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Are precious metals as precious as they are?

Marwa Talbi

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Are precious metals as precious as they are?

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With love,

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To my parents,

Preface

This thesis is carried under a joint supervision between the University of Claude Bernard Lyon 1 (ISFA) and University of Sousse (IHEC). This work was financially supported by the “PHC Utique” program of the French Ministry of Foreign Affairs and Ministry of higher education, research and innovation and the Tunisian Ministry of higher education and scientific research in the CMCU project number 18G0411. It was also partially financed by the University of Sousse.

This thesis is made of three chapters and each chapter represents a scientific article. The first and the second chapter are published in *Resources Policy*. The last chapter is submitted to *Economic Modelling*.

For administrative reasons, this thesis started on May 15, 2017.

Résumé

Les métaux précieux sont-ils aussi précieux qu'ils le sont ?

Cette dissertation se focalise sur trois thématiques principales liées aux marchés des métaux précieux avec une attention particulière pour : (1) la dynamique et la causalité entre les métaux précieux au comptant et à terme, (2) les propriétés d'investissement des métaux précieux en tant que couverture, valeur refuge et actifs de diversification pour les marchés boursiers du G-7 et, (3) l'impact de l'incertitude de la politique économique (EPU) sur la dépendance entre les métaux précieux et les marchés boursiers des BRICS.

Nous analysons, dans un premier temps, la structure de dépendance entre les rendements spot et futurs des métaux précieux (or, argent et platine) en utilisant des copules statiques et dynamiques et la causalité de Granger dans la distribution (GCD) entre les paires spot-future de métaux précieux en utilisant le test de causalité de Granger non linéaire basé sur la méthode des copules. Les résultats de l'estimation des copules statiques et dynamiques montrent que la dépendance entre les rendements spot et futurs des métaux précieux est fortement dynamique. Concernant la dépendance durant les conditions extrêmes du marché, elle est fortement symétrique dans les queues pour les paires spot-future de l'or et du platine (décrite par la copule Student) et pour les paires spot-future de l'argent (décrite par la copule SJC). Concernant la causalité, l'évaluation de la causalité de Granger dans la distribution a été effectuée à l'aide du test d'indépendance non paramétrique basé sur la copule empirique.

Les résultats révèlent une causalité unidirectionnelle dans la distribution du marché des métaux précieux futurs vers le marché comptant, en période normale. On peut donc dire que pendant les périodes normales les rendements au comptant des métaux précieux dépendent des valeurs passées des rendements futurs, ce qui signifie que le marché futur est en tête du marché au comptant. Alors que, l'effet causal semble être bidirectionnel en temps de crise pour l'or (de 2002 à 2007) et de platine (de 2002 à 2010) en raison de la forte demande sur le marché physique des métaux précieux dans ces périodes. Ces résultats sont importants pour les investisseurs, car la compréhension des conditions du marché est une question centrale lors de la construction des stratégies de trading.

Le deuxième chapitre propose une nouvelle méthode pour analyser les propriétés d'investissement de couverture, de valeur refuge et de diversification des métaux précieux (or, argent et platine) pour les marchés boursiers du G-7. À l'inverse des études existant dans la littérature qui n'utilisent que des copules bivariées, nous utilisons le modèle GARCH basé sur des copules multivariées de vine. Les résultats montrent que l'or est l'actif de couverture et de refuge le plus fort, sur presque tous les marchés boursiers du G-7. Pour l'argent et le platine, les résultats montrent qu'ils peuvent jouer un rôle de couverture mais plus faible que l'or. En plus, contrairement à la littérature existante, l'argent ne peut jouer un rôle de valeur refuge que sur les marchés boursiers Allemands et Italiens. Alors que, le platine joue un faible rôle de valeur refuge pour la plupart des marchés boursiers développés. En nous proposons une nouvelle mesure de risque, appelée la Value at Risk bivariée (BiVaR), pour analyser la propriété de diversification des métaux précieux. Les résultats ont prouvé que les métaux précieux peuvent dans tous les cas offrir des avantages de diversification sur les marchés boursiers du G-7.

Enfin, le troisième chapitre traite l'impact de l'incertitude des politiques économiques (EPU) sur la dépendance en quantile entre les métaux précieux et les marchés boursiers des BRICS en appliquant l'approche des quantiles croisés (« cross-quantilogram »). Nos résultats conduisent aux mêmes conclusions, que l'on contrôle ou pas l'EPU. En effet, nous avons montré que l'or est un actif de couverture parfait en Russie et en Inde. Alors que l'argent et le platine ne peuvent être considérés comme des actifs de couverture que pour le marché boursier Chinois. En outre, sur l'ensemble de la période d'étude, nous constatons que les rendements boursiers extrêmement négatifs ont été suivis par des rendements positifs extrêmes pour l'or sur tous les marchés boursiers, à l'exception du Brésil et de la Chine. Par conséquent, l'or n'est pas une valeur refuge sur ces marchés boursiers. Toutefois, l'argent n'est une valeur refuge qu'en Chine et le platine en Chine et en Afrique du Sud.

Mots-clés : Métaux précieux, marchés boursiers, copules, propriétés d'investissement, causalité, incertitude économique, structure de dépendance

Abstract

Are precious metals as precious as they are?

This dissertation focuses on three main themes related to precious metals markets with particular attention to: (1) the dynamics and causality between spot and forward precious metals, (2) the investment properties of precious metals as hedge, safe haven and diversification assets for G-7 equity markets and, (3) the impact of economic policy uncertainty (EPU) on the dependence between precious metals and BRICS equity markets.

We first examine, in the first chapter, the dependence structure and the Granger causality in distribution (GCD) between spot and future returns of precious metals (gold, silver, and platinum) via copula modelling. This study considers the evidence on real precious metals returns from Jan 2, 2002 to Jan 13, 2017. Throughout literature, the use of copula in precious metals markets is still limited. Indeed, unlike linear methods, using a copula-based approach has several attractive advantages. Using static and dynamic copulas, we find that the dependence between the spot and the future returns of precious metals is relatively strong and time varying with a strong tail dependence for all pairs. Then, applying independence test based on the empirical copula, we detect a unidirectional GCD from future to spot precious metals market during normal times. This result means that past information from the future returns improves forecasts of spot returns. However, the causal relationship seems to be bidirectional in the case of gold and platinum during crisis periods. Our findings are important to investors for investigating hedging strategies since the efficacy of a hedging strategy is dependent on the price discovery mechanism. Hence, they should take the above findings into consideration to make optimal decisions, especially during periods of marked instability.

The second chapter discusses the hedge, safe haven, and diversification properties of precious metals—namely gold, silver, and platinum—for the G-7 stock markets. Therefore, this study proposes a multivariate vine copula-based GARCH model to assess the hedge and safe haven properties of precious metals and a Bivariate Value at Risk-based copula (BiVaR) measure to

analyse the diversification potential of precious metals. Our empirical results suggest that gold is the strongest hedge and safe haven asset in almost all the G-7 stock markets. Whereas silver and platinum results show that they may act as weak hedge assets. Results of safe haven analyses show that silver bears the potential of a strong safe haven role only for Germany's and Italy's stock markets; however, platinum provides a weak safe haven role for most developed stock markets. Finally, precious metals appear as interesting assets for diversifying a portfolio for G-7 stock markets investors. Overall, our findings provide noteworthy practical implication for investors.

The last chapter investigates the impact of the Economic Policy Uncertainty (EPU) on the quantile dependence between precious metals and BRICS stock markets. Applying the cross-quantilogram approach, our results lead to the following findings. First, we provide evidence that gold is a perfect hedge in Russia and India. While silver and platinum may be seen as hedge assets only in the China stock market. Adding to that, over the entire sample period, we find that extreme negative stock market returns were followed by extreme positive gold returns for all stock markets except for Brazil and China. Hence, gold is not a safe haven in these stock markets. However, silver is a safe haven only in China stock market and platinum is a safe haven in China and South Africa stock markets. Second, the estimation results of the partial cross-quantilogram (PCQ) reveal that the dependence structure across quantiles is found to be consistent, even after controlling for EPU.

Keywords: Precious metals, stock markets, copulas, investment properties, causality, Economic Policy Uncertainty, dependence structure

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General Introduction

“Good as gold,” “silver lining,” “platinum record”—these familiar expressions are all references to supreme value. It is not a coincidence that precious metals are interwoven into concepts of value, good fortune, and accomplishment.¹

1. Research overview

In the aftermath of the Global Financial Crisis (GFC), the world’s financial markets have seen substantial and continuous changes which have affected the worldwide economies. Over time, due to the globalization and liberalization of capital markets, financial markets have become more integrated and the interest in studying the interaction between financial assets has grown. In this context, investors sought to minimize their potential losses by shifting from risky assets to less risky ones by holding commodities in their portfolios, practically precious metals, due to their special features related to store of value and risk diversification. (Adrangi et al.2003; Lucey & Tully, 2006a-b). This herd-like behavior is called “flight-to-quality” or “flight-to-safety”.

Since then, the demand for precious metals has become increasingly important and remarkable not only for an industrial use but also for investment purposes. In particular, gold is the oldest commodity that has served historically as a currency and still remains a monetary asset. According to Capie et al. (2005), gold has been a key component of global monetary reserves for trading and currency hedging. Therefore, issues related to precious metals markets have become the main focus of research in the field of Finance.

¹ Gotthelf (2005)

This thesis will cover three main topics related to precious metals markets with a special concern for: (1) dynamics and causality between spot and future precious metals, (2) the investment properties of precious metals as hedge, safe haven and diversification assets for the G-7 stock markets and, (3) the impact of economic policy uncertainty (EPU) on the dependence between precious metals and BRICS stock markets.²

The first topic assesses the price discovery mechanism by analyzing the dependence structure and causality between precious metals (gold, silver and platinum) spot-futures pairs. Since the last two decades, trading in precious metals futures has become increasingly important followed with an increase in the growth rate and volatility of precious metals spot prices which is known as the “financialization” phenomenon.

Hence, understanding the co-movements across spot and future markets is important since it provides economic implications for different market actors (hedgers, speculators, and arbitrageurs) in price discovery, information transmission and efficient allocation. Identifying the direction of information flows between spot and futures prices, then, appears to be essential in understanding how fast one market reacts to the new information relative to the other.

The causal relationship between spot and futures markets has been an area of extensive empirical research, as it can help investors during decision-making process and help in discovering potential arbitrage opportunities between spot and futures prices. Therefore, this topic still attracts noteworthy attention from the academic scene.

Regarding the causality between precious metals spot and futures markets in assessing the price discovery mechanism; gold market has received the most attention from academic researches. Indeed, the empirical results of the literature are mixed. Evidence for a unidirectional causality from the futures market to the spot market is frequently found in the literature (e.g., Joseph et al., 2014; Jena, 2018). Nonetheless, unidirectional causality from spot to futures market (for instance, Srinivasan, 2012) and bidirectional causality were fully identified (e.g., Dash and Andrews, 2010 and Bhatia et al., 2018).

