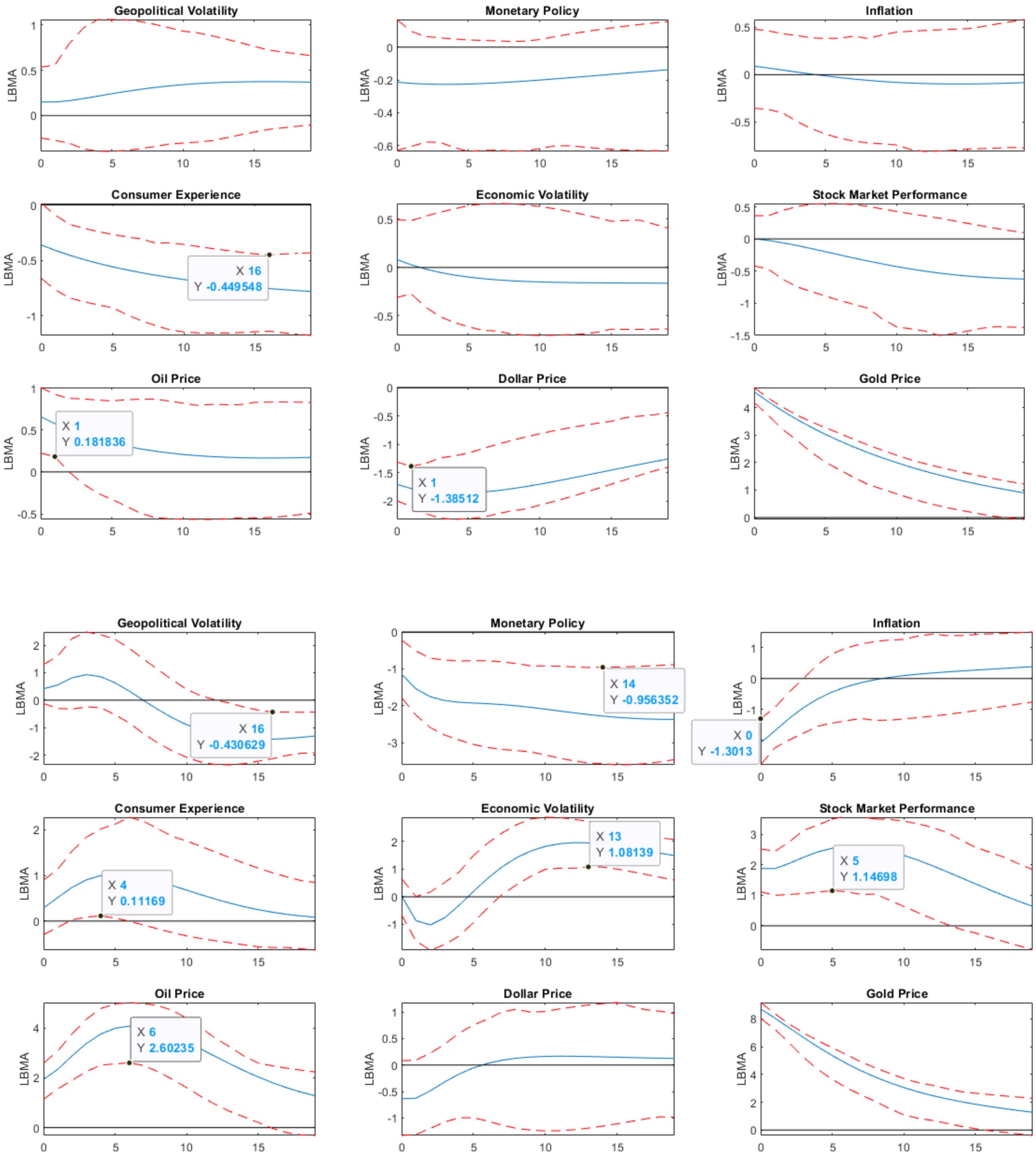

Fig. 19. Gold response to impulses in factors during an expansion and recession state, respectively

```
>> std_1=sqrt(diag(EstMdl.Submodels(1,1).Covariance))'

std_1 =

   12.9174    0.2701    7.1566    0.1915    0.0002    5.4332   10.0897    2.0982    4.9570

>> std_2=sqrt(diag(EstMdl.Submodels(2,1).Covariance))'

std_2 =

   32.8084    1.9427    9.7691    0.2668    0.0006    6.6704   18.6736    2.9592    9.4648
```

