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Modelling the Gold Market

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Abstract

Motivated by a detailed exploration of the intricate relationships influencing gold prices, this research employs a comprehensive empirical analysis using a Vector Autoregressive (VAR) model. The methodology unfolds in three phases: initial exploration of interdependencies among variables in the benchmark model, iterative enhancements, and a detailed analysis of Impulse Response Functions (IRF) and Historical Decomposition. The final model, refined through iterations, incorporates Geopolitical Volatility (GPR), Shadow Rate of Interest (SRI), Economic Volatility (VIX), Stock Market Performance (MSCI World), and Dollar Price (DXY). Given that the gold price is denoted by the LBMA (London Business Market Association) Gold Price. The study identifies key moments, such as financial crises and global events, shaping gold trajectories. The research not only contributes to a deeper comprehension of gold price dynamics but also develops promising ideas for future exploration. The observed sensitivity of the model to economic states prompts contemplation on the potential integration of dynamic regression coefficients that adapt to the fluctuating economic environment, potentially incrementing the model's predictive capabilities during both growth and contraction periods. In essence, this document serves as a crucial guide, navigating the complexities of the global economic landscape and providing insights into the multifaceted influences shaping the precious metal's price.

Keywords

Gold Price, Vector Autoregressive (VAR), Impulse Response Function (IRF), Historical Decomposition, Shadow Rate of Interest, Volatility, Stock Market Performance, Dollar Price, Inflation.

Resumen del proyecto

Motivados por una exploración detallada de las intrincadas relaciones que influyen en los precios del oro, esta investigación utiliza un análisis empírico integral mediante un modelo Autorregresivo Vectorial (VAR, por sus siglas en inglés). La metodología se desarrolla en tres fases: exploración inicial de las interdependencias entre variables en el modelo de referencia, mejoras iterativas y un análisis detallado de las Funciones de Respuesta a Impulsos (IRF, por sus siglas en inglés) y la Descomposición Histórica. El modelo final, perfeccionado a través de iteraciones, incorpora la Volatilidad Geopolítica (GPR), el Shadow Rateo of Interest (SRI), la Volatilidad Económica (VIX), el Rendimiento del Mercado de Valores (MSCI World) y el Precio del Dólar (DXY). Siendo el precio del oro representado por el LMBA (London Business Market Association) Gold Price. Los resultados resaltan la sensibilidad del modelo a los estados económicos y ofrecen percepciones matizadas sobre la dinámica de los precios del oro a lo largo de la historia. El estudio identifica momentos clave, como crisis financieras y eventos globales, que dan forma a las trayectorias del oro. Surgieron oportunidades para investigaciones adicionales, sugiriendo coeficientes de regresión dinámicos para mejorar las capacidades predictivas. En esencia, este documento sirve como una guía crucial, navegando por las complejidades del panorama económico global y proporcionando percepciones sobre las influencias multifacéticas que dan forma al precio de este metal precioso.

Palabras Clave

Precio del Oro, Modelo Autorregresivo Vectorial (VAR, por sus siglas en inglés), Función de Respuesta a Impulsos (IRF, por sus siglas en inglés), Descomposición Histórica, Shadow Rate of Interest, Volatilidad, Rendimiento del Mercado de Valores, Precio del Dólar, Inflación.

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1 Introduction

Throughout history, gold has had a wide variety of purposes. Undoubtedly, its most significant usage has been and continues to be its role as a store of value. On numerous occasions, this role has been accomplished by functioning as a currency in its own right, as seen in ancient Mesopotamia, the Roman Empire, and throughout the Middle Ages. In other instances, it established the proper value of the currency, as was the case of the Second Gold Standard between 1944 and 1971 when the Bretton Woods International Monetary System prevailed (Eichengreen, 2021).[1] And since then, it has been considered a safe haven against various forms of volatility, and even as a hedge against inflation (Huang, Jia, Xu, & Shi, 2019).

In the last two decades, we have witnessed a remarkable transformation in the behavior of gold, distancing itself from its traditional role as a raw material to evolve practically into a speculative financial asset. This fundamental shift has led investors to use it not only as a store of value but also as a tool for buying and selling in financial markets. Its value is no longer simply tied to its physical supply and demand; rather, it is strongly influenced by financial demand, whose elasticity exerts a substantial impact on its price, far surpassing technological and jewelry demand.

After the real estate crisis of 2008, gold experienced a significant revaluation, serving as a safe haven in times of economic uncertainty. More recently, during the COVID-19 crisis and amid geopolitical tensions such as the Ukraine war, we have witnessed a new surge in its demand. This resilience and ability to maintain its appeal in moments of economic crisis and global conflicts reinforce the perception of gold as a strategic asset in investment portfolios (Pan, 2018). The intersection of economic and geopolitical events has further solidified its status as a safe haven, granting it a more complex and multifaceted role in the contemporary financial landscape.

In the current context, several countries have chosen to acquire gold as a strategic reserve, seeking to safeguard themselves against the growing global uncertainty. Geopolitical tensions, particularly between the United States and China over the situation in Taiwan, as well as the recent conflict between Israel and Hamas, have fueled the perception that gold will remain a safe haven, and its price will continue to rise. However, this optimistic outlook is accompanied by an underlying fear. There is concern that this upward trend could lead to the formation of a bubble, in which the price of gold would significantly deviate from its intrinsic value. The possibility that, in periods of really extreme instability, gold may revert to behave more like a traditional commodity and be vulnerable to sharp declines adds a nuance of caution. In this scenario, the future evolution of gold will depend not only on geopolitical tensions but also on the market's ability to maintain a sustainable balance between demand as a safe haven and the possibility of extreme fluctuations in its value.

Gold, as a financial asset, exhibits a unique duality by playing roles as both a commodity and a currency. Despite its dazzling status and intrinsic value, it is classified as a raw material due to its tangible nature and prominent presence in key industrial sectors. Its corrosion resistance makes it a valuable resource for technological and jewelry applications. However, it is this very property that

[1] This system was based on low international capital mobility, stringent financial regulation, and the predominant role of the United States and the dollar.

gives gold an exceptional monetary character. It's ability to be inert results in an accumulative supply; the amount of gold currently in circulation equals the sum of all gold extracted throughout history, following the logic of any currency. Additionally, the amount mined annually is relatively insignificant compared to the circulating amount, generating minimal supply that contributes to its resilience and prevents significant depreciations in its value. This uniqueness also makes it less susceptible to manipulation by governments, adding an additional layer of stability.

The analysis of the price of gold emerges as a fundamental topic of interest in the fields of economics and finance. The importance of understanding the determinants of the value of gold lies in the unique ability of this metal to reflect and absorb the complexities of a dynamic global economic environment. Its appeal goes beyond its intrinsic value as a store of wealth; the sensitivity of gold to macroeconomic events provides valuable indicators about the future direction of markets and the economy as a whole. Therefore, this study not only addresses the nature of gold as an asset but also unravels crucial connections between its behavior and the forces shaping the global financial landscape.

This article addresses gaps in current knowledge and highlights opportunities to advance understanding of the determinants of the price of gold. Its distinctive focus lies in modeling rather than forecasting, diverging from the predominant trend in the literature that primarily centers on forecasting strategies. The study delves into a meticulous modeling process, prioritizing a profound understanding of causal relationships between factors and their influence on the price of gold. Additionally, it validates existing literature by consolidating variables such as interest rates, volatility indicators, portfolio performance, and the value of the dollar. Simultaneously, it classifies and clarifies crucial indicators with the aim of improving the accuracy and relevance of the model. Moreover, the research offers an insightful perspective on the relationship between gold, markets, and geopolitics, exploring the interconnection between gold and portfolio performance, represented by the MSCI World index.

Within the framework of this research, the main objective of this Bachelor's Thesis is to develop a VAR model with the purpose of analyzing and explaining the behavior of the price of gold, specifically represented by the London Bullion Market Association (LBMA) Gold Price. This model will be carried out considering various factors that potentially influence the price of gold, among which are: geopolitical volatility, represented by the Geopolitical Risk Index (GPR); monetary policy, represented by the Federal Funds Rate (DFF) or the Shadow Rate of Interest (SRI) (Wu & Xia, 2016); inflation, represented by the Consumer Price Index (CPI) Core; economic instability, represented by the Volatility Index (VIX); portfolio performance, represented by the Morgan Stanley Capital International (MSCI) World index; and the price of the dollar, represented by the U.S. Dollar Index (DXY).

2 Review of Related Literature

The existing body of literature pertaining to the price of gold primarily focuses on forecasting rather than modelling. A majority of these studies emphasize financial factors related to gold demand. This preference for demand-related variables can be attributed to the unique characteristics of gold, as detailed by O'Connor, Lucey, and Baur (2016). Gold possesses exceptional resistance to corrosion, leading to a gradual accumulation of its supply year after year. In accordance with their research, physical gold production constituted a mere 1.6% of the total accessible gold in 2010. These notably low production figures underscore the limited impact of supply fluctuations on the price of gold when compared to the significant influence of demand-related factors.

However, the financial dynamics underlying these factors can be identified through the work of Erb and Harvey (2013). According to the World Gold Council (2023) classification, gold demand is categorized into three main sectors: jewelry, technology, and investment. Their research argues that investment demand exhibits a substantially higher degree of price elasticity compared to the other two sectors. Between 2001 and 2011, the price elasticity coefficient for investment demand stood at 0.98, in contrast to -0.24 and 0.10 for the jewelry and technology sectors, respectively. In practical terms, this implies that a 10% increase in the price of gold corresponded to a robust 9.8% increase in investment demand.

Ismail, Yahya, and Shabri (2009) conducted a multiple linear regression analysis to predict gold prices. They employed various independent variables in their model, including the Commodity Research Bureau (CRB) index, the EUR/USD foreign exchange rate, the inflation rate, the money supply (M1), the New York Stock Exchange (NYSE) composite index, the Standard & Poor's 500 (SPX), the Treasury Bill index (T-BILL), and the US Dollar index (USDX). However, their analysis encountered two primary challenges related to multicollinearity and associated error terms. These issues were effectively addressed through a stepwise regression procedure aimed at eliminating insignificant independent variables from the model. Ultimately, only the first four variables remained as statistically significant predictors considering a one-month lag for the CRB index and the EUR/USD exchange rate, and a two-month lag for the inflation rate and money supply (M1).

Białkowski, Bohl, Stephan, and Wisniewski (2014) embarked on an investigation aimed at discerning the presence of a potential bubble within the gold market. Their primary objective was to clarify whether periodic bubbles could be identified based on their distinct characteristics, particularly the differentiation between a phase of moderate growth and one characterized by explosive expansion followed by a subsequent collapse. Firstly, they calculate the fundamentally justified value of gold through a combination of factors: the percentage change in the trade-weighted value of the U.S. dollar, inflation rates, the three-month U.S. Treasury bill rate, portfolio performance gauged by the MSCI World index, and economic volatility determined by contrasting the GDP-weighted average of 10-year government bond yields in southern European countries with similar yields in Germany. Subsequently, they conducted a Markov regime-switching test and realized that the sharp fluctuations observed in gold prices could be attributed to the 2008 European sovereign crisis, thus leading to the dismissal of the presence of bubbles in the gold market. Furthermore, they test the model by substituting the economic volatility crisis factor with a more general commodity price index (CRB) and the demand for gold-backed exchange-traded funds (ETFs). These alternative approaches underscored the significant explanatory power of these variables in understanding gold price fluctuations.

The study conducted by Ayea, Guptaa, Hammoudeh, and Kim (2015) developed a set of dynamic models to examine potential predictors of gold return rates. These models consider six critical factors, which include the business cycle, nominal interest rates, commodities, currency exchange rates, stock market dynamics, and levels of uncertainty. The dynamic model with the best performance is the Dynamic Markov-Switching (DMS) model. This model reveals that the predictive power of certain factors fluctuates over time into three different periods: firstly, the period spanning the three major wars from 1992 to 2005, characterized by a steady increase in gold prices; secondly, the period encompassing the Great Recession and the commodities boom from 2005 to 2009, marked by a rapid surge in gold values; and finally, the phase of gold price recovery observed since 2009. The primary finding of this study underscores the predominant influence of financial factors in forecasting gold returns. Particularly, the stock market, financial stress index and exchange rates emerge as three prominent examples where this influence is particularly pronounced.

Xian, He, and Lai (2016), utilized Ensemble Empirical Mode Decomposition (EEMD) to analyse the gold price. EEMD breaks down the time series data into Intrinsic Mode Functions (IMFs), capturing various patterns and oscillations. IMFs were transformed into Virtual IMFs (VIMF) for refined analysis and then broken down into Statistically Independent Components (ICs), the linear combination of which could explain the gold price. The results yielded seven distinct ICs (economic development, gold supply and demand, US dollar, inflation (CPI), market emergencies, international geopolitics, and cyclicality), representing economic data.