To the best of our knowledge, although several studies investigate the dynamics and causality among precious metals, the causality among pairs of spot-futures precious metals, other than gold, has not been discussed in the existing literature, which serves as a motivation to undertake this study. Our second contribution remains in the use of copula-based models. In

² The G-7 stock markets are Canada, France, Germany, Italy, Japan, the United Kingdom and the United States. The BRICS stock markets are Brazil, Russia, India, China and South Africa.

the existing literature, the most applied conventional methods are Granger causality test, cointegration test, vector error correction model and GARCH models. However, these methods do not fully consider the stochastic properties of metals prices, such as nonlinearity, uncertainty, and dynamics. Consequently, to overcome this literature gap, static and dynamic copulas are applied to analyse the dependence structure between spot-future precious metals pairs. Then, a Granger causality-based copula test is applied, as in Lee and Yang (2014), to assess for the causal relationship between spot-future precious metals pairs. In addition, seeking robustness, since precious metals prices are affected by inflation and the interest rates, we use the real prices of precious metals by considering deflated spot prices and deflated-implied spot prices (rather than futures prices).

A second interesting topic of this thesis analyses the investment properties of precious metals for the G-7 stock markets. The literature on the hedging and safe haven potentials of precious metals, especially gold, is among the faster growing fields of the financial literature since the turmoil period of the last decade. Therefore, we move forward the academic debate on the precious metals-stock markets nexus by examining the hedge, safe haven and diversification properties of precious metals for the G-7 countries using more flexible copula-based models, named vine copula, which allows a finer analysis. We also deepen the analysis of our results using the BiVaR novel method.

The existing literature provides evidence that precious metals, especially gold, may serve as hedge and/or safe haven assets against various factors such as exchange rates (e.g., Ciner et al., 2013; Reboredo, 2013b; Bedoui et al., 2019; Nguyen et al., 2020), inflation (e.g., Hoang et al., 2016; Salisu et al., 2019), oil prices (e.g., Rehman et al., 2018) and stock market indices (e.g., Hood and Malik, 2013; Mensi et al., 2016; Ali et al., 2020). These studies are of key importance regarding information about hedging strategies for investors. On the whole, although the literature has documented the role of precious metals, the results are quite mixed for different markets. This is somewhat to be expected, given the use of different market variables, different countries, different time periods and different methods. Therefore, this incites us to further explore this topic.

In particular, we empirically contribute to the academic literature by extending the analysis of precious metals investment properties using vine copula- based GARCH model and BiVaR measure. Also, we propose a new definition of “strong safe haven” property by using simulated data from the best-fitting copula model to compute the tail correlation.

The last topic of this dissertation addresses the quantile dependence between precious metals and BRICS stock markets and the impact of the EPU on this dependence structure. In the last century, the BRICS has been the most compelling emerging countries for their economic performance. The BRICS cover more than 40% of the world's population and about 15% of global GDP. Goldman Sachs expects the total nominal GDP of the BRICS countries (excluding South Africa) to rise to \$128 trillion by 2050, meanwhile the G7 countries will have a GDP of only \$66 trillion (Mensi et al., 2014).

On the other hand, co-movements between precious metals and BRICS stock markets have attracted the interest of investors, risk managers and the other market practitioners. In fact, the global production of gold was about \$134 billion (China and Russia are among the top 5 producers) in 2018, while the global production of silver and platinum was \$13 billion and \$4 billion, respectively (China and Russia among the top 5 of silver producers while South Africa alone accounts for more than two-thirds of global platinum production).³

Understanding the interaction between precious metals and BRICS stock markets is of key importance regarding the information that they may give about portfolio allocation and risk management. Therefore, the rise of investment flows in precious metals has intensified the connection between precious metals and other financial markets which leads to the overall economic fluctuations. Consequently, since economic policy plays an important role in shaping financial markets, then uncertainty related to economic policies decisions should matter (Adjei and Adjei, 2017).

By leading this study, we contribute to the existing literature, which focused on the impact of EPU on precious metals prices and stock market prices separately, by introducing a new empirical investigation of the impact of EPU on the dependence between precious metals and BRICS stock markets using the cross-quantilogram approach. The cross-quantilogram is a 2-in-1 method that enables us to model the quantile dependence structure between precious metals and BRICS stock markets and the impact of the EPU on this dependence.

This article-based thesis includes three related studies that provide new insights on the dynamics of precious metals and their interaction with stock markets, by answering several inter-related research questions:

- How do spot and future precious metal markets co-move?

³ Source: IFM World Economic Outlook, October 2019

- Do precious metals act as hedge, safe haven and/or diversifier assets for the G-7 stock markets?
- Does EPU have an impact on the dependence structure between precious metals and BRICS stock markets?

2. Generality on precious metals markets

Since the last decades, industrialization and the technological advance have increased the demand for precious metals for industrial use, as well as for investment purposes.

Gold is the oldest commodity that has served historically as a currency and still remains a monetary asset. Through the existing literature, gold has been treated particularly due to its specific characteristics as a monetary unit and a store of value. According to Capie et al. (2005), Gold has been a key component of global monetary reserves for trading and currency hedging. In addition, gold has been used as an investment vehicle since it serves as a hedge against inflation in market crises periods. It has also been widely documented that gold serves as hedge against fluctuations in exchange markets. The major demands in gold in 2019 are: jewelry (49%), investment (29%), Central banks (15%) and technology (7%). (See Figure 1)

Today, the most important markets where gold is traded are the London OTC market, the US futures market (COMEX) and the Shanghai Gold Exchange (SGE). Together, these markets, account for over 90% of global trading volumes. (source: World Gold Council)

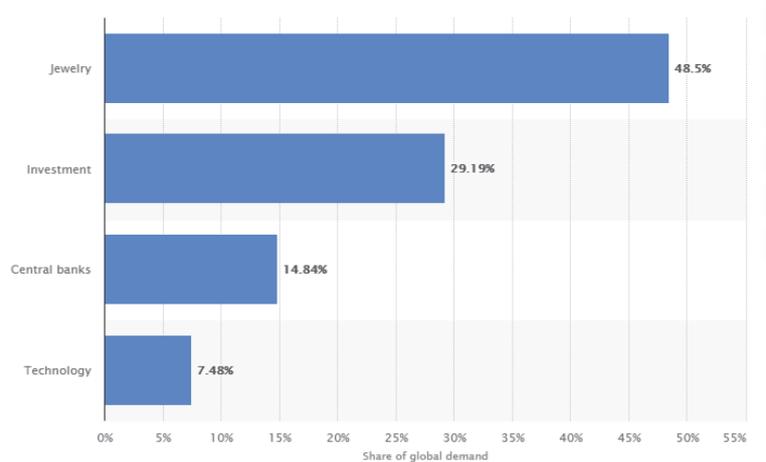


Figure 1: Gold demand worldwide - share by sector 2019

Source: Statista.com

Next to gold, silver is the most malleable of all metals. Similar to gold, silver was historically used as currency. Silver serves as an important financial and industrial commodity. In fact, silver has been considered among the most versatile metals since it has widely desirable for various industrial uses such as jewelry and industry. (See Figure 2)

Since the global economy continue to expand, silver will continue to play a major role in the global markets (Cochran et al., 2012).

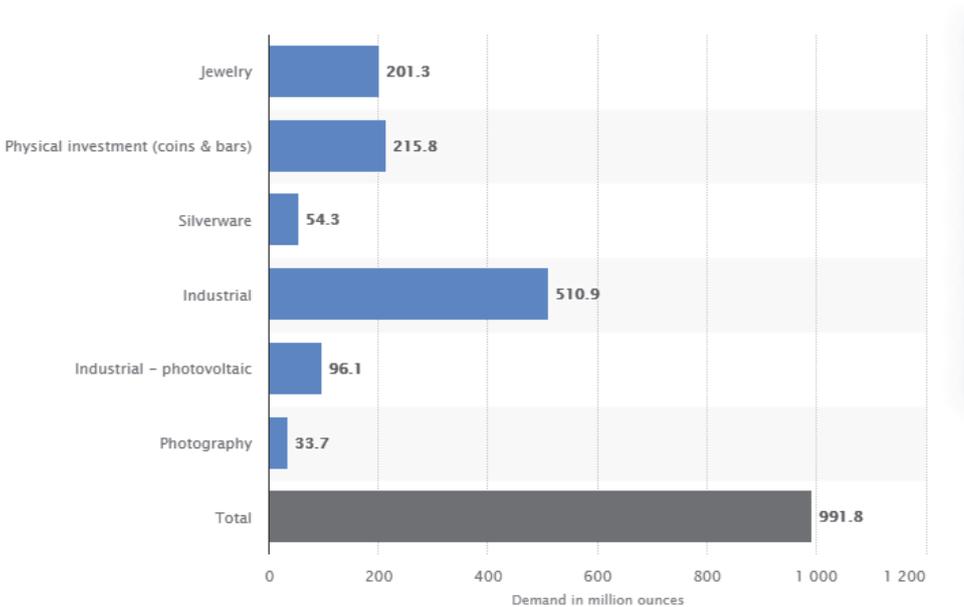


Figure 2: Global silver demand by end use 2019 (in million ounces)

Source: Statista.com

Platinum is much rarer than gold and silver. The most of the world’s concentration of platinum mines is located in South Africa. Similar to other precious metals, platinum is used as both for industrial and investment purposes. However, platinum has been fewer documented as an investment throughout the existing literature compared to the gold and silver.

Platinum is the rarest of the precious metals and it is very used in jewelry production and automotive industries. Over 40% of exploited Platinum of the last decade was used in the automobile industry, especially as catalyst for waste gas purification in Diesel engines (See Figure 3).

Recently, investors began to give more attention to platinum in portfolios investment due to its similar properties to gold.

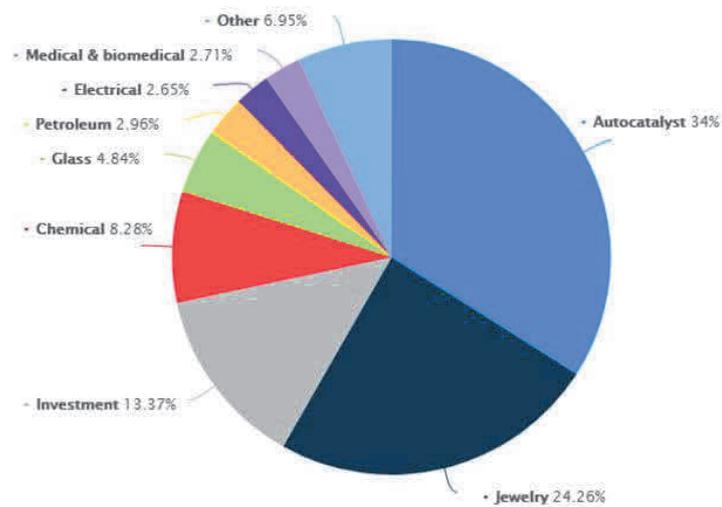


Figure 3: Global Platinum demand 2019

Source: Statista.com

- **Precious metals spot market**

The spot price is defined as the current market price at which the precious metals can be transacted and delivered immediately. Each precious metal has its own spot price that fluctuates frequently throughout the day. The spot price differs from futures or forward prices since it is the most available recent price. For example, the gold spot price reflects the price of a troy ounce of gold and, in general, the higher the demand, the higher the price.

When determining the precious metals spot price, several factors are taken into consideration, other than futures contracts. In fact, precious metals are influenced by macroeconomic environment such as inflation, interest rate, economic uncertainty, major financial crisis and many other factors. Precious metals prices are very volatile, as supply and demand for these metals around the world are constantly fluctuating.