Code 2. Standard deviations of the residuals from the expansion and recession models

A more in-depth second analysis reveals more constructive insights:

- Unlike the static model, in this case, all variables impact the price of gold significantly, either during an expansion or recession regime. This indicates a good selection of variables.
- In an expansion regime, the factors that most impact the price of gold are Consumer Experience, Oil Price, and Dollar Price. In contrast, in a recession regime, all factors are significant except Dollar Price. The difference in the number of significant variables demonstrates that the price of gold is easier to explain during a recession. This may be due to our focus on financial demand through macroeconomic variables, which exhibit higher elasticity in the price of gold (Erb & Harvey, 2013). Nevertheless, it would be interesting for future research to investigate if other types of variables prove to be more significant during economic growth periods without diminishing their relevance during recessions.
- Two consistently influential factors in both regimes are Consumer Experience or Market Sentiment and Oil Price, both of which are quite innovative in comparison to existing literature. The Oil Price shows a clear positive relationship, reflecting its role in this model as a mirror of the gold price, capturing any movement not explained by other variables. Meanwhile, COS exhibits a more complex interrelation, where in expansion periods, the relationship is inverse, and in recessions, it is direct. In times of economic growth, investors tend to have more confidence in the economy and, therefore, prefer more dynamic and profitable financial assets. In times of crisis, even with positive sentiment about the future market improvement, economic uncertainty persists, and gold remains a safe haven, even when anticipating recovery.
- The dynamic between the dollar and gold prices changes according to economic conditions. During expansion, the strength of the dollar may have a dominant impact on the gold price, while in recessions, other macroeconomic factors related to risk

perception and value preservation may become more relevant in investment decisions.

- Monetary policy, identified as negatively significant in the static model during the early months, is revealed as a significant influence only during recession periods in the dynamic model, emphasizing its role in gold's response to adverse economic changes. This dynamic is consistent with the theory that an increase in interest rates leads investors to abandon high-yield assets, seeking refuge in assets that diversify their portfolios and reduce risk, thus increasing the demand and price of gold.
- Regarding inflation, an unusual occurrence is observed. While the static model shows a positive influence on the gold price, the dynamic model reveals an inverse impact only during recession periods. A possible interpretation is that the positive behaviour in the static model reflects the traditional perception of gold as a hedge against value loss, while the inverse relationship in the dynamic model is not the cause but the consequence of a greater influence by other recession-related factors, having a more significant impact than inflation itself. Delving deeper into the issue, in this dynamic context, inflation may be perceived differently, perhaps as a symptom of economic weakness rather than a traditional driver of gold prices.
- Addressing the two volatility indices included in the static model but without significant influence, it is noted that these are indeed significant during a recession. While geopolitical volatility is inversely significant, economic volatility is directly significant. Both exhibit a delayed influence of at least around 10 months. The difference in the sign of influence between both instability indices may indicate that while an increase in VIX generates a moderate increase in market uncertainty for investors, an increase in GPR generates an extreme increase in market uncertainty. Consequently, investors may seek refuge in gold with a moderate increase in uncertainty but not with an extreme one. This reasoning aligns with arguments put forward by Erb and Harvey (2013), who assert that gold serves as a speculative currency during times of instability but as a commodity where its price decreases during periods of extreme instability.

The insights generated by the dynamic model are much more profound and shed light on understanding gold prices. Their comparison with the static VAR model reveals gold's behaviours depending on the economic state and the imperative need to analyse its price using a dynamic model.