The research conducted by Qian, Ralescu, and Zhang (2019) thoroughly investigates the primary factors influencing gold prices. They employ a reverse engineering process of Response Surface Methodology (RSM) to evaluate these influences. Their study reveals significant negative effects on variables such as the dollar index, the federal funds rate, exchange rates, and the S&P500. However, neither the Consumer Price Index (CPI) nor oil prices appear to have a significant impact. Furthermore, their paper underscores the significance of the monetary value of gold, highlighting its high liquidity, making it an ideal asset for quick international market transactions, particularly during currency and inflation fluctuations. Lastly, they emphasize the need for future research to concentrate on measures of uncertainty, such as volatility (VIX), when examining gold price determinants.

The study conducted by Triki and Maatoug (2020) addresses a significant research objective that many have found challenging: establishing a connection between the price of gold and stock markets. The focal point of their research is the introduction of a new index, one that captures the factor of geopolitical volatility. The Geopolitical Risk Index (GPR), was originally proposed by Caldaray and Iacoviello (2016). By incorporating the GPR as an exogenous variable within a GARCH model, their empirical findings reveal Furthermore, their analysis identifies a noteworthy negative spillover effect, but only in the direction from the S&P 500 to gold, with no indication of the opposite direction. The paper also underscores the significance of further in-depth investigation of the GPR influence effect, employing more robust methodologies.

Chiang's study (2022) represents the most recent examination of gold's roles. In his analysis, several key conclusions emerge. Firstly, gold demonstrates its status as an inflation hedge, given its propensity to appreciate owing to its inherent status as a tangible commodity. Secondly, gold gains greater appeal during economic downturns, as illustrated by the global recession triggered by the COVID-19 pandemic. In such recession, investors frequently gravitate toward gold as a secure haven countermeasure to losses in other financial assets. Furthermore, it exhibits a positive correlation with currency depreciation. Lastly, gold is among the top-performing assets in times of geopolitical uncertainty, providing a safeguard for investments. Notably, this holds true across most regions, except for China and Bharat.

In this research, a detailed journey has been undertaken through the existing landscape in the entire literature related to the price of gold. This exhaustive review of previous studies allowed us to address certain gaps in existing knowledge, as well as opportunities to advance our understanding of the determinants of the price of gold in the complex global economic framework. It is in this context that the foundations have been laid to set a new horizon, highlighting the following contributions that this paper brings to the field:

- Modeling instead of forecasting:
  This study marks a significant departure from the prevailing trend in the literature, which mostly focuses on forecasting strategies. In this document, instead of exclusively focusing on predicting the price of gold, we immerse ourselves in a detailed modeling process. The difference involves a deliberate focus on the selection of variables, moving away from a methodology that seeks the most precise accuracy without distinction of the variables used. The modeling is guided by a deeper understanding of the causal relationship between each factor and its influence on the price of gold. This allows us not only to anticipate trends but also to unravel the underlying complexities that drive them, providing us with a clearer and more specific insight into the contribution of each factor to changes in the price of gold.
- Literature validation:
  The consolidation in our model of factors such as interest rates, volatility indicators, portfolio performance, and the value of the dollar, already used in previous research, serves to consolidate the existing understanding of the determinants of the price of gold.
- Classification and clarification of crucial indicators:
  The choice of MSCI World and DXY as prominent representatives over others such as the NYSE composite index or the EUR/USD foreign exchange rate used in previous research reflects a meticulous selection aimed at improving the accuracy and relevance of our model. Additionally, we highlight the innovative incorporation of relatively new indicators, such as the VIX for overall market volatility and the SRI for monetary policies. While these indicators have been used in other contexts, their application to the analysis of the price of gold is limited in the existing literature. Specifically, our research reveals that the SRI significantly outperforms conventional interest, especially when monetary policies adopt unconventional expansive measures near the Zero Lower Bound.
- Reevaluation of the role of inflation:
  Historically, gold was considered a safe haven against the value erosion caused by inflation, and this idea persisted for decades. However, our research provides an enlightening perspective by demonstrating the absence of a significant influence of inflation on the price of gold. Contrary to conventional beliefs, we have identified and corroborated that the inclusion of inflation in the model does not add real value and, therefore, does not figure as an influential variable. This revelation supports recent doubts in the literature about the causal relationship between inflation and gold. The removal of the inflationary factor from our model not only simplifies the structure but also allows for greater attention to other variables that more effectively capture historical events and fluctuations in the price of gold.

- Interconnection between gold, markets, and geopolitics:
  Our research contributes significantly to the extensive body of knowledge by corroborating and expanding on the recent contributions of Triki and Maatoug (2020), who recently highlighted the connection between gold and the NYSE through the introduction of the geopolitical volatility indicator, the GPR. In reality, it goes a step further by exploring the relationship between gold and portfolio performance, more accurately represented by the MSCI World index. This connection would not be evident without the inclusion of the GPR in our model. This finding reinforces the idea that the GPR, by capturing geopolitical volatility, plays a crucial role in mediating the relationship between gold and market movements.

3 Data Description

The dataset used to feed the model comprises various numerical data series collected on a monthly basis from January 1990 to February 2022. This section provides a comprehensive overview of the variables, outlining the factor addressed, the name of the index or rate used, description, and source.

According to the existing literature that examines factors influencing gold prices previously shown, in addition to the price of gold we have incorporated the following variables into our empirical analysis: dollar price, inflation, interest rates, economic volatility, stock market performance and geopolitical volatility.

Table 1
Variable description and sources.

Factor	Name	Abbreviation	Description	Source
Gold Price	London Bullion Market Association Gold Price	LMBA	London-based gold price benchmark	World Bank Database (2023)
Dollar Price	Dollar Index	DXY	Measures USD strength against major world currencies basket	FRED Economic Data (Bank of St. Louis, 2023)
Inflation	Core Consumer Price Index	CPI	Inflation measure excluding volatile food and energy	FRED Economic Data (Bank of St. Louis, 2023)
Monetary Policy as interest rate	Federal Funds Effective Rate	DFF	U.S. interest rate set by central bank	FRED Economic Data (Bank of St. Louis, 2023)
	Shadow Interest Rate	SRI	Unobservable interest rate	(Wu & Xia, 2016)
Economic Volatility	Volatility Index	VIX	Measures market fear and uncertainty	FRED Economic Data (Bank of St. Louis, 2023)
Stock Market Performance	Morgan Stanley Capital International World Index	MSCI	Tracks global stock performance	MSCI
Geopolitical Volatility	Geopolitical Risk Index	GPR	Measures global political stability	(Caldaray & Iacoviello, 2016)

3.1 Gold Price

In the realm of measuring the gold price, there exist two principal indices, namely those established by the COMEX and the LMBA. They both play a pivotal role in providing comprehensive insights into the dynamics of this precious metal within the financial landscape. The COMEX index reflects the future expectations and sentiments of market participants regarding gold prices. This is facilitated through the trading of standardized futures contracts, allowing investors to speculate on the future price movements of gold. The interplay of supply and demand dynamics within these futures contracts contributes to the real-time valuation of gold. While the COMEX and LMBA indices both contribute significantly to the understanding of gold prices, their methodologies introduce distinct nuances.

In the context of this analysis, the selected index for examining gold prices is the LMBA Gold Price. This particular index holds significant merit as a benchmark, primarily due to its robust emphasis on physical gold, the transparency embedded in its pricing mechanisms, and its global participation that collectively reinforces its credibility within the financial markets. It is noteworthy that the determination of the London gold price occurs twice a day; however, for the sake of enhanced precision, the afternoon fixing, known as PM fixing, is commonly utilized (Caminschi & Heaney, 2013). This deliberate choice of using the PM fixing contributes to a more nuanced and accurate representation of the gold price, aligning with the pursuit of meticulous and reliable data in the analytical processes conducted throughout this study.

Figure 1 shows that the price of gold, measured in troy ounces, has an exponential behavior and follows a temporal trend. These introduces two challenges:

1. Regression analysis involves optimizing model parameters to minimize the sum of squared errors. When one of the variables in the model displays an exponential behavior, it can significantly magnify errors during regression analysis compared to other variables. The solution to this issue involves linearizing the numerical series, which results in a more symmetrical distribution and stabilizes variance.
2. In cases where two variables share a similar temporal trend and are integrated into a model spanning an extended period, they will inevitably exhibit a relationship. To draw accurate conclusions from the model, it is necessary to remove the temporal trend.

In the context of this research, two transformations have been applied to the gold price data to address these challenges. Firstly, the natural logarithm to adjust the dimension of the series. Secondly, a '*detrend()*' function has been performed using Matlab (Mathworks, 2023), to eliminate the linear time-trend component. The outcome is represented by the orange curve in **Figure 1**.

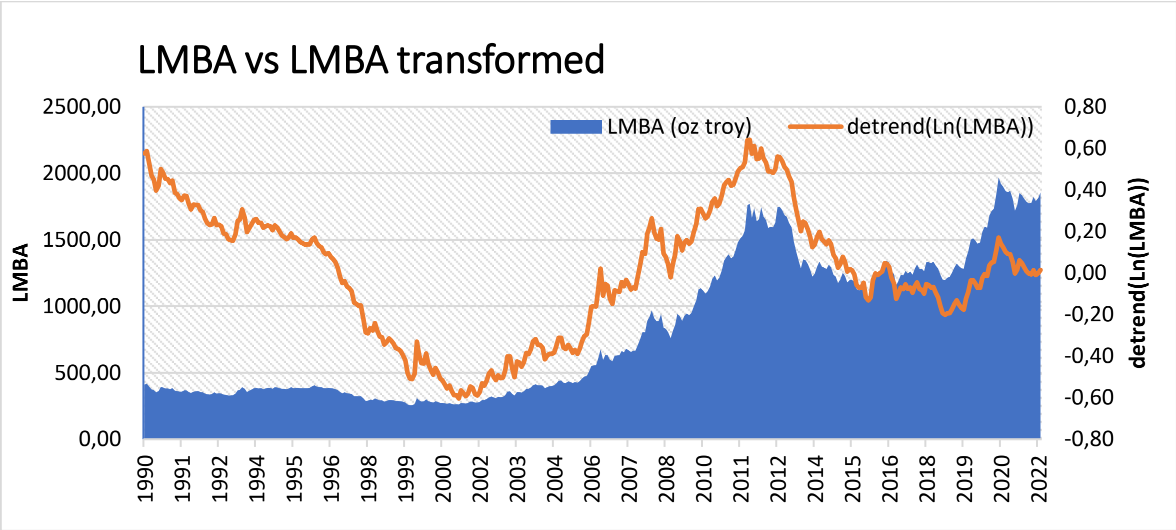

Figure 1. Comparison LMBA -with LMBA transformed

3.2 Dollar Price

In all the existing analyses, there is a consensus that fluctuations in the exchange rates of the U.S. dollar relative to other currencies directly influence the price of gold. This make sense, as gold is traded on the international markets with the U.S. dollar serving as the benchmark currency.

A multitude of research endeavours have delved into the intricacies of economic phenomena by employing the exchange rate between the U.S. dollar and the euro as a focal point in their analytical models. However, this report will opt for the use of the Dollar Index (DXY or USDX). This index goes beyond a singular currency pair and offers a broader perspective by assessing the value of the U.S. dollar (USD) against a diversified basket of other significant currencies, including the euro, the yen, the British pound, the Canadian dollar, the Swiss franc, and the Swedish krona, among others. By incorporating this diverse range of currencies, the index provides a nuanced and inclusive evaluation of the U.S. dollar's strength or weakness on the global stage.

In **Figure 2**, we can observe that the relationship between the U.S. dollar and the price of gold is inverse: when the dollar depreciates, a larger amount of dollars is required to purchase the same quantity of gold. It is important to note that the price of the dollar has undergone the same two transformations as the price of gold, for the same reasons.