- **Precious metals futures market**

The futures contracts of precious metals are agreements in which a price for future delivery of the precious metal is predefined. These futures contracts are used by producers, hedgers, and other market participants involved with precious metals as a way to manage price risk. For example, the futures contracts for gold and silver represent the futures price of one ounce of silver or gold.

According to traditional hedging theory, futures contracts are mainly used to hedge physical positions. Indeed, two types of positions can be placed by traders: a long (buy) position, which represents an obligation to receive delivery of the physical metal, while a short (sell) position which is the obligation to make delivery. Most commodity traders close their position before the maturity (delivery date). To do so, traders take the futures opposite positions with the same magnitude regarding the physical market position (Ederington, 1979; Johnson, 1960). For example, this occurs when a trader with a long position initiates a short position in the same contract to eliminate the original long position. Therefore, they take long positions on futures contracts if prices are expected to increase in the future or take short positions if prices are likely to decline in the future. Consequently, in the futures market the physical delivery is not a must. The majority of futures contracts are rolled over before maturity since they are mostly used for hedging and speculation purposes.

Futures contract is a particular type of a forward contract. A forward contract is similar to the futures contract except that it is not traded in exchange. It is basically a commitment today to make a future transaction (Bodie et al., 2014). Therefore, forward contract is a private agreement, traded in cash values at maturity with no standards (flexible terms and conditions due to the default risk of counterparty). Whereas future contract is a standardized contract under the control of clearinghouses, which limits the risk of default. It is traded on futures exchanges. One of the important features of a Futures contract is that the settlement of gains and losses is made on each trading day. This is called Mark to Market (MTM) settlement which denotes that the value of the contract is marked to its current market value.

- **Investment properties of precious metals**

Studies on precious metals investment properties have received extensive attention from investors and market practitioners. The literature focused on three aspects: first of all, precious metals could be used for diversification purposes by adding them to an investment portfolio, secondly, a precious metal may act as a hedge against different market risk such as stock market movements, exchange rates and inflation. Finally, precious metals may have a safe haven property during extreme market conditions. The last two properties look quite similar, but they are two different concepts. To sum up, a precious metal may be beneficial to investors due to its role as diversification, hedging and/or safe haven assets.

Despite being one of the oldest financial assets, precious metals were underused and neglected as an investment alternative. Therefore, investors would consider this as a diversification opportunity by holding these metals to their portfolios and benefit from their valuable investment characteristics that have been historically proven.

Precious metals, like any commodity, are partially driven by supply and demand in the long run. However, in contrast to commodities, they tend to behave like a currency as well. The main determinants are macroeconomic factors, such as interest rates, exchange rates and inflation. Precious metals, therefore, have been historically less correlated to other markets, particularly equities, which tend to be highly cyclical. Such unique factors can make precious metals a "good alternative" with distinctive diversification, risk management and investment potential.

Other than the diversification property, precious metals also may serve as hedge assets. Hedging is a form of insurance for investors that consists of holding one or more assets on a portfolio to mitigate the risk of price movements. Therefore, in order to reduce the risk of adverse (price) movements in the portfolio, the added assets should be uncorrelated or not perfectly correlated with other portfolio assets.

As defined in Baur and Lucey (2010), who provide the first operational definition of hedge, an asset is considered to be a strong hedge instrument when it is negatively correlated on average with another asset while a low (or zero) correlation is defined as a weak hedge. With respect to the stock markets, investors seek to hedge against their portfolios from price fluctuations. There have been several studies investigating the hedge potential of precious metals against stock markets movements in order to reduce the risk of their investment portfolio.

A precious metal may act as a safe haven asset during extreme market conditions. Safe haven and hedge properties might be seen similar, but they are completely different. According to Baur and Lucey (2010), an asset is considered to be a strong (weak) safe haven instrument when it is negatively correlated (uncorrelated) during turmoil periods. Therefore, a hedge is held on average while a safe haven is only held asset during extreme market conditions. In their paper, they examine the static and time-varying relations between US, UK and German stock return and gold returns using daily data from 1995 to 2005 to evaluate gold as a hedge and a safe haven. They find that gold serves as an effective hedging tool for stocks and has a role as a safe haven in extreme stock market conditions. As an extension of Baur and Lucey

(2010)'s work, Baur and McDermott (2010) study the relationship between gold and stock markets in developed and developing countries using multiple- frequency data from 1979 until 2009. They apply rolling window regression to analyse the time-varying relationship between of the gold return on the world portfolio index. They find that gold serves as a hedge and safe haven only in European markets and the US market but not in the BRICs markets (Australia, Canada and Japan). Adopting the same methodology, Hood and Malik (2013) study the role precious metals (gold, silver and platinum) relative to volatility Volatility Index (VIX) as a hedge and safe haven against the US stock market and they find that, unlike gold, platinum and silver serve neither as a hedge nor as a safe haven for the US stock market. Recently, Ali et al. (2020) examine the safe haven, hedge, and diversification potentials of 21 commodities (including precious metals) for 49 international stock markets. Using cross-quantilogram approach (the quantile dependence across the whole range of quantiles), they find that precious metals in general and gold in particular provide strong safe havens for developed and frontier stock markets.

Global economies have seen several financial crises throughout history. During these times, investors seek assets that might be able to protect them against potential losses. The ability of commodities, in particular precious metals, to be safe havens has been investigated in a number of academic studies to illustrate the interaction between commodities and stock markets during financial turmoil. Generally, gold has been extensively studied and proven to be a good safe haven during extreme stock market downturns.

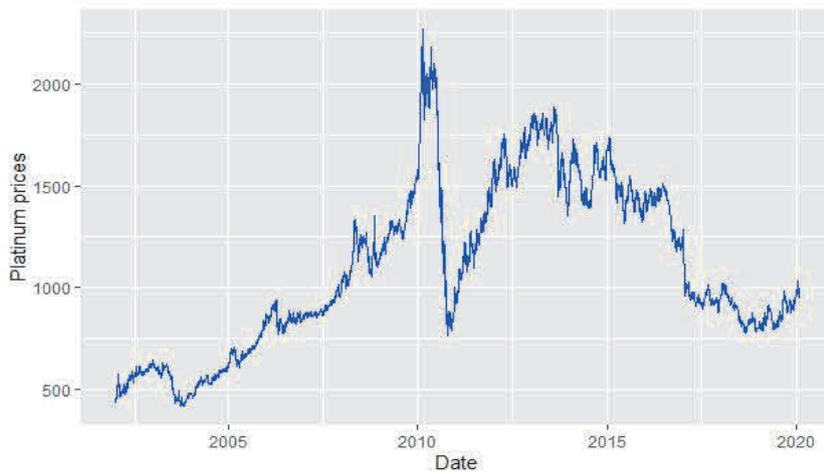
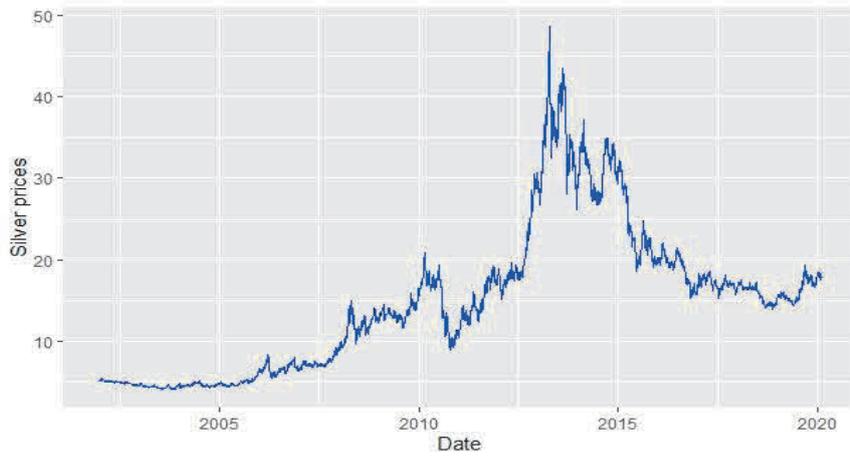
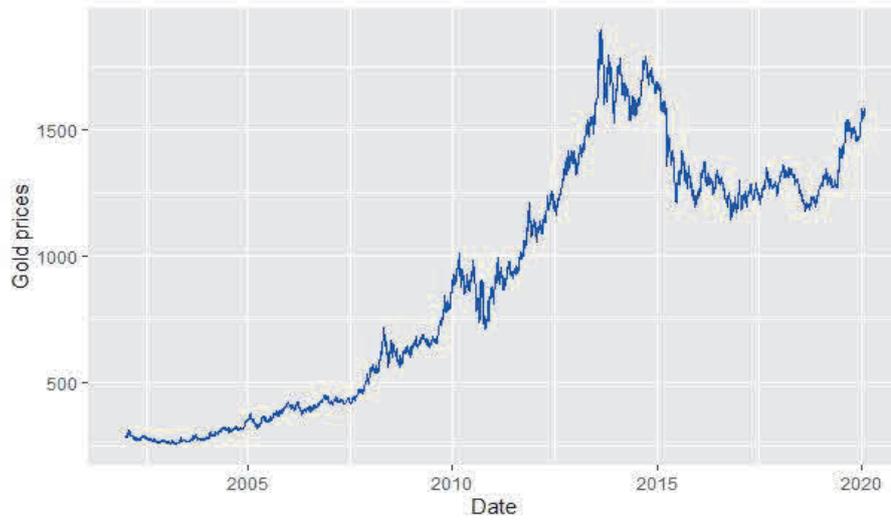


Figure 4 : Precious metals prices dynamics

Source: Author's calculation

- **The 2000s commodities boom**

The commodity price bubble, known as the 2000s commodities boom, emerged in the mid-2000s following the Great Commodities Depression of the 1980s and 1990s.

The price bubble can be defined as; “a speculative bubble that exists when the price of something does not equal its market fundamentals for some period of time for reasons other than random shocks.”⁴ (Rosser 2000, p. 107).

When the GFC took hold and the Great Recession occurred, stock prices dropped, and commodities prices began to rise again. Between 2003 and 2008, nominal prices of precious metals doubled, and by the end of 2010, prices were at or near to their peaks.⁵ This was due to the increased interest of investors about holding precious metals, especially gold, due to their investment properties as safe haven assets during market turmoil periods. The price boom could be the consequence of many factors including speculation, the role of biofuels and economic policies. As shown in Figure 4, investing in precious metals has begun to increase in the early 2000s as these assets’ prices start to fluctuate. We can notice that prices continue to grow due to commodity financialization and register a pick during the GFC 2008-2010.

Figure 5 highlights precious metals performance against global equities during different market turmoil periods in recent decades. As we can see precious metals remain resilient during extreme periods and have shown positive returns, meanwhile global equities have experienced dramatic decrease and negative returns. During these turbulent periods, investors fear great losses, so they seek less risky investments to reduce potential market risk exposure by holding alternative assets like precious metals. As it is shown in Figure 5, precious metals record a good performance during extreme market conditions, hence they represent a more stable and defensive assets against market uncertainty.