Chapter 5. CONCLUSIONS

This document employs a Vector Autoregression (VAR) model with Markov-Switching regime change involving nine variables to elucidate the behaviour of gold prices and identify dominant driving factors in different economic regimes. In contrast to existing literature, this study encompasses a much more extensive timeframe, spanning from January 1974 to November 2023, aiming to discern the influence on gold prices through the representation of global indices, unbiased towards any specific region. The factors and data series include geopolitical volatility (Geopolitical Risk Index Historic - GPRH), monetary policy through interest rates (Federal Funds Rate and Shadow Rate of Interest - SRI), core inflation (Consumer Price Index Core - CPI Core), market sentiment (Consumer Opinion Survey - COS), economic volatility (adaptation of Volatility Index through GARCH model for MSCI World - VIX_0), portfolio performance (MSCI World Index), oil price (average price in many countries - OIL_AVG), dollar price (U.S. Dollar Index - DXY), and gold price (LBMA Gold Price.

Primarily, the model's accurate identification of recessionary periods over the last five decades instils confidence in its ability to capture the complexity of the dataset. The effective detection of significant events, such as the COVID-19 pandemic and key economic crises, validates the robustness of the Markov-Switching approach.

In contrast to the static model, this dynamic approach emphasizes the significant influence of all variables on gold prices, whether during expansion or recession periods. This finding supports the effective selection of variables, suggesting that during recessive phases, gold prices are more easily explained, possibly due to the emphasis on financial demand through macroeconomic variables, exhibiting greater elasticity in gold prices.

Two consistently influential factors in both regimes are Consumer Experience and Oil Price. The Oil Price acts as a mirror, having a direct relationship and capturing all movements unexplained by other variables. Meanwhile, Market Sentiment demonstrates a complex interrelation, inverse during expansion and direct during recession.

The dynamic between the dollar and gold prices undergoes notable changes based on economic conditions. During expansions, the dollar's strength may dominate in determining gold prices, while in recessions, other macroeconomic factors related to risk perception and value preservation become more prominent in investment decisions.

Monetary policy, initially identified as negatively significant in the static model's early months, reveals itself as a significant influence only during recession periods, emphasizing its role in gold's response to adverse economic changes. This dynamic aligns with the theory that interest rate increases lead investors to seek refuge in low-risk assets, diversifying their portfolios and increasing gold demand and prices.

Regarding inflation, the positive relationship observed in the static model reverses only during recession periods in the dynamic context. This shift suggests that inflation may be perceived differently during recessions, possibly as a symptom of economic weakness rather than a traditional driver of gold prices.

Finally, focusing on volatility indices, previously lacking significant influence in the static model, both indices reveal significance in opposite directions. This leads to the conclusion that gold plays a dual role as a speculative currency in times of moderate instability and as a commodity in periods of extreme uncertainty.

Chapter 6. ALIGNMENT WITH SDGS

The present Master's Thesis pursues several Sustainable Development Goals. The following outlines which of them are aligned with this Project:

- SDG 8 - Decent Work and Economic Growth:
  - The identification of dominant driving factors in different economic regimes is crucial for understanding economic patterns and fostering economic growth. This study contributes to this understanding by analysing the influence of key variables on gold prices, which can have implications for job creation.
- SDG 9 - Industry, Innovation, and Infrastructure:
  - By employing a VAR model with regime change, this research demonstrates an innovative approach to understanding gold prices. This technical approach may promote innovation in financial analysis and contribute to the development of robust analytical infrastructures to address economic issues.
- SDG 12 - Responsible Consumption and Production:
  - Identifying factors influencing gold prices, especially those related to inflation and monetary policy, has implications for more responsible investment decisions. This can promote financially sustainable production and consumption practices.
- SDG 16 - Peace, Justice, and Strong Institutions:
  - The effective detection of significant events, such as the COVID-19 pandemic, validates the robustness of the regime-change approach. This contributes to a more solid understanding of economic dynamics and can support informed decision-making to promote stability and justice in financial institutions.
- SDG 17 - Partnerships for the Goals
  - Collaborating with other organizations and presenting findings can foster partnerships to address economic and financial challenges. By sharing knowledge and perspectives, this research contributes to building the necessary alliances to achieve the SDGs collaboratively.

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