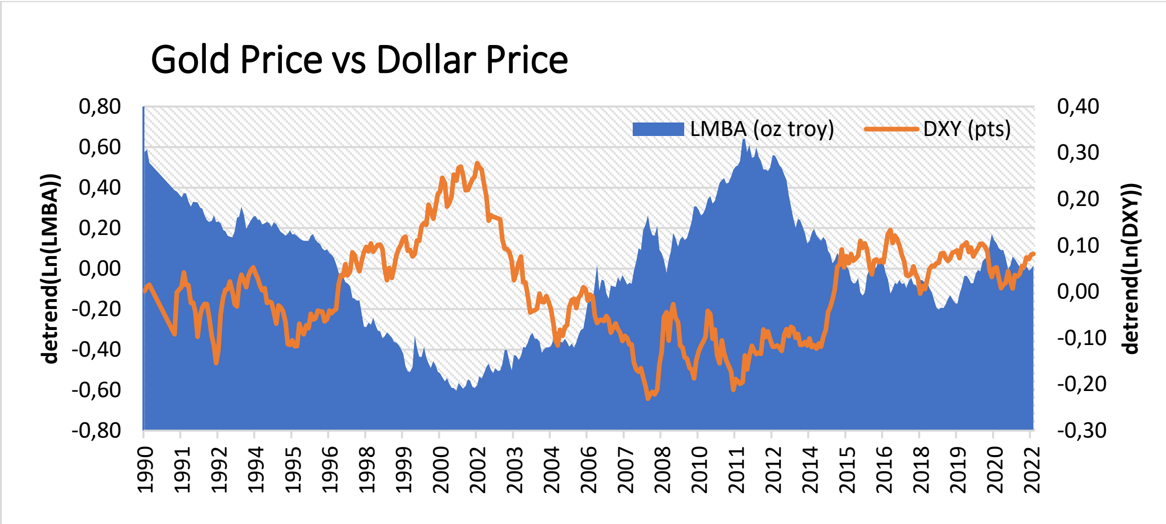

Figure 2. Comparison between LMBA and DXY

3.3 Inflation

In contrast to the DXY, numerous sources have explored the impact of inflation on gold prices. Historically, before the 2000s, gold was widely acknowledged as a safe haven against inflation. This association was logical given that gold, being a physical asset and a raw material, tends to maintain a relatively constant monetary value. However, since the early 2000s, potentially due to the surge in commodities during that period, the price of gold has experienced a notable increase and has become less tied to inflation. Nevertheless, the discourse on this matter remains nuanced, and many investors persist in using gold as a means to safeguard their purchasing power over time.

The study conducted by Erb and Harvey (2013) delves into the potential correlation between gold and inflation, yielding several noteworthy conclusions. In stable economic conditions, gold does not seem to serve as an effective hedge against short-term inflation, as its movements in such scenarios are primarily influenced by immediate economic factors. However, over the long term, these dynamics could prove to be 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 selecting the data series that best represents inflation, two options were considered: the CPI Headline and the CPI Core. The disparity between these indicators lies in the components included in their calculation. While the CPI Headline reflects price changes incorporating all components within the basket of goods and services, the CPI Core excludes food and energy. This exclusion is attributed to the heightened volatility of these two components, rendering them more susceptible to temporal variations influenced by external factors such as weather conditions, geopolitical events, and other fluctuations. The CPI Core provides a more stable and underlying measure of long-term inflationary trends. Additionally, it is essential to note the inclusion of other more specific variables in the model that will more accurately capture the influences of geopolitical fluctuations on gold prices.

Figure 3 illustrates the potential inverse relationship between inflation and the price of gold.

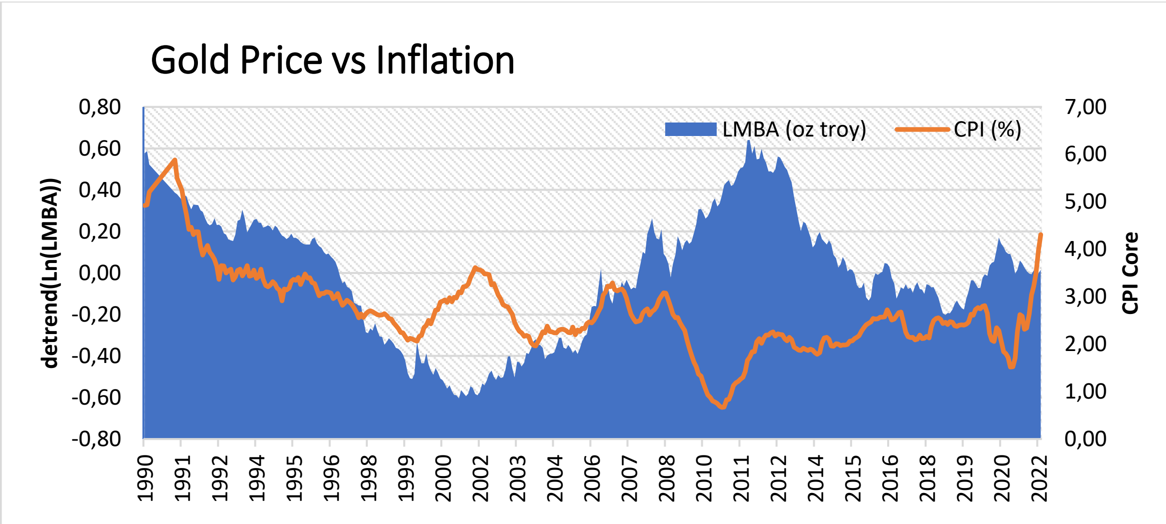

Figure 3. Comparison between LMBA and CPI Core

3.4 Monetary Policy as Interest Rate

In **Section 2**, we examined a study conducted by Ismail, Yahya, and Shabri (2009), which explored the potential factors affecting the price of gold. This study considered both the money supply (M1) and interest rates. Notably, it was observed that these two variables exhibited a strong correlation, leading to the exclusion of one of them. Generally, most research tends to focus on interest rates due to their direct impact on financial markets, in contrast to the money supply, which entails more complex and indirect implications. Consequently, for our research, we opted to exclusively utilize interest rates as an indicator of monetary policy.

The Fed Funds Rate is the interest rate at which banks in the United States lend money to each other in the short term. This rate plays a key role as a tool used by the United States Federal Reserve to influence monetary conditions and its macroeconomic goals. However, a problem arises when the Federal Reserve seeks to stimulate spending and investment to boost economic growth. During such scenarios, when the Federal Funds Rate approaches the zero lower bound (ZLB), the central bank turns to unconventional measures, such as the purchase of assets named quantitative easing, to further stimulate the economy. This strategy involves the massive purchase of 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 it can help stimulate the economy, it has also sparked debates about its long-term effects, including concerns about the creation of asset bubbles and the uneven distribution of economic benefit (Benford et al., 2009). These extraordinary policies, which are implemented when interest rates are extremely low, cause the Fed Funds Rate to be less effective in reflecting monetary policy accurately.

The "Shadow Rate" (SRI) has emerged as a valuable tool in the realm of econometric and statistical modelling, gaining increased prominence in recent years (Wu & Xia, 2016). Functioning as a hypothetical interest rate, the SRI is meticulously crafted to mirror the dynamics of effective monetary policy. Its significance becomes particularly pronounced when official interest rates hover at the Zero Lower Bound, unable to fully encapsulate the impact of unconventional monetary measures.

In the aftermath of the 2008 financial crisis and the disruptions caused by the COVID-19 pandemic, the global economy faced formidable challenges. Central banks responded by implementing expansive monetary policies, a strategy involving the reduction of interest rates to stimulate economic activity. However, as the official interest rates approached the Zero Lower Bound, central banks found themselves constrained from further reductions. Undeterred, they turned to unconventional measures to sustain economic momentum. **Figure 4** illustrates these events, depicting the Fed Funds Rate holding steady near zero. Yet, the Shadow Rate allows us to assess how far these expansive monetary policies went, as if central banks had continued to reduce official interest rates without the need to resort to other methods.

In our analysis, we will compare the Fed Funds Rate with the Shadow Rate to determine which of these variables best reflects the influence of monetary policy on the price of gold.

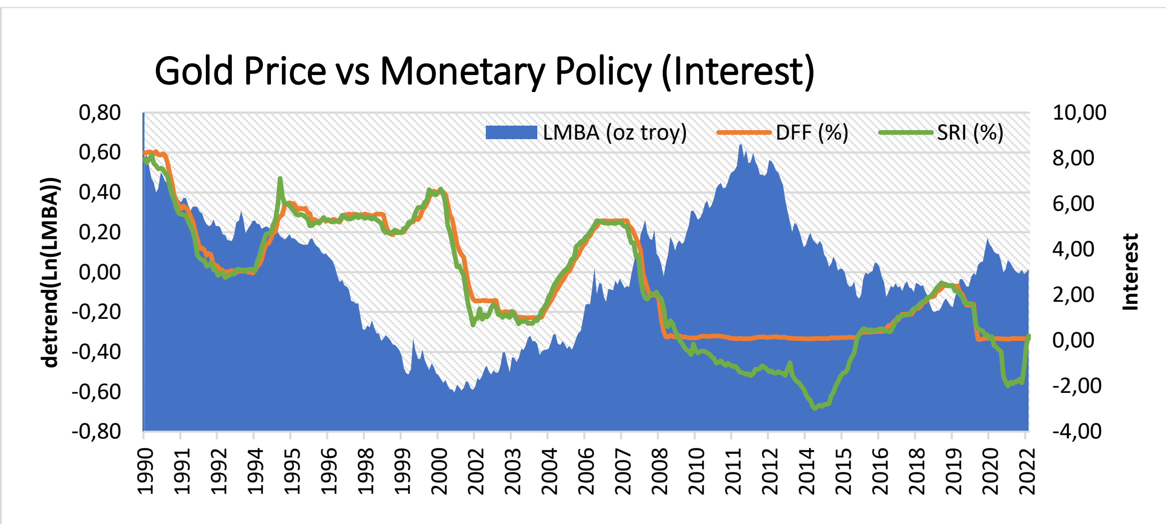

Figure 4. Comparison between LMBA and U.S. monetary policy interest rates (DFF or SRI)

3.5 Economic Volatility

Gold serves as robust store of value, especially during times of uncertainty in financial markets. It is a highly liquid asset that can be easily sold, even when there are few buyers in the market. For this reason, many investors turn to gold during periods of maximum uncertainty regarding future economic risks.

The VIX also known as the "Fear Index", is a tool that reflects the uncertainty present in the market. This key indicator shows investors' expectations regarding future volatility in the S&P 500, based on the purchase and sale of options associated with that index. It has gained popularity in recent years and wasn't until 2019 that was mentioned in the article authored by Qian et al. (2019). In this study the significance of investigating VIX in future research as an indicator of market uncertainty was recommended and emphasized. At first glance, as illustrated in **Figure 5**, it can be observed that during peak market instability, identified by an increase in the VIX, there is often a corresponding increase in the price of gold.

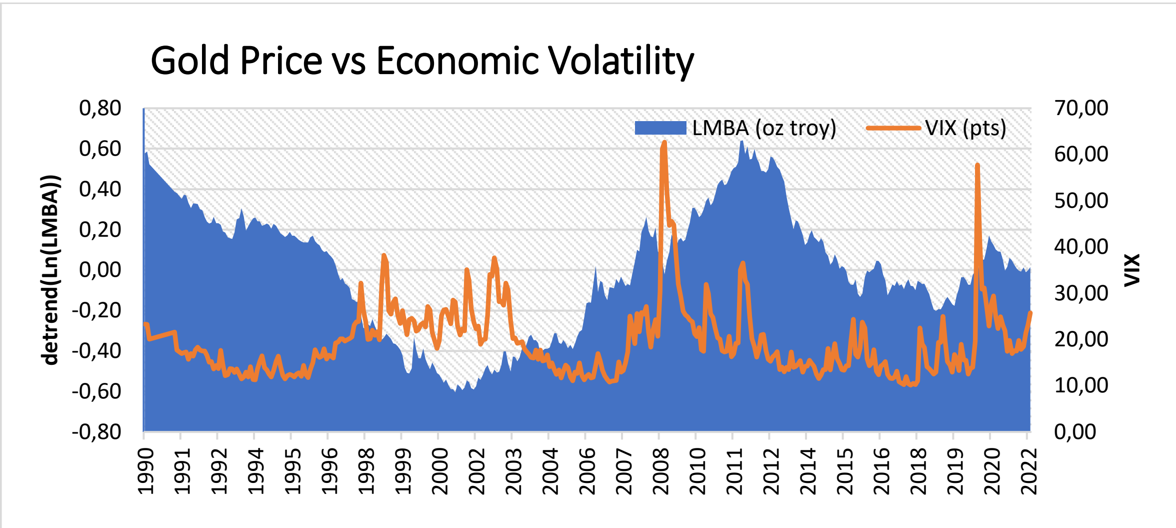

Figure 5. Comparison between LMBA and MSCI World Index

3.6 Geopolitical Volatility

Geopolitical tensions often increase demand for gold, as it is used as a safe haven, protection against inflation, and safeguard against currency depreciation. Although these effects should be captured by other variables in our model, it is crucial to incorporate this factor due to the specific approach our model takes in handling the sequence order of data series, as will be explained in the ¡Error! No se encuentra el origen de la referencia..

We will use the Geopolitical Risk Index (GPR) to represent this factor, following the recommendation of Triki and Maatoug (2020). This index was created by Caldaray and Iacoviello (2016) and evaluates the likelihood that political, social, or geopolitical factors have an impact on the business environment. It is now widely used by investors, multinationals, and political analysts.

Comparing geopolitical volatility with the price of gold through **Figure 6**, we can highlight the reaction of the gold price to the peak of the GPR during the first four years after 2000.