⁴ Fundamental is usually referred to the long-run equilibrium consistent with a general equilibrium

⁵ Source: World Bank, Development Prospects Group

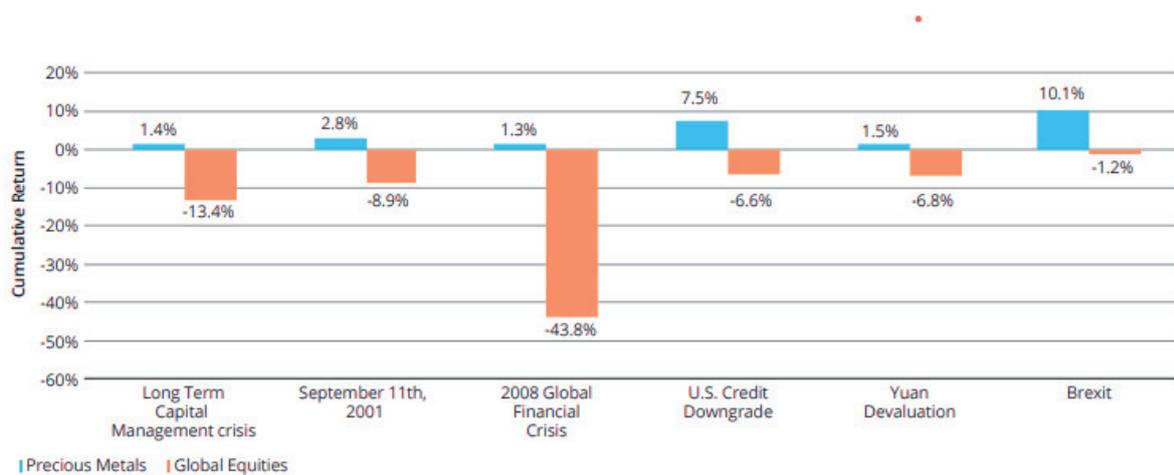


Figure 5: Precious metals performance during market turmoil periods

Source: Bloomberg, ASI. Global Equities = MSCI World index. Event date ranges evaluated from: LTCM & Ruble crisis (7/1/1998 – 9/30/1998), September 11th, 2001 (9/1/2001 – 9/30/2001), Global Financial Crisis (9/1/2008 – 2/28/2009), US Credit Downgrade (8/1/2011 - 8/31/2011), Yuan Devaluation (8/1/2015 – 8/31/2015), Brexit (6/1/2016 - 6/30/2016).

- **Precious metals and Macroeconomic Environment**

Precious metals market is affected by supply and demand but also by different macroeconomic factors including fluctuations of inflation rate, interest rate, exchange rate, stock prices as well as economic policies and geopolitical tensions. These events may have implications on market efficiency and other market features. (See, e.g., Ciner, 2001; Batten et al., 2010; Hood and Malik, 2013; Areal et al., 2014).

Since precious metals are denominated in dollars, they are particularly sensitive to the dollar fluctuation. Therefore, when the dollar drops, precious metals may be seen as a good store of value and cheaper alternative asset for investors, which may lead to an increase in the precious metals' prices. Moreover, precious metals generally perform better during rising-inflation periods. Batten et al (2010) and Arouri et al (2012) find that gold is highly sensitive to exchange rate and inflation, which means that it may be a good hedge during exchange rates fluctuation and inflationary periods. Monetary policies play, also, a crucial role in determining the price movement of precious metals. Therefore, when interest rates are falling, precious metals may be good alternative for fixed income investors, whose investments offer

lower returns. Adding to that, during periods of economic and political uncertainty, precious metals may act as safe haven assets.

3. Theoretical background: What has been learned so far?

Studies on the precious metals market, including the nexus between spot and futures prices, and their interaction with stock markets relies on several theories.

- **Efficient Market Hypothesis**

The efficient market hypothesis (EMH), alternatively known as the efficient market theory, was firstly introduced by Fama (1970). They found that stock markets are efficient since stocks follow unpredictable and random processes. According to the EMH, security prices should fully reflect all possible and available information about the securities being traded in the market. This means that actual price of an asset should reflect past events and events expected to occur in future as well.

There are three types of the EMH, classified by the degree to which it can be applied to markets: Strong, semi-strong and weak efficiency. Accepting the EMH strong form may be difficult since, in reality, the majority of markets are inefficient or have some level of inefficiency due to information asymmetries, low liquidity, transaction costs, investors psychology, among others. The weak form of EMH has been related to the random walk theory in 1973 by Burton Malkiel in his book "A Random Walk down Wall Street". The Random walk theory states that the past movement of the stock price or overall market cannot predict its future movement.

- **The price discovery mechanism**

Theoretically, under the market efficiency hypothesis, spot and futures prices must simultaneously reflect new information because they both reflect the same aggregate value of the underlying assets. They should move together across time to avoid constant arbitrage opportunities. However, the relationship between the spot–futures prices pairs depends on many factors including the nature of the commodity (storable or non-storable), transaction costs, market expectations and asynchronous trading. All these frictions may drive one market to respond more quickly to new information flows than the other market and a lead–lag relationship occurs. When a market reflects new information more rapidly, it is said that this market have a price discovery function. In particular, as far as the precious metals market is

concerned, it is quite important to identify the direction of information flows between spot and futures prices to understand how fast one market reacts to the new information relative to the other. The causal relationship between spot and futures markets has been an area of extensive empirical research, as it can help investors during decision-making process and help in discovering potential arbitrage opportunities between spot and futures prices.

4. Thesis road map

This thesis is concerned with precious metals markets. More specifically, it is developed through three studies. First, we focus on the dependence structure and causality between precious metals spot and future returns. On the former study, the aim is to bring new insight about the role of precious metals as hedge, safe haven and diversification assets for the G-7 stock markets. Concerning the latter study, we analyse the impact of the EPU on the dependence structure between precious metals and BRICS stock markets.

First, chapter one investigates the dependence structure and the Granger Causality in Distribution (GCD) between spot and future returns of precious metals (gold, silver, and platinum) via copula modelling. This study uses the spot and future returns deflated by the U.S. CPI and the future prices transformed to implied spot returns to consider the effect of the interest rate. The period of our research spans from 2 January 2002 to 13 January 2017.

Using static and dynamic copulas based GJR-GARCH model, we find that the dependence between spot-future returns pairs of precious metals is relatively strong and time varying with a strong tail dependence. Then, to assess for the causality between spot-futures pairs an independence test based on the empirical copula is used. This test detects a unidirectional GCD from future to spot precious metals market during normal times. This result means that past information from the future returns improve forecasts of spot returns. However, the causal relationship seems to be bidirectional in the case of gold and platinum during crisis periods.

This study has important implications for investors. Since the efficacy of a hedging strategy is dependent on the price discovery mechanism, investors should take the above findings into consideration to make optimal decisions, especially during periods of marked instability.

Second, chapter 2 revisits the international evidence on hedge, safe haven, and diversification properties of precious metals for the G-7 stock markets. Therefore, this study proposes a multivariate vine copula-based GARCH model to assess the hedge and safe haven properties of precious metals and a Bivariate Value at Risk-based copula (BiVaR) measure to analyse

the diversification potential of precious metals. This study uses daily prices data for precious metals and stock indices from 01 January 2002 through 05 February 2018, which covers several turbulent periods and crises, including the energy price instability period and 2008–2009 global financial crisis.

Our empirical results improve that gold is the strongest hedge and safe haven asset in almost all the G-7 stock markets. For silver and platinum, results show that they may act as weak hedge assets. Silver bears the potential of a strong safe haven role only for Germany's and Italy's stock markets. However, platinum provides a weak safe haven role for most developed stock markets. Finally, precious metals may be interesting diversification assets for G-7 stock markets investors. Overall, our findings provide noteworthy practical implication for investors.

Finally, the aim of the last chapter focuses on is to investigate if the EPU has an impact on the quantile dependence between precious metals and BRICS stock markets using the cross-quantilogram approach, developed by Han et al. (2016). This study considers daily closing prices of precious metals and BRICS stock market indices from 3 January 2002 to 23 October 2020, encompassing the Global Financial Crisis (GFC), the European Sovereign Debt Crisis (ESDC) and the COVID-19 recent crisis.

Our results lead to the same findings when controlling or not for the EPU. Indeed, we provide evidence that gold is a perfect hedge in Russia and India. While silver and platinum may act as hedge assets only in the China stock market. Adding to that, over the entire sample period, we find that extreme negative stock market returns were followed by extreme positive gold returns for all stock markets except for Brazil and China. Hence, gold is not a safe haven in these stock markets. However, silver is a safe haven only in China stock market and platinum is a safe haven in China and South Africa stock markets. Even though countries under study correspond to the same group, each country has its own financial risk exposure and business cycle connectedness with different taxes and legislations the reason why results are different from one country to another. Hence, this will affect the reaction of each financial market to economic uncertainty. Our findings may be useful to policy maker since understanding the impact of the EPU on the spillover between BRICS stock markets and precious metals is important in the decision process of economic and financial policies.

The thesis road map is summarized in Figure 6.

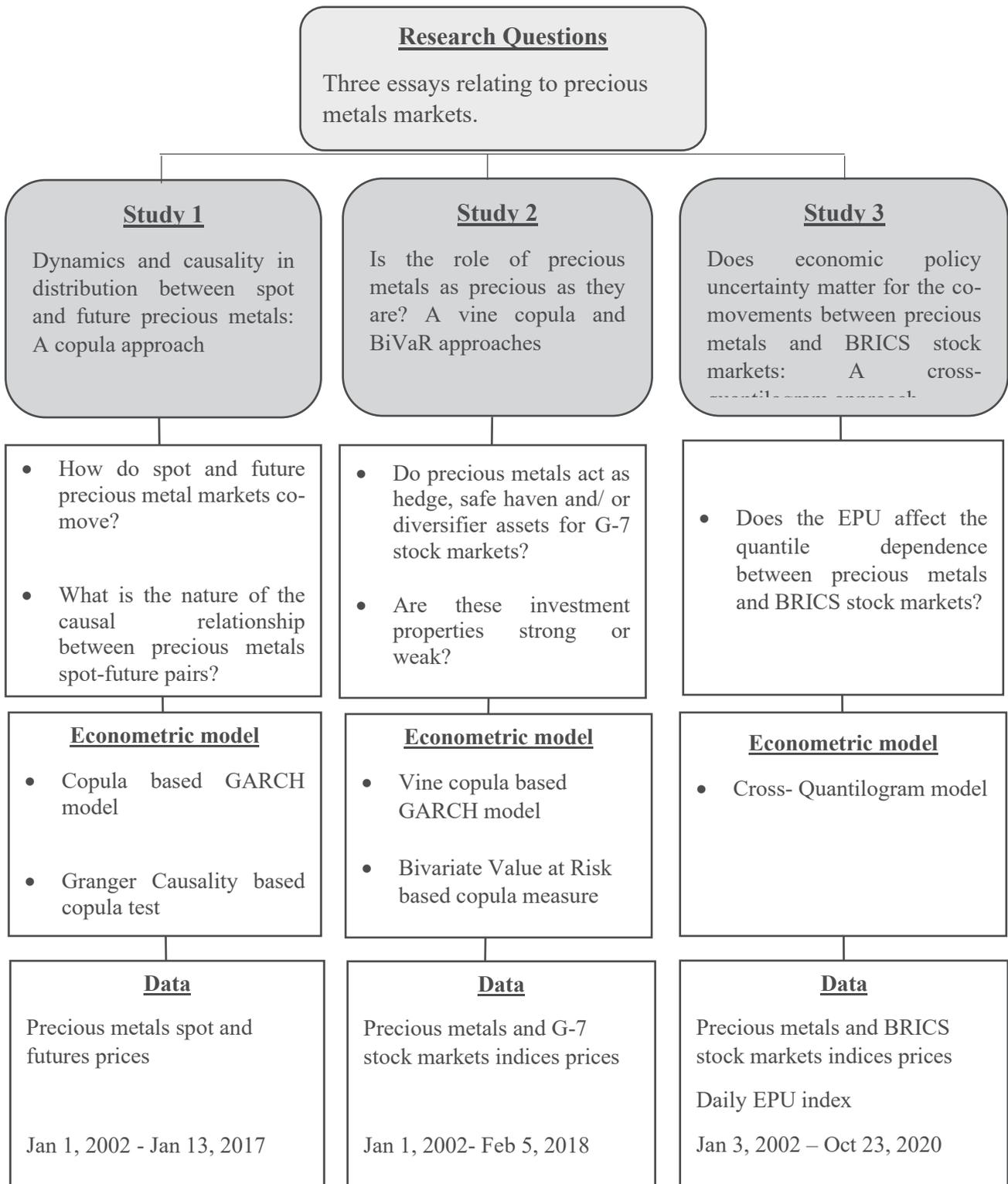


Figure 6: Thesis road map

Note: this figure presents the sub-research questions of the three studies of this dissertation, the different econometric models and data used by study.