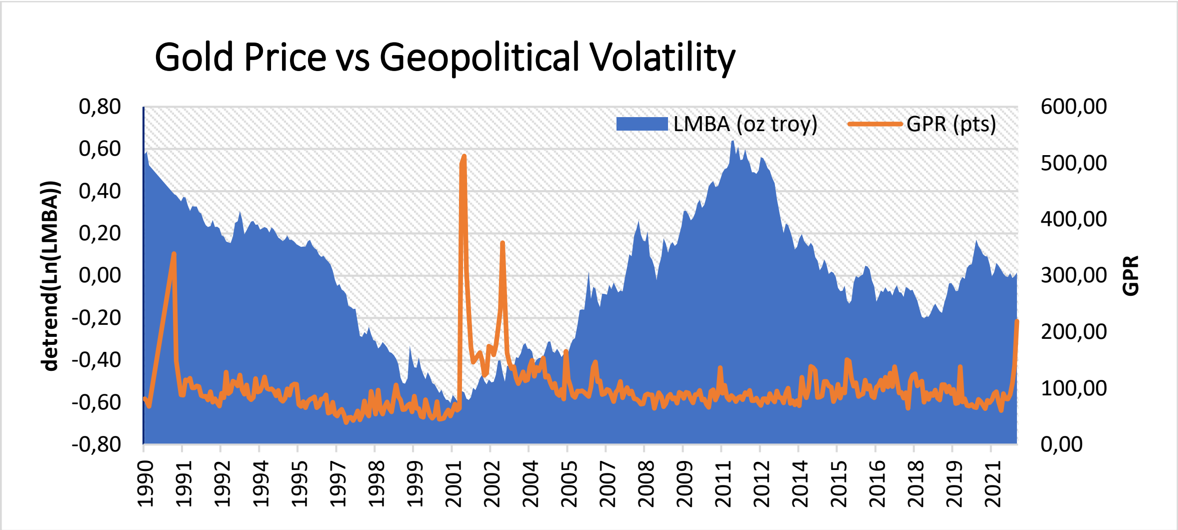

Figure 6. Comparison between LMBA and GPR

3.7 Stock Market Performance

An inverse relationship is established between the performance of stocks and the price of gold (Caliskan & Najand, 2015). When markets are in a period of growth and investors have strong confidence in the economy, they tend to invest in assets that are riskier than gold. However, in opposing situations, it is common for them to opt for gold as a way to diversify their portfolio and reduce their exposure to risk.

Both numerical series are displayed over time for comparison in **Figure 7** where an inverse relationship can be clearly observed. The MSCI World Index has also undergone the same transformations of log-linearization and removal of temporal trend.

The MSCI World Index is used as a benchmark for evaluating the performance of global stock markets. It includes shares of thousands of companies operating in various industries and sectors of the global economy. Since it is a solid indicator of growth periods in the stock markets, it is expected to affect the behaviour of gold.

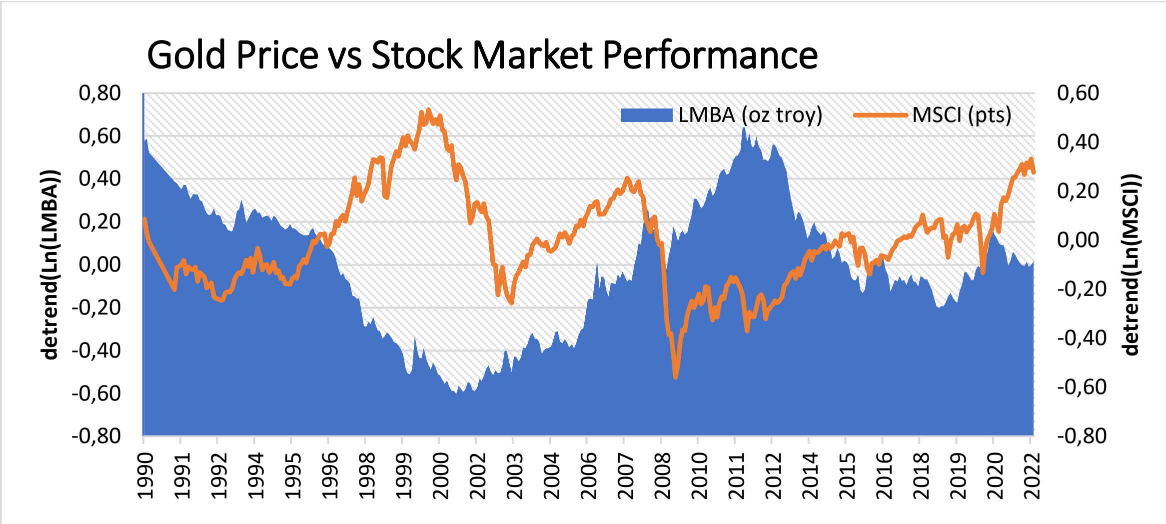

Figure 7. Comparison between LMBA and MSCI World Index

4 Methodology

4.1 VAR Model

The model employed in this study utilizes a Vector Autoregressive (VAR) approach, which is commonly employed for analyzing multivariate time series data. It involves a system of multiple regression equations in which each variable depends on its own past values (lags) as well as the past values of other variables (Kilian & Lütkepohl, 2016).

A VAR model can be expressed as a system of K equations as in **Eq. (1)**

$$y_{it} = \sum_{j=1}^{K} \sum_{l=1}^{L} a_{ij,l} y_{j,t-l} + \mu_{it}, \forall i \in \mathbb{N}, 1 \leq i \leq K$$

Eq. (1): System of Equations of a General VAR Model

The equation system, expressed in matrix form, can be represented as **Eq. (2)**

$$Y_t = \sum_{l=1}^{L} A_l Y_{t-l} + \mu_t$$

Eq. (2): Matrix-Expressed System of a VAR Model

Where:

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

In other words, Y_t represents the column vector of all the variables in the model, A_l is the matrix of unknown coefficients at lag l, and μ_t is the column vector of errors, also referred to as the linearly unpredictable component of Y_t.

The model can also be presented in its structural form as in **Eq. (3)**.

$$B_0 Y_t = \sum_{l=1}^{L} B_l Y_{t-l} + \omega_t$$

Eq. (3): Structural-Expressed System of a VAR Model

Where:

$$A_l \equiv B_0^{-1} B_i, \qquad \mu_t \equiv B_0^{-1} \omega_t$$

Eq. (4): Instantaneous Response Matrix for the Computation of Coefficients and Error

In other words, B_0^{-1} denotes the instantaneous response matrix and ω_t is the column vector of shocks corresponding to each variable.

Then, the variables are arranged such that it can be asserted that the error stemming from a variable is contingent solely upon the shocks generated within it and the variables that precede it, while remaining unaffected by those that follow. This arrangement is usually referred as the decreasing order of exogeneity and shapes the matrix B_0^{-1} as a triangular matrix, as can be observed in **Eq. (5)** and is explained after.

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

Eq. (5): Instantaneous response matrix shape

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 employing a Cholesky decomposition of the variance-covariance matrix of the error terms. To accomplish this, a shock vector is introduced into the model, filled with zeros except for the variable corresponding to the impulse to be simulated. The error is then estimated accordingly. **Eq. (6)** illustrates the computation of errors for the Impulse Response Function corresponding to an impulse in variable i.

$$\mu_t \equiv \begin{pmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_i \\ \vdots \\ \mu_K \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 & \cdots & 0 \\ b_{21} & b_{22} & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{i1} & b_{i2} & \cdots & b_{ii} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{K1} & b_{K2} & \cdots & b_{Ki} & \cdots & b_{KK} \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_i \\ \vdots \\ \omega_K \end{pmatrix} \equiv \begin{matrix} \mu_1 = 0 \\ \mu_2 = 0 \\ \vdots \\ \mu_i = b_{ii}\omega_i \\ \vdots \\ \mu_K = b_{Ki}\omega_i \end{matrix}$$

Eq. (6): Calculation of the Error Vector

It becomes evident that each error, in the estimation of the IRFs, is affected solely by its own impulse and the preceding shocks. This ensures the independence of the preceding variables in the instantaneous response matrix. Therefore, it is imperative to place the variables in decreasing order of exogeneity to justify the zeros within this matrix. Failure to do so would compromise the model's functionality.

4.2 Impulse Response Functions (IRFs) Interpretation

Impulse Response Functions are valuable tools for analyzing the interactions and dynamics of temporary series models, especially VAR models. They provide insights into how a change in one variable can impact other interconnected variables. IRFs prove particularly effective when assessing the ramifications of economic policies or unforeseen events on a group of interlinked variables, aiding in the identification of cause-and-effect relationships, spillover effects, and feedback mechanisms.

In this context, an "impulse" represents an exogenous disturbance, such as a sudden shift in a variable, equivalent to a standard deviation from the corresponding time series. For example, a rapid increase in interest rates stemming from a change in monetary policy. The "response" refers to how another specific variable (or the same variable) reacts over time following this peak. Following the previous example, a subsequent decline in inflation after a few months to this monetary policy shock.

The estimation of the IRFs begin with the statistical representation of how variables relate to each other concerning their historical patterns by estimating the model. It then simulates the impact of an impulse on one variable while holding all others constant to observe the system's evolution over several time periods. Repeating this procedure for each variable yields a $K \times K$ matrix of IRFs, as depicted in **Figure *8***. In this matrix, the columns represent the responses of each endogenous variable to each of the shocks (rows). Within each IRF, the horizontal axis stands for the periods after the impulse, while the vertical axis indicates the magnitude of the response. However, it is important to note that the horizontal axis is not restricted to representing the response only within the influence period, i.e., P lags. It can be extended as far as necessary, depending on the specific aspects under investigation.

In our study, we have supplemented each IRF with contour curves. These curves encircle the estimated response and denote a 95% confidence interval, within which the real response to a disturbance of similar characteristics is expected, based on our historical data or sample. This feature assumes great significance as it informs us about the strength of the relationships between the variables. If the zero value falls within the contours after the impulse occurs, we cannot assert with 95% confidence that any change in the endogenous variable has taken place.

5 Empirical Analysis

In the context of this research, the employed methodology entailed initiating the analysis with an benchmark model, scrutinizing the outcomes comprehensively, and subjecting them to a thorough examination. Subsequent iterations were systematically conducted with the explicit aim of refining the model, consistently striving for increased precision in the results.

During the analysis of the preliminary models, this document will confine its evaluation to assessing the significance of the confidence intervals of the Impulse Response Functions (IRFs). This limitation is attributed to the primary goal of the preliminary analysis, which is to iteratively enhance the final model to be retained. The detailed quantification of gold response estimation and historical decomposition will be addressed more extensively in the final model analysis.

5.1 Benchmark Model

The benchmark model, serving as the foundation, comprises six key variables that collectively capture various factors influencing Gold Price (LMBA): Geopolitical Volatility (GPR), Monetary Policy (FDD), Inflation (CPI), Economic Volatility (VIX), Stock Market Performance (MSCI), and Dollar Price (DXY). With seven integrated time series in the model ($K = 7$), we examine the interdependencies among these variables over a one-year influence period. Given our dataset's monthly time series nature, we set the number of lags to 12, such that $L = 12$.

The incorporation of numerous variables, particularly macroeconomic ones, may introduce challenges related to multicollinearity. That is the reason why an incremental approach has been adopted, commencing with an benchmark model and systematically addressing these challenges, retaining variables that most effectively represent changes in gold prices.

The sequence in which factors affecting gold prices are introduced into the model is not arbitrary. This sequence follows an order where the initial variables are deemed more independent of contemporaneous disturbances from subsequent variables, as explained in **Eq. (4)**. Grounded in logical inference, we have organized the variables based on the following assumptions:

- The Dollar Price and stock market performance are the most dependent factors among other variables such as economic and geopolitical volatility, inflation, and interest rates. This dependency is attributed to the following reasons:
    - The economic benefit of financial assets is highly sensitive to market expectations. While economic and geopolitical volatility can generate considerable uncertainty, forecasts of interest rates and inflation are consequences that ultimately impact investment decisions.
    - The dollar is, in essence, another financial asset that can be bought and sold.
    - Regarding the mutual dependency between the Dollar Price and MSCI, no clear preference has been identified. Generally, stock and asset performance can influence the value of the dollar, but it is also true that dollar movements can impact financial performance. This relationship is bidirectional, complex, and multifaceted, varying based on market circumstances and conditions at any given moment.
- Economic volatility has been considered the next indicator of gold price most dependent on other variables. This is because elevated levels of estimated inflation can lead to restrictive monetary policies affecting borrowing costs and, consequently, investment. However, high economic volatility is not necessarily tied to high inflation or interest rates. Moreover, international conflicts or tensions can impact uncertainty, supply, commodity prices, energy, and other critical resources, resulting in economic instability and investor distrust.