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Chapter1

Dynamics and causality in distribution between spot and future precious metals: A copula approach

This chapter, published in *Resources Policy*, examines the dependence structure and the Granger causality in distribution (GCD) between spot and future returns of precious metals (gold, silver, and platinum) via copula modelling. This study considers the evidence on real precious metals returns from Jan 2, 2002 to Jan 13, 2017. *Throughout literature*, the use of copula in precious metals markets is still limited. Indeed, unlike linear methods, using a copula-based approach has several attractive advantages. Our empirical findings show the following: (1) Using static and dynamic copulas, we find that the dependence between the spot and the future returns of precious metals is relatively strong and time varying with a strong tail dependence for all pairs (2) Using independence test based on the empirical copula, we detect a unidirectional GCD from future to spot precious metals market during normal times. This result means that past information from the future returns improves forecasts of spot returns. However, the causal relationship seems to be bidirectional in the case of gold and platinum during crisis periods.

Our findings are important to investors for investigating hedging strategies since the efficacy of a hedging strategy is dependent on the price discovery mechanism. Hence, they should take the above findings into consideration to make optimal decisions, especially during periods of marked instability.

Keywords: Copula, Granger causality in distribution, nonparametric test based on the empirical copula, precious metals, future market, spot market

1.1 Introduction

Commodity futures markets are generally considered to perform two major economic functions including risk transfer and price discovery roles.

The futures contract prices transmit information to all economic agents. Indeed, producers may base their supply decisions on the futures contract prices to hedge against the undertaken risks, while physical traders might use futures contracts as a reference to price their commodities. Theoretically, under the market efficiency hypothesis, futures and spot prices must simultaneously reflect new information because they both reflect the same aggregate value of the underlying assets. However, in real word, commodity markets are imperfect; frictions including transaction costs and asynchronous trading drive one market to respond more quickly to new information flows than the other market and a lead–lag relationship occurs.

In particular, as far as the precious metals market is concerned, knowledge of precious metals' future price movements is quite important. Identifying the direction of information flows between spot and futures prices, then, appears to be essential in understanding how fast one market reacts to the new information relative to the other.

The causal relationship between spot and futures markets has been an area of extensive empirical research, as it can help investors during decision-making process and help in discovering potential arbitrage opportunities between spot and futures prices. Therefore, this topic still attracts noteworthy attention from the academic scene.

As might be expected, the empirical results of the literature are mixed. Evidence for a unidirectional causality from the futures market to the spot market is frequently found in the literature (e.g., Joseph et al., 2014; Jena, 2018). Nonetheless, unidirectional causality from spot to futures market (for instance, Srinivasan, 2012) and bidirectional causality were fully identified (e.g., Dash and Andrews, 2010 and Bhatia et al., 2018).

Regarding the methods used in the academic literature, the most conventional methods are Granger causality test, cointegration test, vector error correction model and GARCH models (see, e.g., Shihabudheen and Padhi, 2010; Srinivasan, 2012 and Mayer et al., 2017 among others).

Considering the stochastic properties of metals prices; such as nonlinearity, uncertainty and dynamics, non-linear causality models; including causality via quantile approach (e.g., Bhatia et al., 2018; Jena et al., 2019) and causality via copula approach (e.g. Lee and Yang, 2014), has been growing.

In our study, we apply a copula-based approach to model the dependence and causality between spot-future pairs of precious metals. First, static and dynamic copulas are applied to analyse the dependence structure between spot-future precious metals pairs. Then, Granger causality in distribution test is applied, as in Lee and Yang (2014), to assess for the causal relationship between spot-future precious metals pairs.

Thus, our contribution to the literature on dynamics and causality between the spot and futures returns in precious metals market is two-fold. First, to the best of our knowledge, this work being the first of its kind investigates the dynamic and causal relationship between the spot-futures pairs of precious metals returns namely; gold, silver, and platinum using causality copula based model. Second, seeking robustness, this is the first study considering the real prices of precious metals by taking into account inflation and the interest rate. We therefore consider deflated spot prices and deflated-implied spot prices (rather than future prices).

Therefore, the use of a copula-based model enables us to answer two main questions: (1) How do spot and future precious metal markets co-move? (2) What is the nature of the causal relationship between precious metals spot-future pairs?

Our results show a time varying dependence with strong tail dependence for all spot-future pairs. Also, a unidirectional causality from future to spot precious metals market was detected during normal times and the causal relationship seems to be bidirectional in the case of gold and platinum during crisis periods. These results have implications for producers, policy makers, hedgers and speculators.

The remainder of this chapter is structured as follows: Section 1.2 is a review of previous works. Section 1.3 describes the dataset used in this study. Section 1.4 details the methodology with a brief theoretical background of copula theory. Section 1.5 reports and discusses the empirical results of our analysis. Finally, section 1.6 concludes.

1.2 Literature Review

There exists a considerable body of literature on the dynamics of precious metals which can be divided into different topics. A First main area of interest has been investigating the relationship between precious metals and other market factors such as; exchange rates (e.g., Ciner et al., 2013 and Pierdzioch et al., 2016), inflation (e.g., Hoang et al., 2016 and Salisu et al., 2019), stock market uncertainty captured by the VIX (e.g., Jubinski and Lipton, 2013), oil prices (e.g., Rehman et al., 2018), stock market indices (e.g., Hood and Malik, 2013 and Klein

2017) and risk aversion (e.g., Qadan, 2019). These studies are of key importance regarding the information that they may give about hedging and diversification strategies for investors.

Second stand of literature highlights the stochastic properties of precious metals, their dynamic interlinkages and their volatility spillover. Arouri et al. (2012), find strong evidence of long-range dependence in the conditional returns and volatility processes for the daily spot and future precious metals returns. Sensoy (2013) show that gold has a uni-directional volatility shift contagion effect on the other precious metals while silver has a similar effect on platinum and palladium. Lucey et al. (2014) study returns and volatility spillovers between gold cash market and gold futures. They find that returns spill over more strongly than do volatilities. Antonakakis and Kizys (2015) suggested that gold is the dominant commodity transmitter of return and volatility spillovers to the remaining assets under study conditional on time and event-specific patterns. Kang et al. (2017) reported that gold and silver may serve as sources of information transmission among the commodity futures markets and the spillover effects are particularly intensified during recent financial crises. More recently, Balcilar and Ozdemir (2019) examine the dynamic relationships between the price of spot precious metals and their volatility showing that volatility negatively affects the returns of precious metals and the changes in precious metal price returns have positive effects on volatility, meaning that periods with higher (lower) metal price returns are accompanied with higher (lower) return volatility.

Regarding the causality between precious metals spot and futures markets to assess price discovery mechanism; gold market has received the most attention from academic researches. Praveen and Sudhakar (2006) analysed causality between stock market and the commodity futures market. They considered Nifty futures traded on National Stock Exchange (NSE) and gold futures on Multi Commodity Exchange of India (MCX). Based on causality test in the commodity market, a unidirectional causal relationship from the gold futures market toward the spot gold market was detected meaning that gold futures price influenced the spot gold price, but the opposite was not true. Shihabudheen and Padhi (2010) examined the price discovery mechanism and volatility spillovers effect for six Indian commodity markets including gold and silver. For that end, Johansen cointegration test, Error Correction Model (ECM) and bivariate EGARCH model were used. The results for gold and silver supported that futures price acts as an efficient price discovery vehicle. They found that the volatility spillover exists from futures to spot market. Further, Dash and Andrews (2010) studied the causality with reference to many commodities among them gold and silver. Using Granger

causality techniques, they find that for most commodities under study there was bidirectional causality between futures and spot. Pavabutr and Chaihetphon (2010) studied price discovery for gold futures contracts in the Multi Commodity Exchange of India (MCX) over the period 2003 to 2007. By applying Vector Error Correction Model (VECM), results show that gold futures prices lead spot price.

Srinivasan (2012) examined the price discovery process and volatility spillover in Indian spot-future commodity markets including metal market (MCXMETAL) by applying Johansen cointegration test, VECM model and the EGARCH model. VECM model results show that the spot commodity markets play a dominant role and serve as an effective price discovery vehicle. Besides, the bivariate EGARCH model indicates that bidirectional volatility spillover persists and the volatility spillovers from spot to the futures market are dominant.

Arouri et al. (2013) also investigate the efficiency of energy and precious metal markets, by employing four linear and non-linear models based on structural breaks and long memory. Their findings confirm that futures prices do not constitute unbiased predictors of future spot prices although futures prices are found to be cointegrated with spot prices.

Chinn and Coibion (2009) examine whether futures prices are unbiased and/or accurate predictors of subsequent prices by analyzing four groups of commodities including gold. Results show that precious metals are poor predictors of subsequent prices changes, while energy futures fair much better. Using a frequency domain approach, Joseph et al. (2014), find a unidirectional causality from futures to spot market in eight different commodities including gold and silver.

Lakshmi et al. (2015) explore the nexus between spot and futures contracts for crude oil and gold. Results reveal that trading volume of gold futures respond faster to information in market and help to predict gold spot returns, which is not the case for crude oil. Nicolau and Palomba (2015) analyze the dynamic relationship and the direction of causality between spot and futures prices of crude oil, natural gas and gold. Using recursive bivariate VAR model, they find the existence of some interactions between spot and futures prices.

Mayer et al. (2017) looked at the causal relationship between trading activity and spot price volatility for metals; specifically, copper, gold, palladium, platinum, and silver over the period of January 1993 – December 2013. Using Granger causality tests and EGARCH model, they find that there is a strong evidence to suggest that spot prices and volatility drive changes in trading activity. Jena et al. (2018) examine time and frequency varying co-movements between gold LBMA spot market and gold futures traded in COMEX, SGE (Shanghai), and

MCX (India) using daily closing price from 2008 to 2013. Applying wavelet analysis, they find a strong interaction among gold futures and the spot market at different time scales, with the correlation being very high at lower frequencies.

Bhatia et al. (2018) examine the causal relationship among the spot prices of precious metals (gold, silver, platinum and palladium) from April 2000 to July 2016 using a quantile causality approach. Their results show an evidence of bidirectional causality in mean and variance among the prices of precious metals. More recently, Jena et al. (2019) investigate causality between spot and future commodities, including gold and silver, using nonparametric causality -in - quantiles tests. Their results reveal a strong predictability of the futures market in the normal market which declines into extreme bearish and bullish conditions.

Hence, to the best of our knowledge, although several studies investigate the dynamics and causality among precious metals, the causality among pairs of spot-futures precious metals, other than gold, has not been described in the existing literature, which serves as a motivation to undertake this study.

1.3 Data

1.3.1 Data description on precious metals

Our dataset consists of daily prices for gold, silver and platinum over the period from Jan 1, 2002 to Jan 13, 2017, making a total of 3924 observations.

Gold and silver bullion spot prices are provided by the London Bullion Market Association (LBMA), while platinum spot prices are collected from the London Platinum Free Market. Gold and silver future prices are from Commodity Exchange, Inc. (COMEX), while platinum future prices are from the New York Mercantile Exchange (NYMEX). With regard to precious metals future prices, the nearby contracts (front-month contracts)⁶ were considered in this study, as they are mostly heavily traded as compared to next month and far month futures contracts. All data were extracted from Datastream, a division of Thomson Reuters, and priced in US dollars per troy ounce. These preliminary prices series will be transformed, as described here after, in order to obtain our final dataset.

1.3.2 Data transformation

Precious metals are by tradition traded in U.S. dollars per troy ounce (oz). Since the dollar exchange rate is changing, it is possible that inflation and other monetary variables like

⁶ Futures front month contract refer to the contract month with an expiration date closest to the current date, which is often in the same month.

interest rate have real effects on precious metals prices. Hence, considering the real prices is likely to be more important for precious metals.

For robustness, we therefore consider the spot and future prices deflated by the U.S. CPI and the future prices transformed to implied spot prices to take into account the effect of the interest rate. For that end, daily US three-month LIBOR rate and monthly U.S.CPI were derived from the Federal Reserve Bank.

- ***Calculation of the deflated precious metals prices***

The spot and future prices of precious metals are deflated by the US CPI. The choice of the US CPI as deflator is a fairly standard practice in the literature.⁷

The daily CPI values are computed from monthly CPI values using linear interpolation method as follows:

$$CPI_d = CPI_{M-1} + \left[\frac{(d-1)}{D-1} (CPI_M - CPI_{M-1}) \right], \quad (1.1)$$

where;

d : the date of settlement (day in a month),

M : the month in which d occurs,

D : the number of days in the month M ,

CPI_d : The daily index on day d ,

CPI_M : The CPI in the month M .

- ***Calculation of the implied spot precious metals prices***

The future pricing formula:

$$F(t) = S(t) - K \exp(-r(t)(T-t)), \quad (1.2)$$

where; $F(t)$ is the price of future contract, $S(t)$ is the spot price of the underlying asset, $r(t)$ the US interest rate at date t , $(T-t)$ is the time until maturity of the contract and K is the strike price.

In order to eliminate the interest rate effect, the implied spot prices for each corresponding underlying asset are calculated by inverting the theoretical future pricing formula as follows:

$$S^*(t) = F(t) + K \exp(r(t)(T-t)), \quad (1.3)$$

⁷ Deaton and Laroque (1996) in their celebrated paper deflated commodity prices by the U.S. Consumer Price Index and the literature has followed their lead.

where; $S^*(t)$ is the implied spot price.

As usual, we consider logarithmic returns, which are defined as the first difference in the natural logarithm of the transformed daily prices such that: $R_t = \ln(P_t) - \ln(P_{t-1})$, where R_t are returns at time t , P_t and P_{t-1} are current and one-period lagged spot/future prices of precious metals respectively. After eliminating the mismatching transaction days, we finally obtain 3882 log-returns for each series.

Figure 1. 1 shows that spot and future returns exhibit periods of high and low volatility. We can clearly see that all of precious metals returns have similar patterns and display volatility clustering. For each market, the frequency of large and negative price movements is more frequent than that of large and positive price movements reflecting that returns are negatively skewed.

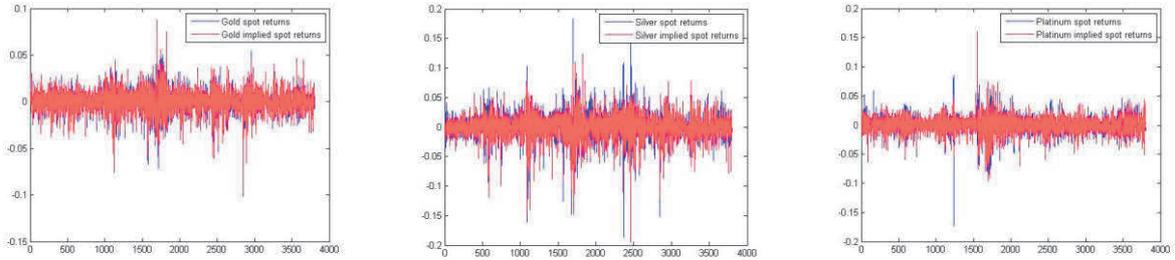


Figure 1. 1: Precious metals spot and future returns dynamics

1.4 Methodology

1.4.1 Copula and dependence

The copula expresses the joint distributions of two or more random variables. Its biggest advantage is, it separates marginal distribution modelling from modelling the copula that combines these marginal into a joint distribution and therefore provides the flexibility to consider the clustering effect of return series and the complexity of the dependence structure at the same time. The cornerstone of the copula theory is the Sklar's theorem which states that a joint distribution $F_{XY}(x, y)$ of two continuous random variables X and Y can be expressed in terms of a copula function $C(u, v)$ and the marginal distribution functions of the random variables, $F_X(x)$, $F_Y(y)$, as:

$$F_{XY}(x, y) = C(u, v), \quad (1.4)$$

where $u = F_X(x)$ and $v = F_Y(y)$. Hence, a bivariate copula $C(u, v)$ is a multivariate distribution function in $[0,1]^2$ with uniform marginal distribution in the interval $[0,1]$.⁸

The joint probability density of the variables X and Y can be obtained as follows:

$$f_{XY}(x, y) = c(u, v)f_X(x)f_Y(y), \quad (1.5)$$

where $f_X(x)$ and $f_Y(y)$ denote the marginal densities of the variables X and Y, respectively and $c(u, v)$ is the copula density which given by $\frac{\partial^2 C(u,v)}{\partial u \partial v}$.

An appealing feature of a copula is that it provides information on average dependence and on tail dependence.

On one hand, the dependence on average is given by dependence measures such as Kendall's tau which measure the dependence as the difference between probability of concordance and probability of discordance which is defined as follows: $\tau(X, Y) = \Pr[(X_1 - X_2)(Y_1 - Y_2) > 0] - \Pr[(X_1 - X_2)(Y_1 - Y_2) < 0]$. And it can be written as a function of the copula as follow: $\tau(X, Y) = 4 \int_0^1 \int_0^1 C(u, v) d(u, v) - 1 = 4E[C(U, V)] - 1$, where $U, V \sim U(0,1)$ with joint distribution function C . On the other hand, the dependence structure during periods of extreme market conditions is given by upper (right) and lower (left) tail dependence measures, respectively, as follows:

$$\lambda_U = \lim_{u \rightarrow 1} \Pr [X \geq F_X^{-1}(u) | Y \geq F_Y^{-1}(u)] = \lim_{u \rightarrow 1} \frac{1-2u+C(u,u)}{1-u}, \quad (1.6)$$

$$\lambda_L = \lim_{u \rightarrow 0} \Pr [X \leq F_X^{-1}(u) | Y \leq F_Y^{-1}(u)] = \lim_{u \rightarrow 0} \frac{C(u,u)}{u}, \quad (1.7)$$

where $\lambda_U, \lambda_L \in [0,1]$ and X and Y are random variables with distribution functions, respectively F_X and F_Y .

Our study uses a diverse range of copulas with different dependence structures and time-invariant and time-varying parameters to capture the nexus between spot and future precious metal markets.

The symmetric copulas include the Gaussian copula (with tail independence) and Student- t copula (with equal lower and upper tail dependence). The asymmetric copulas include the Gumbel copula (with strong upper tail dependence), the Clayton copula (with strong lower tail dependence) and the symmetrised Joe-Clayton copula (SJC), which can be either symmetric or asymmetric and captures the lower and the upper tail dependence at the same time. The main characteristics of copulas functions used in this study are summarized in Table 1. 1.

⁸ For an introduction on copulas, see Joe (1997) and Nelsen (2006).

Furthermore, in our study, we consider several time-varying copulas that capture different patterns of time-varying dependence, namely, time-varying Normal, time-varying Student, time-varying Clayton and time-varying SJC copulas.

The time-varying, dynamic or conditional copulas have been introduced by Patton (2006) who extended Sklar's theorem to the conditional case as follow: Given some information set ω , let $F(x, y|w)$ be the bivariate conditional distribution of $(X, Y)|W$ with continuous conditional marginals $F(x|w)$ and $F(y|w)$. Then there is a unique conditional copula function C such that; $F(x, y|w) = C(F(x|w), F(y|w))$.

In this work, we assume that the dependence parameter is allowed to vary over time following an ARMA(1,10) process.

Table 1. 1 : Bivariate copula functions

Copula	Function	Parameter	Tail dependence
Gaussian	$C(u, v \rho) = \Phi(\Phi^{-1}(u), \Phi^{-1}(v))$	$\rho \in [-1, 1]$	No tail dependence
t-copula	$C(u, v; \rho, \vartheta) = T(t^{-1}_{\vartheta}(u), t^{-1}_{\vartheta}(v))$	$\rho \in [-1, 1]$	Symmetric tail dependence
Clayton	$C^C(u, v; \theta) = (u^\theta + v^\theta - 1)^{-\frac{1}{\theta}}$	$\theta \in (0, \infty)$	Lower tail dependence
Gumbel	$C^G(u, v; \theta) = \exp(-((- \ln(u))^{\frac{1}{\theta}} + (- \ln(v))^{\frac{1}{\theta}})^\theta)$	$\theta \in [1, \infty)$	Upper tail dependence
Joe- Clayton	$C^{JC}(u, v \tau^U, \tau^L) = 1 - (1 - \{[1 - (1 - u)^k]^{-\gamma} + [1 - (1 - v)^k]^{-\gamma} - 1\}^{-1/\gamma})^{1/k}$	$\tau^U \in (0, 1)$ $\tau^L \in (0, 1)$	$\tau^U = \Lambda\left(\omega_u^{SJC} + \beta_u^{SJC} \tau_{t-1}^U + \alpha_u^{SJC} \frac{1}{q} \sum_{i=1}^q u_{t-i} - v_{t-i} \right)$ $\tau^L = \Lambda\left(\omega_v^{SJC} + \beta_v^{SJC} \tau_{t-1}^L + \alpha_v^{SJC} \frac{1}{q} \sum_{i=1}^q u_{t-i} - v_{t-i} \right)$
SJC	$C^{SJC}(u, v \tau^U, \tau^L) = 0.5(C^{JC}(u, v \tau^U, \tau^L) + C^{JC}(1 - u, 1 - v \tau^U, \tau^L) + u + v - 1)$	$\tau^U \in (0, 1)$ $\tau^L \in (0, 1)$	$\tau^U = \tau^L$

Notes: λ_U and λ_L denote the lower and upper tail dependence, respectively. For the Gaussian copula $\Phi^{-1}(u)$ et $\Phi^{-1}(v)$ are the standard normal quantile functions and Φ is the bivariate standard normal cumulative distribution function with correlation parameter ρ . For the t-copula $t^{-1}_{\vartheta}(u)$ and $t^{-1}_{\vartheta}(v)$ are the quantile functions of the univariate Student-t distribution and T is the bivariate Student-t cumulative distribution function with ϑ the degree-of-freedom and ρ the correlation parameter. For the SJC copula, $k = \frac{1}{\log(2 - \tau^U)}$ and $= \frac{-1}{\log \tau^L}$. τ^U and τ^L denote the upper and lower tails of the SJC and the Joe-Clayton copulas.