- Despite the potential influence of inflation changes on interest rates, impacting credit costs, consumer, and business expenditures, it is asserted that monetary policy holds a more substantial influence on inflation than the reverse. This assertion is substantiated by periods such as the last decade, where economic stimulation occurred through the encouragement of borrowing via low-interest rates. The elevated inflation levels witnessed throughout 2022 may have been exacerbated by geopolitical tensions between Russia and Ukraine, but unequivocally, they were nurtured by the extensive expansionary policies of the past two decades.
- Lastly, the variable considered most influential on others is geopolitical volatility. Every asset, macroeconomic tool, and indicator is subject to and dependent to some extent on international conflicts that govern the rules of the game.

The Impulse Response Functions (IRFs) of the base model are depicted in **Figure *8***. The columns represent the responses of each endogenous variable (vertical axis of each IRF) to each exogenous shock (rows). Therefore, our primary interest lies in the IRFs corresponding to the last row, as they represent the estimated response of gold concerning potential impulses from each influencing factor. Nevertheless, the rest of the IRFs can offer value by facilitating the understanding of the interplay among the system's variables or by enabling the early detection of potential spillovers. The impulse response functions (IRFs) of the main diagonal are typically expected to be consistently positive, as changes in a macroeconomic system are gradual and take a certain time to materialize. Therefore, we will not analyze them.

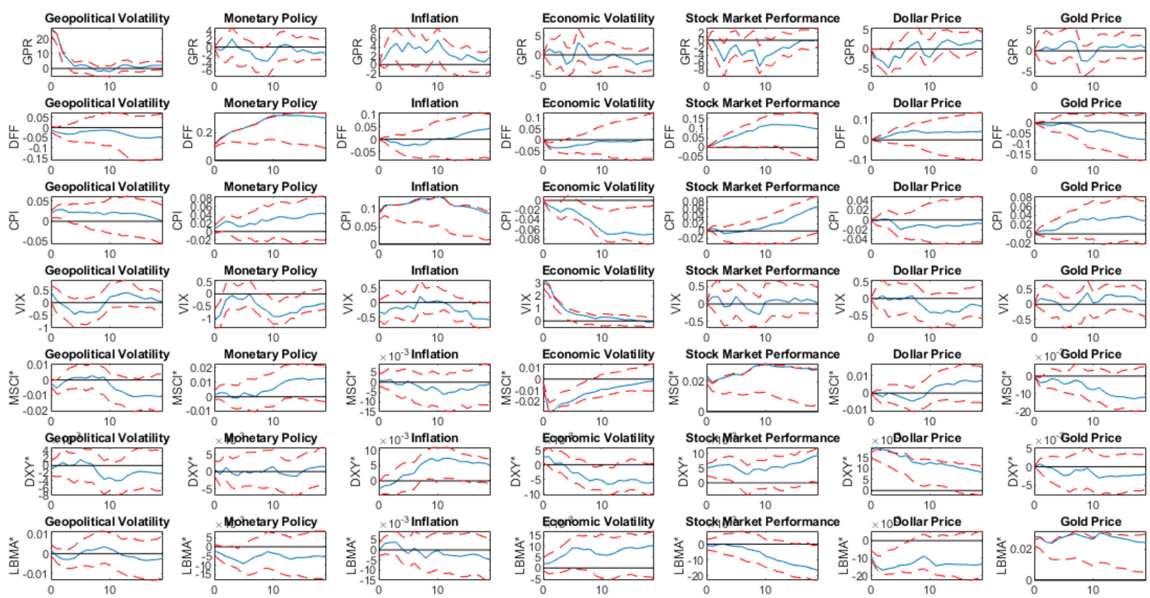

Figure 8. IRFs of the base model

First and foremost, we will examine the last row to determine if the responses of the price of gold to impulses in the variables are statistically different from zero at any horizon, whether such significant responses are positively or negatively related to the shock, and its economic and financial interpretations:

- When there is a peak in the price of the dollar, the response of gold is negative, with a significance level of over 95% confidence, extending beyond the seventh month. If the dollar falls in comparison to other currencies, more dollars will be needed to purchase the same amount of gold after the fall. This aligns with what was presented in **Figure *2***. The speed of change in the price of gold is almost immediate since gold is quoted in dollars, and the change is automatic.
- When a sudden surge occurs in the Stock Market Performance, the relationship is negative, as shown in **Figure *7***. However, in this case, the speed of the gold price response seems to be more delayed, becoming significant only around 15 months after the impulse in portfolio performance. In this regard, we could understand that once investors realize they can trust the market because it is in a bullish state, they tend to redirect their capital to other, riskier, but more profitable assets. This leads to a drop in the demand for gold and its price in consequence. The delayed reaction can be attributed to a "human" factor in decision-making.
- Faced with a surge in Economic Volatility, gold's dependence is positive, understood by the role gold plays as a safe haven. However, this is not significant until a small period around the 5th month after the economic rapid increase. This suggests that the variable may have limited influence on the gold price, leading us to consider its exclusion from the model.
- When there is a peak in Inflation, the LMBA appears to have a positive response during the initial months, which then turns negative over the following months. However, it does not seem to be statistically significant, raising questions about gold as hedge for inflation.
- When Monetary Policy changes, the gold price drops. Furthermore, this relationship remains significant for at least the first five months, after which the influence of interest rate changes may begin to be overshadowed by other factors. This explains that when the central government raises interest rates, investors begin to be reluctant to assume the risk associated with their financial assets, especially when the expected benefits are relatively low and increase the demand of gold, thereby driving up its price.
- A surge in Geopolitical Volatility does not appear to impact the gold price. This is crucial because, being the first variable as explained in Section Eq. (4), its elimination could generate the most significant changes in our benchmark model.

In a second step, we will explore the most significant interdependencies among the remaining variables. This will help us determine if any adjustments are warranted for the earlier conclusions. To achieve this, we will go column by column, examining which variables react most to an impulse in the corresponding factor (excluding how they affect gold, i.e., the last row, which has been previously addressed):

- Peaks in gold or dollar prices do not affect the overall set of other variables, as evidenced by the confidence intervals of the last and the next to last- columns remaining within the initial values of each variable when impulses occur.
- In the scenario where the impulse is generated in Stock Market Performance, two insights emerge. Once this occurs, it can be interpreted as a signal of economic growth, elevating

inflation expectations, as observed in the latest months. This, in turn, prompts banks to increase interest rates to counteract inflation risk. Additionally, during these periods, there is increased buying and selling of stocks, contributing to a higher demand for the dollar.

- An impulse in economic volatility is correlated with a decrease in inflation and a significant short-term decline in portfolio returns. This shift arises from a change in investors' risk perception, leading them to make more conservative decisions that slow down the economy.
- The most substantial impact resulting from an inflation peak is on geopolitical volatility. This is due to the social discontent sparked by tensions and conflicts resulting from the sudden increase in prices for goods and services. Moreover, pressure on essential resources rises, fostering international competition and conflict.
- Turning our attention to the second column and then the fourth row, as previously noted in the variable arrangement, one of the factors significantly affecting economic volatility is the interest rates and policies set by central banks. Ultimately, they define the metrics governing the economy; altering them induces adjustments in asset performance, which can ripple through the economy.
- Similar to our analysis of the IRFs in the last row, it appears that geopolitical volatility is the factor least impacting the rest of the variables. Hence, later, consideration will be given to its potential removal from the model and the ensuing consequences.

In third and final consideration, we will now study and summarize the conclusions drawn from the preceding analysis. This forms the basis for identifying the changes and improvements to be introduced to the benchmark model.

- The occurrence of an impulse in Geopolitical Volatility (GPR) as a measure of geopolitical volatility appears to lack significance for the gold price. On one hand, this may have substantial implications within our model, as inferred in the explanation of **Eq. (4)** and **Eq. (5)** based on the ordering of our variables. On the other hand, this factor could be influencing the interdependent relationships among the others by reducing errors and making them more meaningful. Its examination is detailed in **Section 5.4**.
- Gold is not influenced by a disturbance equivalent to a one standard deviation in inflation rates. Consequently, its removal from the benchmark model has been advocated to facilitate the creation of an improved model. **Section 5.2** examines this case and confirms that it does not affect the rest of the variables.
- To further refine the model, **Section 5.3** substitutes the indicator representing interest rates, the Federal Funds Rate (DFF), with another indicator believed to encompass aspects of monetary policy not previously addressed: the Shadow Interest Rate (SRI). With this latest model, it is deemed that no further improvement can be made given the factors studied, and it is accepted as the final outcome.

5.2 No Inflation

As previously discussed in **Section 3.3**, the options for representing inflationary trends were narrowed down to two different ways of calculating the price of the basket of goods and services: the CPI Core and the CPI Headline. Although not displayed in this document, the significance of the CPI Core was higher, with narrower confidence intervals in relation to its influence on the gold price after an impulse. Nevertheless, this makes sense as the CPI Headline includes the prices of food and energy, which can be affected by geopolitical and economic fluctuations, diminishing the significance of other variables that more accurately capture these disturbances.

Despite opting for the more relevant choice, the influence of the CPI Core is insufficient. This is evident when observing that the Impulse Response Function (IRF) following a peak in inflation does not shift the estimated gold price beyond the initial value at a 95% confidence level in the subsequent months. Therefore, under the premise of enhancing the benchmark model, a decision has been made to create a second model in which the inflation variable is removed from the set. This results in an IRF matrix as depicted in **Figure *9***.

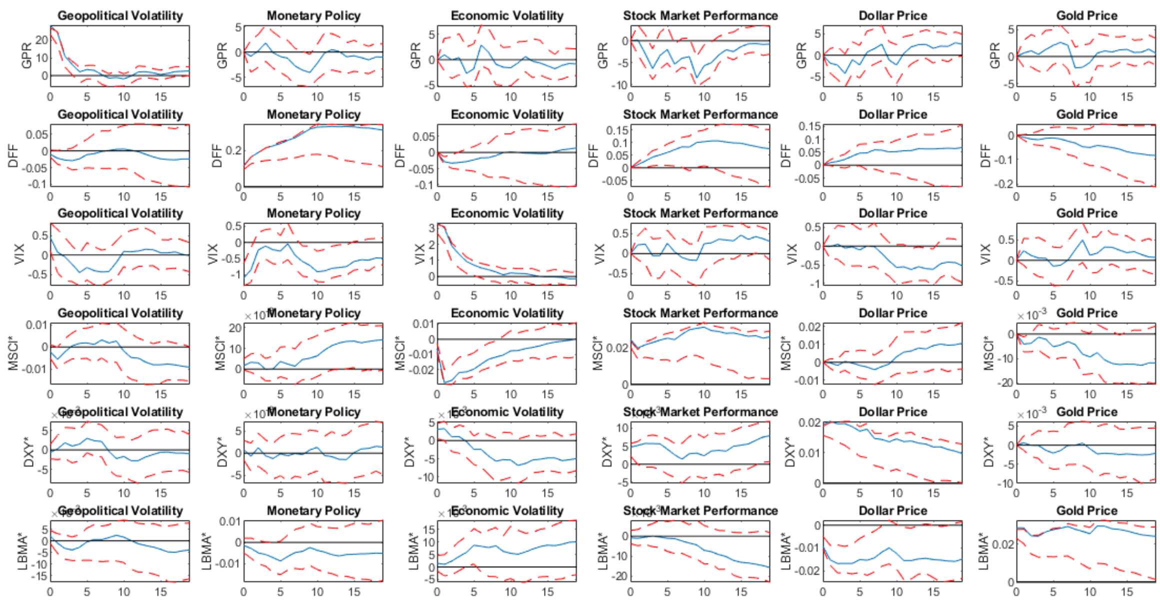

Figure 9. IRFs of the base model without inflation

When comparing with **Figure *8***, the Impulse Response Functions (IRFs) exhibit only slight changes both in form and significance. Thus, we can conclude that eliminating inflation from the model does not generate any significant alterations in the outcomes. Moreover, in all cases, it improves them by removing correlations, for example, with economic volatility. Observing the last row in the case of a peak in economic volatility and its response in the LMBA, it becomes more significant, surpassing the initial value of the gold price's lower confidence interval. In other words, the VIX has gained influence by eliminating inflation. This is likely because some economic disturbance throughout our sample affected both data series, redistributing their impact on gold. By making this change, we verify that at least some of the economic disruptions captured by inflation, affecting the gold price, are probably also identified through economic volatility.

This correlation between exogenous variables in a model is often referred to as a multicollinearity problem. The regression coefficients have been calculated less precisely by introducing two more closely related variables than the model allows, leading to higher variances, making the results less reliable and complicating the interpretation of each variable's unique contribution to the model. As predicted in **Section 5.1**, this issue was anticipated, and it underscores the rationale for our incremental methodology to enhance the benchmark model.

The relationship between the price of gold and inflation has always been a subject of interest and debate in economic literature. Traditionally, it has been argued that there is an inverse relationship between inflation and the price of gold. However, as demonstrated in this research, the relationship is not always immediate. While historically gold has been viewed as a hedge against inflation, factors such as interest rates, macroeconomic conditions, and financial market trends play a more direct role. Moreover, in some cases, gold has proven to be a safe-haven asset not only during inflation but also in periods of deflation. During strong economic crises when investors seek secure assets, gold has shown its real value power.