For the time-varying Gaussian copula, the parameter ρ is defined by Patton (2006) as follow:

$$\rho_t = \tilde{\Lambda}\left(\omega + \beta \rho_{t-1} + \alpha \frac{1}{10} \sum_{i=1}^{10} \Phi^{-1}(u_{t-i}) \Phi^{-1}(v_{t-i})\right), \quad (1.8)$$

where Φ^{-1} is the inverse of the standard normal cumulative density function, $\tilde{\Lambda}(x) \equiv (1 - e^{-x})(1 + e^{-x})^{-1}$ is the modified logistic transformation used to keep ρ within the interval $[-1, 1]$, $\beta \rho_{t-1}$ is the autoregressive term that captures the persistence effect and the mean of the product of the last 10 observations of the transformed variables $\Phi^{-1}(u_{t-i})$ and $\Phi^{-1}(v_{t-i})$

captures the variation effect in dependence. For the Student-t copula, the parameter dynamics are also given by Eq. (1.8) by substituting Φ^{-1} by t^{-1}_g .

The time-varying dependence processes for the Clayton copula is described as:

$$\theta_t = \left(\omega + \beta\theta_{t-1} + \alpha \frac{1}{10} \sum_{i=1}^q |u_{t-i} - v_{t-i}| \right). \quad (1.9)$$

Finally, for the SJC copula, we specify that the tail dependence parameters τ^U and τ^L vary overtime according to:

$$\tau_t^U = \Lambda \left(\omega_U^{SJC} + \beta_U^{SJC} \tau_{t-1}^U + \alpha_U^{SJC} \frac{1}{10} \sum_{i=1}^{10} |u_{t-i} - v_{t-i}| \right), \quad (1.10)$$

$$\tau_t^L = \Lambda \left(\omega_L^{SJC} + \beta_L^{SJC} \tau_{t-1}^L + \alpha_L^{SJC} \frac{1}{10} \sum_{i=1}^{10} |u_{t-i} - v_{t-i}| \right), \quad (1.21)$$

where $\Lambda(x) \equiv (1 + e^{-x})^{-1}$ is a logistic transformation used to retain τ_t^U and τ_t^L in $(0,1)$ all the time, $\beta_U^{SJC} \tau_{t-1}^U$ and $\beta_L^{SJC} \tau_{t-1}^L$ are the autoregressive terms that capture the persistence effect and the forcing variables represented by the mean absolute difference between u_t and v_t over the previous 10 observations captures the variation effect in dependence.

1.4.2 Copula based GJR-GARCH model

The copula based-GARCH-type model is a combination between GARCH and copula theory, where the random variables X and Y in the marginal distributions are assumed to follow some time series models, such as the ARMA model for the conditional mean and GARCH type model for the conditional volatility. Therefore, it is able to model simultaneously the volatility dynamics by GJR-GARCH model and the conditional dependence structure by copula functions.

In this study, an AR (1)-GJR-GARCH(1,1)⁹ model is adopted for the marginal distributions according to the AIC and BIC information criterion for possible values ranging from zero to four. It should be noted that due to market efficiency, the dependence in mean should be very small, even nil. Thus an AR(1) specification is much more enough to capture this dependence. Moreover, the GARCH type models are flexible, and (1,1) orders are in general enough to model most of the financial series of the literature.¹⁰ The model can be written as:

⁹ The GJR-GARCH (Glosten-Jagannathan-Runkl GARCH) model is an asymmetric variation of GARCH model which captures the stylized fact that negative and positive shocks in stock returns tend to have different impacts on volatility. Hence, the model adds an asymmetric term on the variance equation in order to take into account the leverage effect (prices movements are negatively correlated with volatility).

¹⁰ The order of AR terms and the lag orders of the GARCH model are all specified to be 1, which is in line with Brooks, 2008 who stated that a GARCH-family model with lag order of 1 can sufficiently describe volatility clustering in the data, and higher-order models are rarely used in financial literature.

$$r_t = \mu + \phi_1 r_{t-1} + \varepsilon_t, \quad (1.12)$$

$$h_t = \omega + (\alpha_1 + \gamma_1 I_{t-1}) \varepsilon_{t-1}^2 + \beta_1 h_{t-1}^2, \quad (1.13)$$

where $\varepsilon_t = z_t \sqrt{h_t}$ such that the innovation z_t is a zero mean and unit variance i.i.d. random variable that follows a Student-t density distribution and h_t is the conditional variance; where $\omega > 0$, $\alpha_1, \beta_1 \geq 0$, γ_1 are the asymmetric effect coefficient or the leverage effect and I_{t-1} is an indicator function that takes on the unit value when $\varepsilon_{t-1} < 0$ and zero otherwise. To ensure the stationary of GJR-GARCH model, two conditions are imposed respectively: $\alpha_1 + \gamma_1 \geq 0$ and $\alpha_1 + \gamma_1 + \beta_1 < 1$.

The GJR-GARCH-Copula model is implemented in two steps. The first step consist in estimating GJR-GARCH specifications to capture the dynamic volatility and the stylized facts of our data. In the second step, the standardized residuals obtained from the previously estimated GJR-GARCH models are transformed into uniform variables by means of their empirical cumulative distribution functions to be used as an input in copula parameters estimation. The copula functions are then estimated using a semi parametric two-step estimation method, namely the Canonical Maximum Likelihood, or CML (Cherubini et al., 2004).¹¹ This method uses empirical probability integral transform in order to obtain the uniform marginals needed to estimate the copula parameter, as a first step. In the second step, copula parameters can then be estimated by maximizing the log likelihood function of the copula density using the uniform variables by solving the following problem:

$$\hat{\theta} = \operatorname{argmax}_{\theta} \sum_{t=1}^T \ln c(\hat{u}_t, \hat{v}_t; \theta), \quad (1.14)$$

where $\hat{\theta}$ are the estimated copula parameters and c denotes the copula density.

The performance of the different copula functions is evaluated by using the log likelihood values and the AIC and BIC information criteria.

1.4.3 Copula-based Granger causality model

In this section, we will briefly present the Granger causality in distribution (GCD) method used in our study. As it is known, Granger causality is a statistical measure of directional influences between two time series. Throughout literature, Granger-causality in mean and in volatility has been widely investigated whereas these tests assume that series are normally distributed and do not detect causality in higher moments. Thus, it is more informative to test GCD to explore a causal relationship between two financial time series.

¹¹ Using simulation techniques Kim et al. (2007) show that the CML performs better than FML and IFM methods when the marginal distributions are unknown, which is almost always the case in practice.

To explore causality between two time series we use $\{X_t\}$ to denote the preceding variable and $\{Y_t\}$ as the trailing variable. We assume that information set before market X closes is denoted as G_t , and the information set after market X closes but before market Y closes is denoted as Z_t ($Z_t = G_t \cup \{X_t\}$).

Following Lee and Yang 2014, $\{X_t\}$ Granger-cause $\{Y_t\}$ in distribution (in short $\{X_t\}$ GCD $\{Y_t\}$) if $F_Y(y|Z_t) \neq F_Y(y|G_t)$, where $F_Y(y|Z_t) = P(Y_t < y|Z_t)$ and $F_Y(y|G_t) = P(Y_t < y|G_t)$.

There is no Granger-cause in distribution (in short $\{X_t\}$ NGCD $\{Y_t\}$) if $F_Y(y|Z_t) = F_Y(y|G_t)$ a.s. for $\{Y_t\}$.

The above implies that testing NGCD can be based on the following null hypothesis:

$$H_0^1: f_Y(y|Z_t) = f_Y(y|G_t), \quad (1.15)$$

Where; $f_Y(y|Z_t)$ and $f_Y(y|G_t)$ denote densities of conditional distributions respectively $F_Y(y|Z_t)$ and $F_Y(y|G_t)$. Using the fact that joint density function is the product of the conditional density and the marginal density:

$$f_{X,Y}(x, y|G_t) = f_Y(y|Z_t) \cdot f_X(x|G_t), \quad (1.16)$$

and with the assumption that:

$$f_{X,Y}(x, y|G_t) = f_X(x|G_t) \cdot f_Y(y|G_t). \quad (1.17)$$

Hence, the null hypothesis of NGCD can be stated as the null hypothesis that conditional marginal distributions are independent:

$$H_0^2: F_{XY}(x, y|G_t) = F_X(x|G_t) \cdot F_Y(y|G_t). \quad (1.18)$$

Conditional distributions $F_X(x|G_t)$ and $F_Y(y|G_t)$ are modelled using two univariate AR-GARCH(1,1) model and the null hypothesis in Eq. (1.18) is verified using multivariate independence test based on the empirical copula process, following the suggestion of Genest and Rémillard (2004) and Genest et al. (2006, 2007) for standardized residuals.

The test consists in comparing a distance between the empirical copula C_n and the independent copula, which is based on the empirical process:

$$\mathbb{C}_n(u) = \sqrt{n}(C_n(u) - \prod_{j=1}^d u_j), \quad (1.19)$$

where C_n is the empirical copula, which is defined by:

$$C_n(u) = \frac{1}{n} \sum_{i=1}^n 1_{\{U_{i1} \leq u_1, \dots, U_{id} \leq u_d\}}, \quad (1.20)$$

With $u = (u_1, \dots, u_d) \in [0,1]^d$, $u_1 \dots u_d$ are the pseudo-observations.

As it is shown by Genest et al. (2007), this test is applied in two steps. Firstly, we simulate the distribution of the test statistics under independence for the sample size under consideration.

Secondly, we compute the value of the global Cramér-Von Mises statistic derived directly from the independence empirical copula process.