5.3 SRI over DFF

In examining our benchmark model, we observed that the response of the gold price to a monetary policy impulse appears somewhat ambiguous. While its significance is not disputed until at least five months after the disturbance, it is not as pronounced as anticipated. Therefore, upon reviewing the study of variables in Section 3, it became apparent that there are potentially better variables to represent monetary policy.

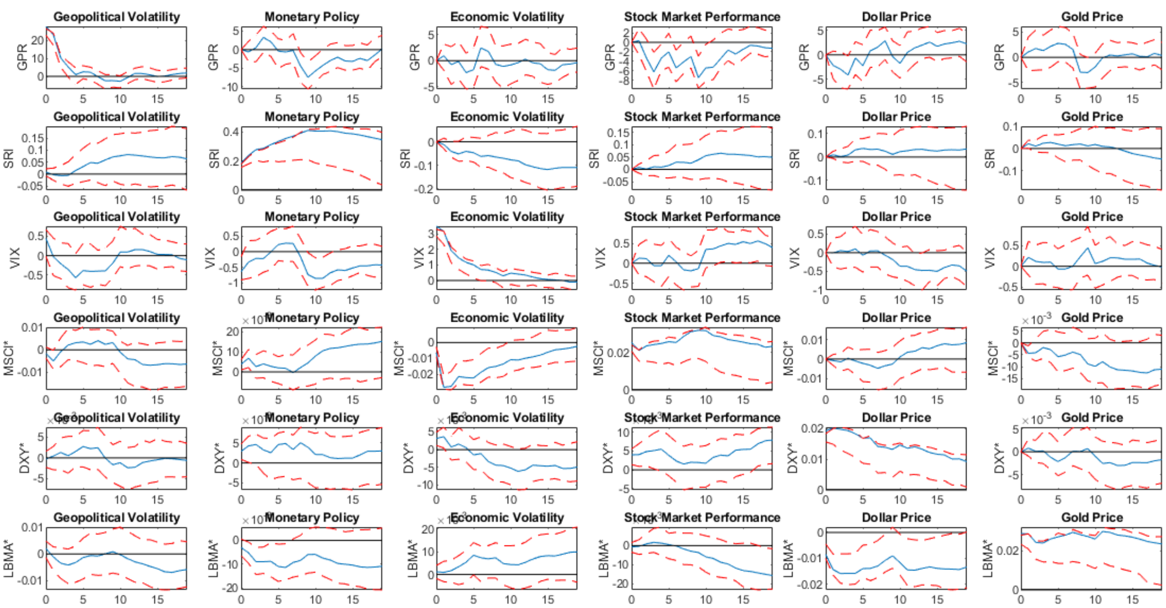

Figure 10. IRFs of the base model without inflation and SRI over DFF

As discussed in **Section 3.4**, while the Fed Funds Rate provides the official interest rate set by the central bank of the United States, the Shadow Rate of Interest offers the equivalent rate as if U.S. monetary policy had been fully implemented through interest rates. This distinction is crucial because, as previously mentioned, once interest rates reach the Zero Lower Bound (ZLB), and there is a need for continued expansionary monetary policy, alternative methods such as quantitative easing come into play.

In **Figure *10***, it can be observed that the impact of substitution is minimal in the Impulse Response Functions (IRFs). This is believed to be since unconventional or non-conventional changes in monetary policy target long-term interest rate. In other words, the trend and influence of conventional monetary policy, which applies changes in official interest rates, explains most of the relationship between short-term interest rates and the price of gold. Therefore, quantitative easing and other unconventional strategies have their real impact in the long term, beyond the 12-month lags of the model.

Nevertheless, this slight impact is crucial in the last row (**Figure *11***), as it causes some of the responses that gold undergoes to either increase or decrease in significance.

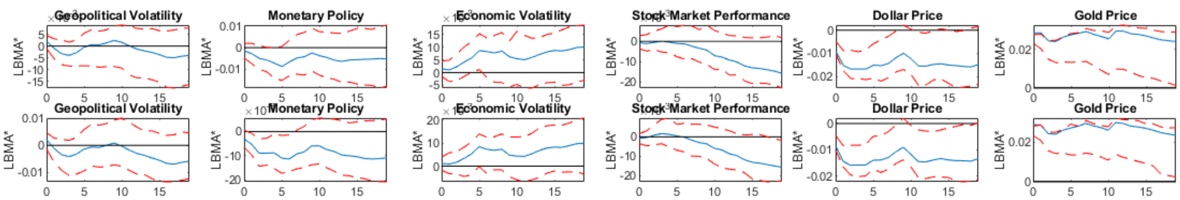

Figure 11. Comparisons of the gold response between the baseline model without inflation with DFF and with SRI

For the case of monetary policy, it can be clearly observed how its significance increases during the first few months after the impulse. In other words, when considering the unconventional measures of an expansionary monetary policy, its impact on the price of gold becomes more significant. This leads us to ask: Is an expansionary monetary policy shock, through measures like quantitative easing more effective than interest rate cuts? In other words, is it necessary to reach the Zero Lower Bound (ZLB) to implement these measures, or would it be more effective to start implementing them earlier? While these questions cannot be conclusively answered with these results, it appears to have a greater sensitivity in our model, at least in terms of the price of gold, when considering measures implemented by central banks.

The alterations observed in the Impulse Response Function (IRF) of the VIX are minimal. Although confidence decreases around the fifth month, we can still assert its significance at that point. Similar dynamics are observed for the MSCI World; however, in contrast, significance improves around the last few months, although these improvements are almost imperceptible.

Conversely, the significance of the impact of a surge in the dollar price increases considerably. Especially in the last 10 months, where confidence was wavering. Moreover, this positions these variables as the one that most significantly affects the price of gold. This impact makes sense since quantitative easing involves the mass purchase of financial assets by the state, increasing the money supply and putting more dollars into circulation, thereby affecting the dollar's value. This effect is further emphasized if central banks have kept interest rates low, making dollar-denominated assets less attractive.

5.4 Impact of Geopolitical Volatility

Having removed inflation from the benchmark model and substituted the Federal Funds Rate (DFF) with the Shadow Rate of Interest (SRI), the next step is to explore the elimination of Geopolitical Risk (GPR), aligning with the conclusions drawn from the analysis of the benchmark model. To assess its relevance in the model, we executed the code to examine its influence on the remaining variables. The Impulse Response Functions (IRFs) matrix for this new model aligns with **Figure *12*.**

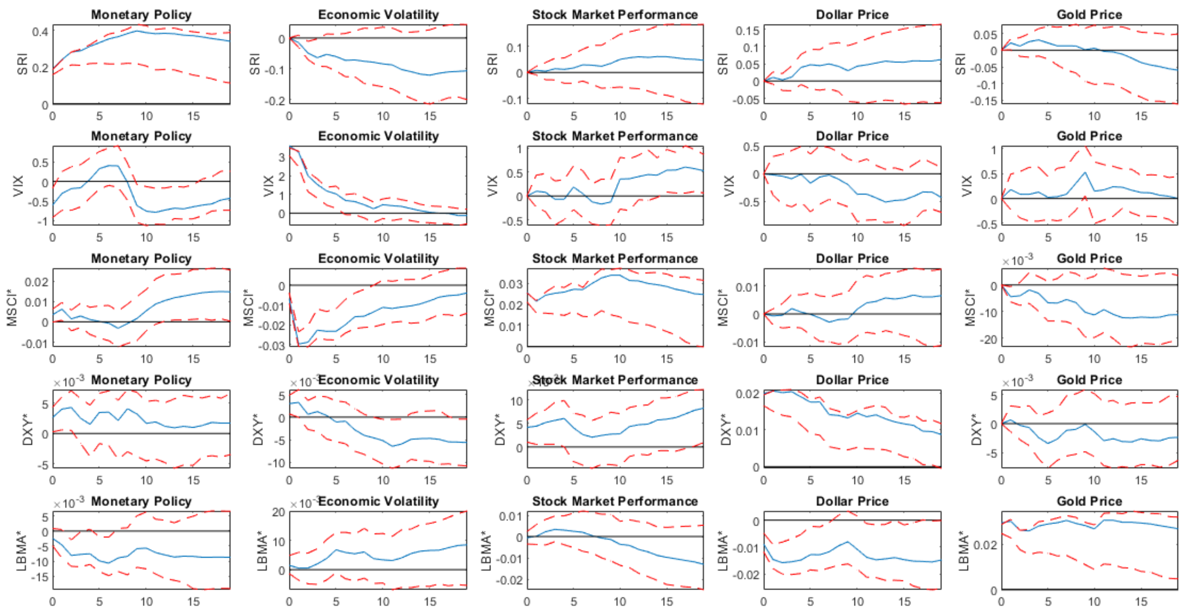

Figure 12. IRFs of the base model without inflation, geopolitical volatility, and SRI over DFF

As observed in comparison with **Figure *10***, most responses do not exhibit significant changes in shape or magnitude, but there are alterations in reliability contours. Focusing on the last row, the gold response to shocks in economic volatility and market performance ceases to be significant at a 95% confidence level. This degradation significantly weakens the model, leaving only monetary policy and the dollar price as significant.

At the end, the variable should not have been removed. GPR was capturing all disturbances in our historical sample related to international conflicts that were impacting other variables, eliminating the associated noise. Like the decision to remove inflation, eliminating geopolitical volatility proves to be ill-advised. The issue lies in the fact that disputes between nations often have a substantial impact on every macroeconomic variable. Given that our model encompasses many such variables, incorporating a factor that accounts for these geopolitical disruptions, even if it is not statistically significant concerning gold, enhances prediction accuracy and strengthens explanatory power.

5.5 Final Model Analysis

After deciding to eliminate the Consumer Price Index Core, substitute the Fed Funds Rate with the Shadow Rate of Interest, and retain Geopolitical Risk, the final model that we adhere to, and believe better represents the gold price, consists of the following five factors: Geopolitical Volatility (GPR), Monetary Policy as Interest Rate (SRI), Economic Volatility (VIX), Stock Market Performance (MSCI), and Dollar Price (DXY).

Although the IRFs matrix has already been presented and analyzed through **Figure *11***, this section will thoroughly examine the IRFs that specifically illustrate the gold price response to shocks introduced in the factors believed to affect it.

Figure 13 depicts the IRF concerning gold when a shock occurs in geopolitical volatility. The GPR does not seem to generate a change in the gold price that can be asserted with 95% confidence. Nevertheless, as mentioned in **Section 5.4**, its contribution to the model is deemed essential.

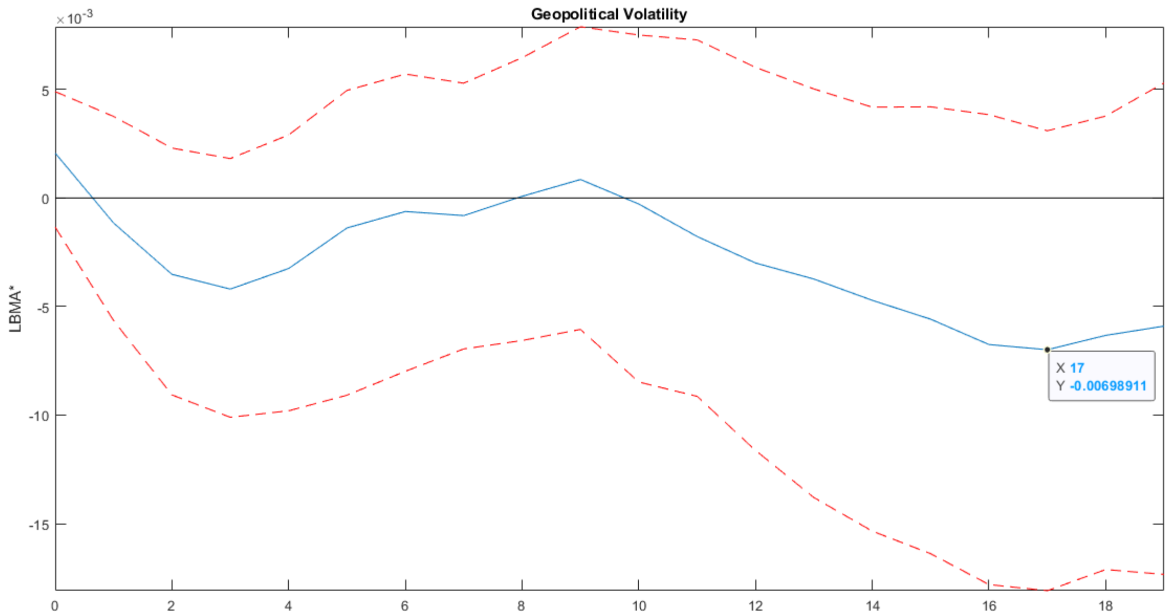

Figure 13. LMBA Gold response to a shock of one standard deviation in GPR

Through **Figure 14**, we can observe the response that gold exhibits over the 19 months following a disturbance equal to one standard deviation in the Shadow Rate. According to our model applied to our chosen sample and period, a peak of 2.7755% (standard deviation) in the SRI causes, by the second month, a gold price drop of more than \$1.76/oz (\$2.12 $* 10^{-3}$ normalized) with a 95% confidence level. In the subsequent months and the last ones, the estimated decline is greater, although the error prevents us from asserting anything (around more than \$5.25/oz for those months where the LMBA response is below the $10 * 10^{-3}$ mark on the vertical axis). This demonstrates a strong negative reaction of the gold price to changes in monetary policy, whether applying interest rates or unconventional measures.

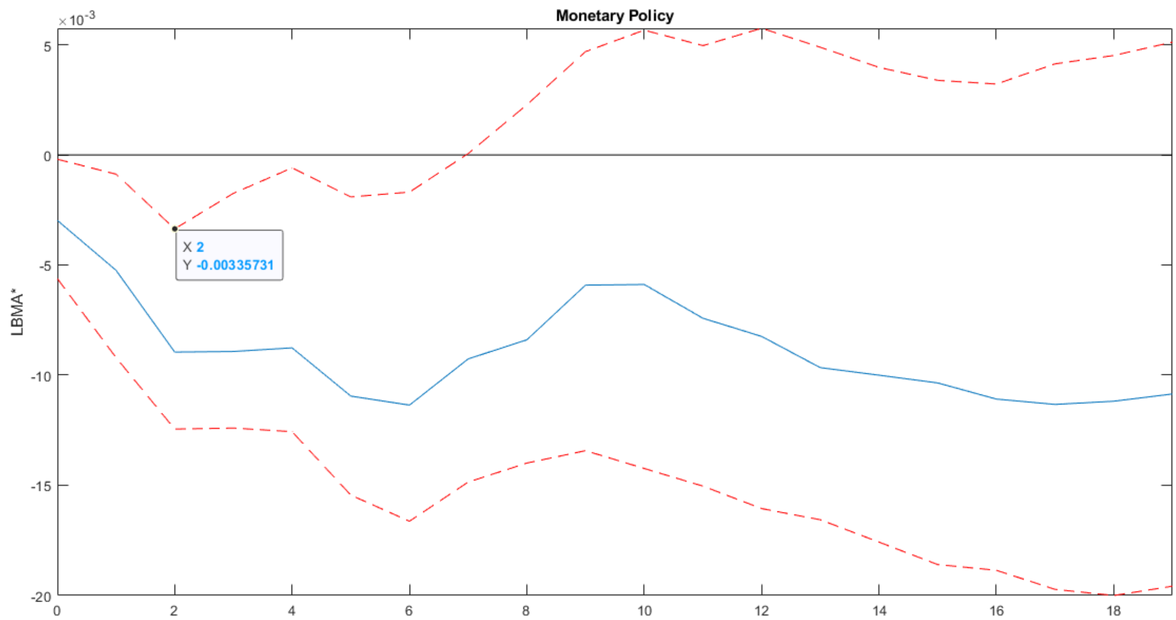

Figure 14. LMBA Gold response to a shock of one standard deviation in SRI

Figure 15 corresponds to the response of the gold price to an impulse of 7.65 points (standard deviation) in the VIX. Unlike monetary policy, gold reacts positively to such a shock, assuring us with 95% confidence that it will rise by more than $0.55/oz after the fifth month. In the following months, our model's estimation suggests that the LMBA will remain around $2.62/oz (equivalent to $5 * 10^{-3}$ on the vertical axis) compared to the initial value, although it cannot assure us with sufficient confidence.

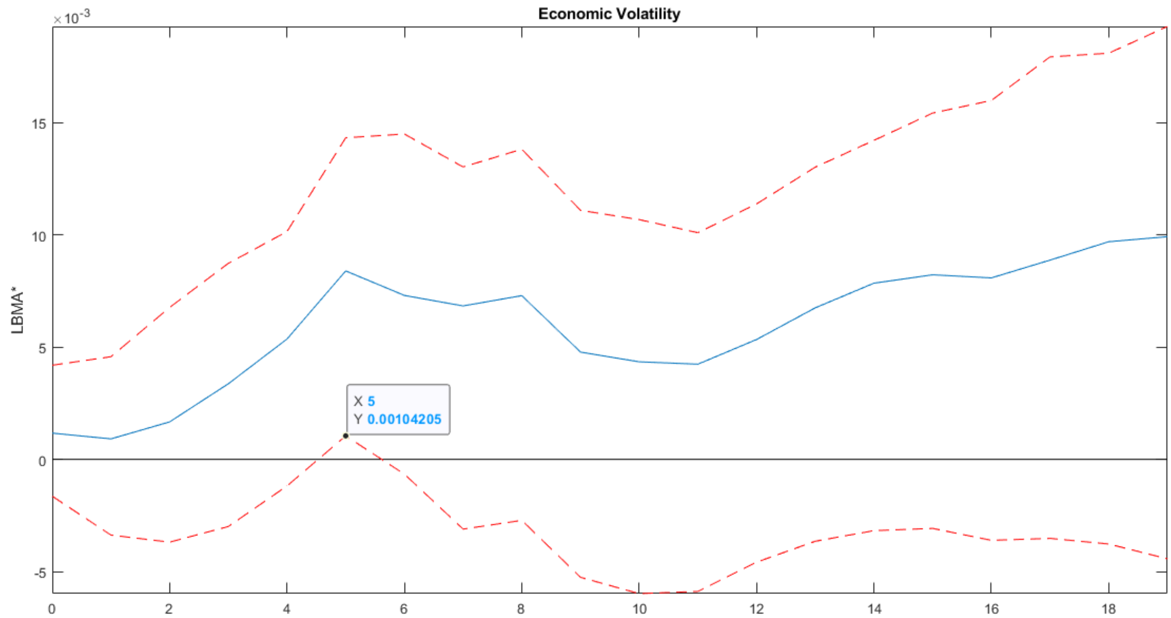

Figure 15. LMBA Gold response to a shock of one standard deviation in VIX

For the MSCI World case, the price reaction is much later, as explained in **Section 5.1**. This is mainly because it depends on human decisions in which investors first see how the performance of assets worsens but trust that it is transitional to avoid losing profits despite the risk, until it is no longer worth running that uncertainty, and they switch to buying gold. The IRF in **Figure 16** expresses this correctly, ensuring that the change will only be seen from the 14th month onwards. With a peak of significance in the 17th month, where gold would drop at least $0.91/oz if a rebound in the MSCI World of 442.69 points (standard deviation) had occurred in the moment of the shock.

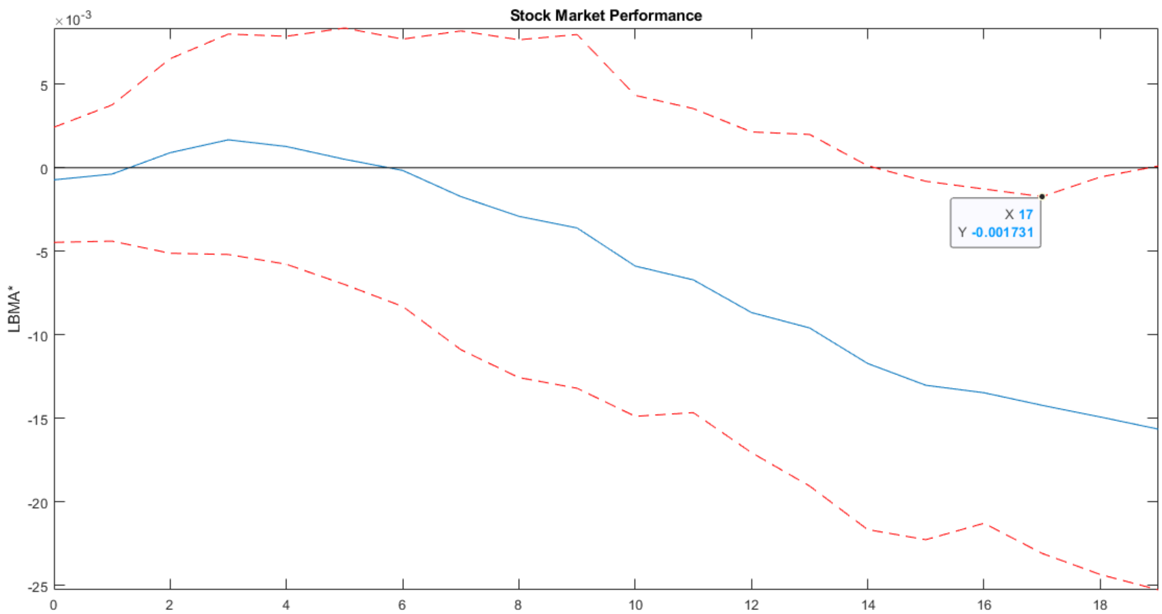

Figure 16. LMBA Gold response to a shock of one standard deviation in MSCI World

Finally, the dollar price is found to be the determining factor in the price of gold. The strong significance of the DXY in our model is largely due to it being the last variable introduced, and as explained in Section 4, the ordering of variables is a determining factor. It is the only dataset whose noise shown in its IRF is composed of itself and the factors that we cannot explain from the gold price, which should be minimal because that's why we made this model. This IRF is found in **Figure 17** and shows an inverse relationship. According to this IRF, due to a rise of 9.92 pts (standard deviation), the peak of significance occurs in the fourth month, with the gold price dropping by at least $4.94/oz at a 95% confidence level. According to the model's estimate, the price should drop by around $7.87/oz and remain there. The reaction of gold is instantaneous because, as explained for the benchmark model, most gold transactions are conducted in U.S. dollars.

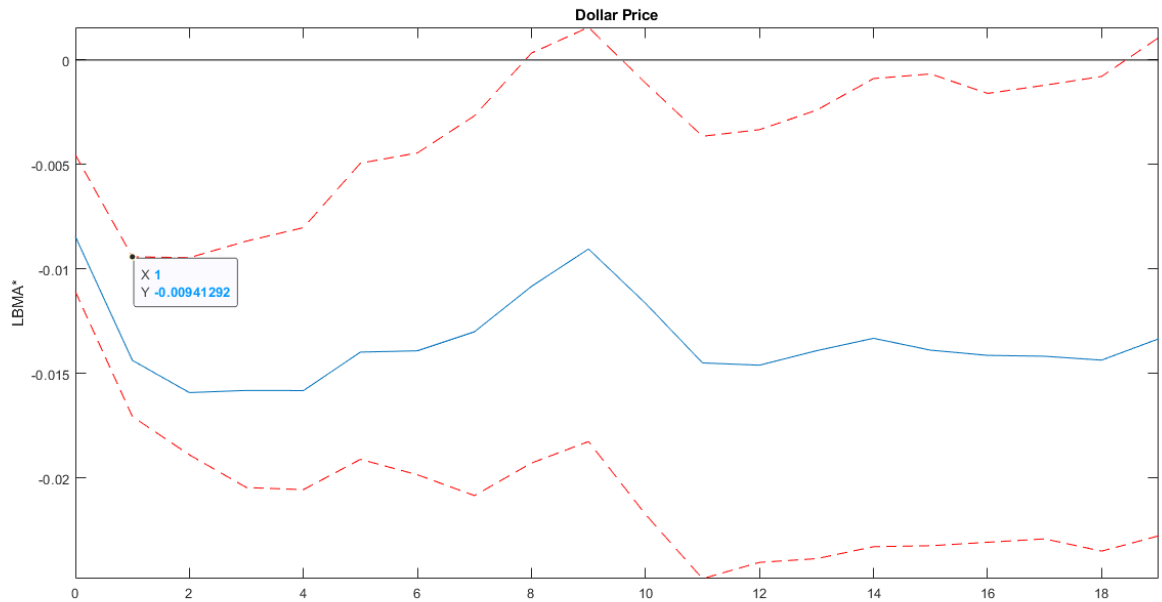

Figure 17. LMBA Gold response to a shock of one standard deviation in DXY

5.6 Historical Decomposition of the Final Model

We now proceed to make use of the impulse response functions to identify the shocks of for the sample period of study. This allows us to build the historical decomposition and, therefore, identify for each point in time, the contribution of each shock to the fluctuations in the price of gold.

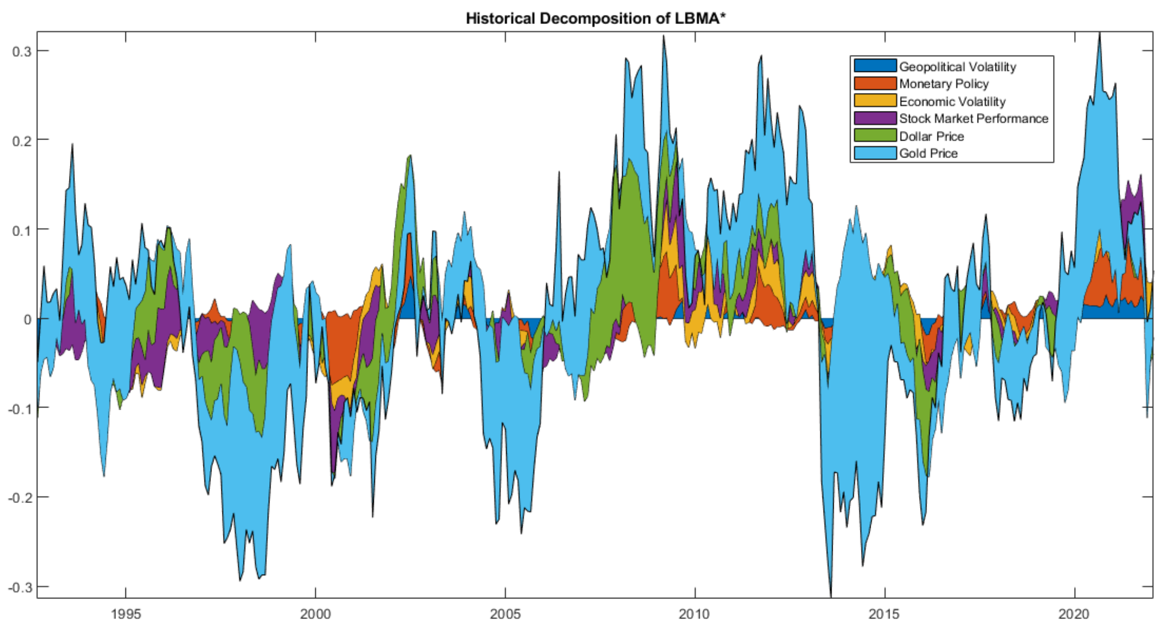

Figure 18. Historical Decomposition of the LBMA Gold.

This historical decomposition (**Figure *18***), covering October 1992 to February 2022, does not start at the initial date of our sample due to how a historical decomposition is estimated, accumulating the IRFs. The first point in this graph (January 1990) is the one that takes into account all possible dependencies of the other variables. According to our analysis, we find the following periods:

- 1992-1996: During this period, gold did not undergo significant changes. The context in the early 1990s was characterized by economic stability, some growth due to the end of the Cold War, but uncertainties stemming from revolutions in Eastern Europe and the Gulf War. In **Figure *18***, our model associates this with the stability of portfolio returns and the price of the dollar.
- 1996-2001:
    - 1996-2000: In this era, gold experienced a certain decline compared to its behavior over the last three decades. The reason lies in the rise of the internet and the exponential growth of technology-related companies, leading investors to shift from gold to dot-coms. This event is perfectly captured in the historical decomposition by MSCI World, which adds to the effect also occurring in the dollar. The problem was that many of these companies were not profitable or did not have sustainable benefits and were valued at extremely high prices. The result was the burst of the bubble at the end of the century, appreciating the value of gold.
    - 2000-2001: Despite everything, it seems that this upturn was not very extensive for LBMA Gold, as the consequence was a restrictive monetary policy affecting its quotation. This is shown by our model, where the major influence is located in the increase of interest rates.
- 2001-2005:
    - 2001: After September 11, the world was turned upside down, experiencing a period of great instability, increasing the price of gold. In **Figure *18***, the GPR perfectly captures this event, which, as it has been explained before, affects the rest of the variables.
    - 2002-2007: After all the irregularity in the markets, calm arrives. Gold undergoes a certain equilibrium mainly due to the performance of assets recovering.
        - 2003: This calm was relative because, as captured by the GPR, there is a slight rebound, probably due to the Invasion of Iraq.
        - 2003-2005: Afterward, economic growth takes center stage again, although it seems that our model finds the response to the decline in the price of gold only in a small part, thanks to MSCI World.
- 2005-2013
    - 2005-2008: It is the prelude to the 2008 crisis, where it seems that gold had already changed its bearish trend. Our historical decomposition cannot find significance other than a little in the price of the dollar.
    - 2008-2013: The real estate crisis arrives, and the world is turned upside down again. It is remarkable how during this period, our variables (the price of the dollar initially and then monetary policy, economic instability, and portfolio returns) are where they best explain the value of gold.

- 2013-2016: Like all crises, recovery follows. Therefore, once again, we observed a decrease in the price of gold. Although the model cannot explain why it dropped so quickly in mid-2013 (it may be due to a small bubble in the price of gold during the crisis, as all investors rushed to it amid so much instability), it can explain from 2016 onwards, when interest rates rise again.
- 2016-2020: It is characterized by being a transitional stage, and the same can be identified in LBMA Gold, which returns to its trend.
- 2020-2022: The arrival of a new crisis caused by a global pandemic, COVID-19, is clearly captured by the geopolitical volatility indicator. This causes the price of gold to soar as demand increases from investors who see no profitability in their assets and desperately buy gold as a safe haven.

After this analysis of the historical decomposition of the value that gold takes, the factors considered most influential lead to a very important inference. Looking at **Figure *18***, our model finds an explanation for the gold's response during bullish periods through variables such as geopolitical instability, economic instability, and monetary policy, while during bearish periods, it finds it through indicators like portfolio returns or the price of gold. This leads us to recommend future studies in which a model is proposed where regression coefficients can change depending on the state of the business cycle.

6 Conclusions

The objective of this research has been to interpret the complex relationship between the price of gold and various distinguished factors. To achieve this, a rigorous empirical analysis based on a Vector Autoregressive model, also known as VAR, has been employed. The methodology used involved implementing a meticulous iterative process. This process started with a benchmark model and progressively refined it through successive iterations, incorporating gradual improvements in each of them. The study explored relationships through a dataset structured in monthly time series, including the Geopolitical Risk Index (GPR), the Federal Funds Rate (DFF), the Shadow Rate of Interest (SRI), the Consumer Price Index (CPI) Core, the Economic Volatility Index (VIX), the Morgan Stanley Capital International (MSCI) World, the U.S. Dollar Index (DXY), and the London Bullion Market Association (LBMA) Gold.

The empirical analysis unfolded in three significant phases: exploration of interdependencies among variables as an examination of the benchmark model; implementation of enhancements, elimination of redundancies, and substitution of indicators; and finally, a detailed analysis of the Impulse Response Functions (IRF) of the final model and historical decomposition of the price of gold.

The benchmark model, constructed rigorously based on existing literature, aimed to capture high-level dynamics of gold. The IRFs matrix formed by the VAR model was used for this purpose, providing a detailed view of temporal dynamics and importance levels between exogenous factors and gold. The results revealed possible compelling ideas for refining the model: eliminating inflation as a reference for gold, replacing the DFF interest indicator with the SRI, and removing the influence of GPR on LBMA Gold.

The removal of inflation from the model was a success, resolving an issue of multicollinearity without affecting the significance of the remaining influential exogenous variables in the value of gold.

The substitution of the Federal Funds rates with the Shadow Rate was a wise decision. This indicator contributed to the model by reflecting the consequences of continuing unconventional monetary policies such as quantitative easing during periods when interest rates are close to the Zero Lower Bound (ZLB).

However, the removal of GPR as a measure of geopolitical instability, initially not significant in relation to the price of gold, did not yield better results. This was due to the nature of the VAR model. As the variable on which many others depend, capturing all global events and conflicts, it is the first to be introduced into the model, adding predictive accuracy, and strengthening explanatory power by mitigating noise from other variables.

The final model, composed of Geopolitical Volatility, Monetary Policy represented by the Shadow Rate of Interest, Economic Volatility, Stock Market Performance, and Dollar Price, best explains the value of the gold price throughout the collected sample. Its IRFs provide a nuanced understanding of the responses and sensitivity of gold to the impacts of each influencing variable.

The historical decomposition further enriched our perceptions, exposing the complex narrative of gold price movements throughout history. From periods of relative stability attributed to economic growth and geopolitical calm to tumultuous moments marked by crises, it offers a vivid account of the multifaceted influences on gold prices. Identifying key moments, such as the dot-com bubble, the aftermath of September 11, the 2008 financial crisis, and the recent upheavals triggered by the global pandemic, underscored the diverse drivers shaping the trajectory of gold.

The study, by contributing valuable insights, also opens avenues for future explorations. The observed sensitivity of the model to economic states prompts reflection on models where regression coefficients dynamically adapt to prevailing economic conditions. This nuanced approach could potentially enhance the predictive capabilities of the model during bullish and bearish periods.

In general terms, this document provides a comprehensive understanding of the intricate relationships governing gold prices. The journey from the benchmark model to the final iteration encapsulates the nuanced dynamics of the gold market, revealing its responsiveness to geopolitical events, changes in monetary policy, economic volatility, stock market performance, and currency fluctuations. As we navigate the complexities of the global economic landscape, this research serves as a valuable compass, guiding us through the intricate interaction of variables shaping the price of this precious metal.

7 References

Ayea, G., Guptaa, R., Hammoudeh, S., & Kim, W. J. (2015). Forecasting the Price of Gold Using Dynamic Model Averaging. *International Review of Financial Analysis*, 257-266.

Bank of St. Louis. (2023). *Federal Reserve Economic Data (FRED).* From https://fred.stlouisfed.org/series/CORESTICKM159SFRBATL

Bank of St. Louis. (2023). *Federal Reserve Economic Data (FRED).* From https://fred.stlouisfed.org/series/DFF

Bank of St. Louis. (2023). *Federal Reserve Economic Data (FRED).* From https://fred.stlouisfed.org/series/VIXCLS

Benford, J., Berry, S., Nikolov, K., Young, C., & Robson, M. (2009). Quantitative easing. *Bank of England | Quarterly Bulletin*, 90-100.

Białkowski, J., Bohl, M. T., Stephan, P. M., & Wisniewski, T. P. (2014). The gold price in times of crisis. *International Review of Financial Analysis*, 329-339.

Caldaray, D., & Iacoviello, M. (2016). Measuring geopolitical risk. *112*, 1194-1225.

Caliskan, D., & Najand, M. (2015). Stock market returns and the price of gold. *Journal of Asset Management, 17*, 10-21.

Caminschi, A., & Heaney, R. (2013). Fixing a Leaky Fixing: Short-Term Market Reactions to the London PM Gold Price Fixing. *Journal of Future Markets, 34*, 1003-1039.

ChatGPT. (s.f.). *For translating and rephrasing purposes*. From https://chat.openai.com/

Chiang, T. C. (2022). The effects of economic uncertainty, geopolitical risk and pandemic. *Resources Policy, 76*.

Eichengreen, B. (2021). Bretton Woods After 50. *Review of Political Economy, 33*, 552-569.

EPU. (2023). *EPU Indices.* From https://www.policyuncertainty.com/gpr.html

Erb, C. B., & Harvey, C. R. (2013). The Golden Dilemma. *National Bureau of Economic Research*, 31-35.

Huang, X., Jia, F., Xu, X., & Shi, Y. (2019). The threshold effect of market sentiment and inflation expectations on gold price. *Resources Policy, 62*, 77-83.

Ismail, Z., Yahya, A., & Shabri, A. (2009). Forecasting Gold Prices Using Multiple Linear Regression Method . *American Journal of Applied Sciences*, 1509-1514.

Kilian, L., & Lütkepohl, H. (2016). Structural Vector Autoregressive Analysis. *Cambridge University Press*.

Mathworks. (2023). *Matlab*. From https://www.mathworks.com/help/matlab/ref/detrend.html#f81-998832

O'Connor, F. A., Lucey, B. M., & Baur, D. G. (2016). Do gold prices cause production costs? International evidence from country and company data. *Journal of International Financial Markets, Institutions and Money, 40*, 186-196.

Pan, W.-F. (2018). Sentiment and asset price bubble in the precious metals markets. *Finance Research Letters*, 106-111.

Qian, Y., Ralescu, D. A., & Zhang, B. (2019). The analysis of factors affecting global gold price. *Resources Policy, 64*.

The World Bank. (2023). *Monthly commodity prices data.* From https://www.worldbank.org/en/research/commodity-markets

Triki, M. B., & Maatoug, A. B. (2020). The GOLD market as a safe haven against the stock market uncertainty: Evidence from geopolitical risk. *Resources Policy, 70*.

World Gold Council. (8 de february de 2023). *Above-ground stocks.* From https://www.gold.org/goldhub/data/how-much-gold

Wu, J. C., & Xia, F. D. (2016). Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound. *Journal of Money, Credit and Banking, 48*, 253-291.

Xian, L., He, K., & Lai, K. K. (2016). Gold price analysis based on ensemble empirical model. *Physica A*, 11-23.

Yahoo. (2023). *Yahoo Finance.* From https://finance.yahoo.com/quote/DX-Y.NYB/history?period1=662688000&period2=1684972800&interval=1mo&filter=history&frequency=1mo&includeAdjustedClose=true