1.5 Empirical results and discussion

1.5.1 Preliminary descriptive statistics of precious metals returns

The descriptive statistics for the spot and implied spot daily returns of precious metals are reported in Table 1. 2. The results show that the mean average returns of the spot and implied spot returns are positive with gold having the highest positive returns. In addition, the silver spot and future markets are the most volatile while the gold spot and future markets are the least volatile. All markets are negatively skewed and have high kurtosis, which means that asymmetry and fat tails in the spot and future returns were evidently rejecting the normality of the series. Moreover, the Jarque–Bera (JB) test reinforce the rejection of the normality hypothesis while, the Ljung-Box (LB) statistic confirm the presence of autocorrelations in the data. Likewise, the ARCH effect test indicates the presence of ARCH effects in all series.

Table 1. 3 reports the linear and rank correlation coefficients between pairs of spot-implied spot precious metals returns. The results show that the correlation between all pairs is positive with higher correlation in the gold market and lower correlation in the silver market. This result is associated with the fact that the silver market is a bit liquid and the total trading volume is low compared to gold and platinum markets.

Table 1. 2: Statistical properties for precious metal log-returns.

	Gold		Silver		Platinum	
	Spot	Implied Spot	Spot	Implied Spot	Spot	Implied Spot
Mean (10^{-3})	0.3019	0.2999	0.2600	0.2610	0.1040	0.1076
Std. Dev.	0.0119	0.0120	0.0220	0.0210	0.0146	0.0145
Maximum	0.0686	0.0879	0.1825	0.1229	0.0847	0.1602
Minimum	-0.1014	-0.0980	-0.1871	-0.1953	-0.1726	-0.0957
Skewness	-0.4449	-0.3314	-0.5638	-0.8854	-0.7101	-0.1158
Kurtosis	7.7140	7.7490	11.7176	9.9642	11.8647	10.0699
JB Stat.	3641.85	3638.44	12227.7	8171.39	12755.04	7918.28
Q (20) stat.	31.109	44.20	22.345	19.4641	30.0141	22.996
Q ² (20) stat.	709.71	561.639	834.75	580.83	1030.57	860.94
ARCH LM (10) stat	40.347	70.85	296.71	118.33	153.70	44.68

Notes: The Sdt. Dev. denotes the standard deviation, JB denotes the Jarque–Bera statistic for normality testing, (*) indicates rejection of the null hypothesis at the 5% level. Q² (20) denotes the Ljung-Box statistic on the squared residual series for autocorrelation testing. The ARCH LM stat denotes Engle’s LM test statistic for heteroskedasticity testing and the P-values are reported in brackets.

The high correlation between spot and futures markets may be explained by the fact that the futures contract is a good hedge device for the corresponding spot asset since futures prices contain information that can help to predict spot prices. Nevertheless, this does not mean that the two markets move in the same direction or have a symmetric relation, regardless the increase or decrease in price. Therefore, we estimated a range of copulas to take into account the possible asymmetric tail dependence and the possible asymmetric co-movements between precious metals spot and future markets.

Table 1. 3: Linear and rank correlation between spot -implied spot returns pairs of precious metals

		Linear correlation		Rank correlation	
		Pearson	Kendall	Spearman	
Spot -Implied spot returns	Gold	0.8194	0.6040	0.7772	
	Silver	0.4010	0.2324	0.3347	
	Platinum	0.7126	0.5009	0.6759	

To have a general insight of the dependence structure, as a preliminary step, we establish the scatter plot of each spot-implied spot pair. Figure 1. 2 shows positive correlation between spot – implied spot pairs of precious metals returns.

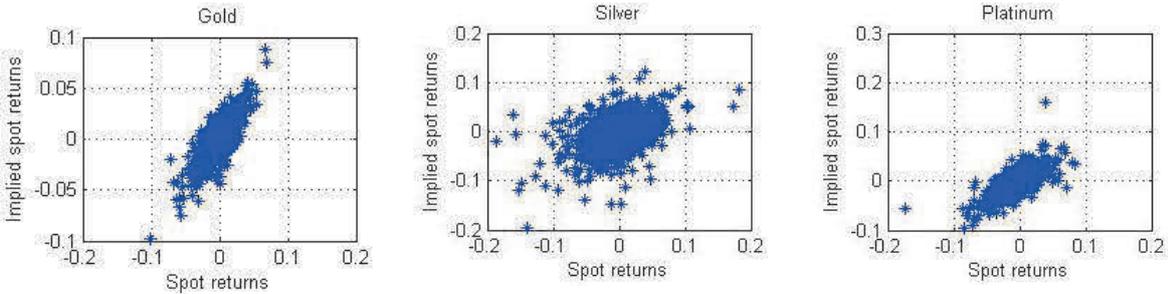


Figure 1. 2 : Scatter plots of spot vs implied spot returns of precious metals

1.5.2 Marginal models results

To identify the most adequate model among the models of the GARCH family, the Akaike information criterion (AIC) and Bayesian information criterion (BIC) have been used. In this work, daily returns are modelled via an AR (1)-GJR-GARCH (1.1)-*t* model.

Table 1. 4 reports the empirical estimates of the marginal model for returns given by equations (1.12) and (1.13). The alpha coefficients which measure the adjustment to past shocks are low and significant for all series. Interestingly, the returns of the gold and silver are characterized by an asymmetric negative impact of shocks on their volatility due to the significance of the gamma coefficient. Moreover, the beta coefficients which measure the volatility persistence of the process are significant for all series which indicates that the conditional volatility is persistent over time and past-dependent.

Indeed, all series are described by significant GARCH effects. The results for the diagnostic tests of our marginal models are reported in the Panel C of Table 1. 4. The Ljung-Box (Q statistic) and ARCH (LM statistic) statistics indicate that neither autocorrelation nor ARCH effects remained in the residuals of the marginal models.

Table 1. 4: Estimates of AR(1)-GJR-GARCH (1, 1) model parameters

	Gold		Silver		Platinum	
	Spot	Implied spot	Spot	Implied spot	Spot	Implied spot
Panel A: Mean equation						
μ	0.000390 (2.411)	0.000400 (2.419)	0.000313 (1.222)	0.000325 (1.175)	0.000250 (1.325)	0.000205 (1.031)
ϕ_1	-0.043547 (-2.904)	-0.055797 (-3.805)	-0.100035 (-6.019)	-0.043522 (-2.900)	-0.013825 (-0.8443)	-0.006900 (-0.4125)
Panel B: Variance equation						
$\omega (10^4)$	0.010199 (3.197)	0.009474 (2.913)	0.023428 (2.957)	0.019412 (2.221)	0.025225 (2.834)	0.016275 (2.560)
α_1	0.052402 (6.657)	0.045813 (6.511)	0.058868 (6.830)	0.057188 (5.638)	0.071050 (5.863)	0.043488 (3.937)
β_1	0.956737 (194.7)	0.960466 (205.7)	0.958085 (148.2)	0.95949 (145.5)	0.924873 (70.65)	0.949827 (92.17)
γ_1	-0.028825 (-3.097)	-0.022015 (-2.552)	-0.040471 (-4.878)	-0.031329 (-3.177)	-0.014340 (-1.268)	-0.001841 (-0.1780)
ϑ	5.108566 (11.37)	4.908707 (11.94)	5.148647 (12.20)	3.922898 (14.65)	6.400495 (9.933)	6.580866 (8.393)
Panel C: Diagnostic tests						
LL	11897.4	11829.4	9734.36	9875.31	11215.3	11139.5
Q(20)	13.9438 [0.8333]	16.58 [0.6801]	9.9895 [0.9684]	18.6158 [0.5469]	12.5901 [0.8943]	17.1231 [0.6450]
Q ² (20)	12.9446 [0.8797]	17.2375 [0.6375]	14.1205 [0.8243]	25.5592 [0.1809]	50.5871 [1.8210 ⁻⁴]	32.0751 [0.0425]
ARCH	38.0616	7.9217	2.2010	19.5413	33.0888	1.3411
LM(10) stat	[6.8510 ⁻¹⁰]	[0.0049]	[0.1379]	[9.8410 ⁻⁶]	[8.8010 ⁻⁹]	[0.2468]

Notes: This table reports the ML estimates and t-statistic (in brackets) for the parameters of the marginal distribution model defined in Eqs. (1.12)-(1.13). LL denotes log-likelihood values. The $Q(20)$ and $Q^2(20)$ are the Ljung-Box statistics for serial correlation in the model's standardized residuals and standardized squared residuals, respectively, using 20 lags. ARCH is Engle's LM test for the ARCH effect in the standardized residuals up to 10th order. K-S denotes the Kolmogorov-Smirnov test. The reported p values (in square brackets) above 0.05 indicate the acceptance of the null hypothesis that the model distribution is correctly specified.

1.5.3 Copula based GJR-GARCH model results

In this section, we investigate the estimation results of the static and dynamic copulas. Then, based on the AIC and BIC criteria, we select the best-fit copula model that describes the best the linkage between precious metals spot and futures markets.

Table 1. 9 in Appendix 1.8 reports the parameter estimates for static copulas. For all pairs, the parameter dependencies of copulas are positive and significant. Regarding the Gaussian and Student copulas, the Spot-Implied spot pairs of Gold and Platinum have higher correlation than the Silver. This means that the spot returns are positive and generally strong in relation with the future returns. The degrees of freedom for the Student-t copula indicate the existence of tail dependence. In considering asymmetric tail dependence, the parameter estimates for Clayton, Gumbel, BB1 and SJC copulas are positively significant which means that the dependence between the spot returns and the future returns vary under different conditions of the market.

Looking to the LL, AIC and BIC values¹², among the static copulas, the Student copula is the best copula to describe the most adequately the dependence structure between pairs of GoldS-GC1 and PlatinumS-PL1 while the dependence between silvers-S11 pair is represented by the SJC copula. Regarding the tail dependencies, results from selected copulas show that the pairs GoldS-GC1 and PlatinumS-PL1 exhibit symmetric tail dependence signifying the possibility that the values of spot price and futures prices crashing (booming) together at the same time. The tail dependence of returns between gold spot and future markets ($\hat{\lambda}_L = \hat{\lambda}_U = 0.6$)¹³ is highest, while the tail dependence in platinum market is equal to 0.31 ($\hat{\lambda}_L = \hat{\lambda}_U = 0.31$). For the SilverS-S11 pair the tail dependence is asymmetric in the upper (τ^U) and lower (τ^L) tail. ($\hat{\tau}^U = 0.25$, $\hat{\tau}^L = 0.021$).

Finally, for each pair, we estimate the time-varying (tv) Gaussian, Student, Clayton and SJC copulas. The obtained results are reported in Table 1. 10 in Appendix 1.9. Based on the LL, AIC and BIC values, we find that the time varying Student copula improves the performance of all the other copula specifications for the Spot-Implied spot pairs of Gold and Platinum. Likewise, the time-varying SJC copula improves the performance of all the other copula specifications for the pairs SilverS-S11. These results show a symmetric dynamic dependence between the spot and future market of gold and platinum whereas, the dynamic dependence between spot and future markets of silver is asymmetric.

¹² We choose the copula which maximizes the LL values and minimizes the AIC and BIC criterion.

¹³ Source: Author calculation

The estimation results of the time-varying SJC copula for the SilverS-S11 pair, show that the parameters β_U^{SJC} and β_L^{SJC} (which represent the degree of persistence) and α_U^{SJC} and α_L^{SJC} (which capture the adjustment in the dependence process) are negative and significant. This result indicates a high persistence in the dependence level and confirms that the dependence varies in time. Also, the conditional tail dependencies estimation shows that the conditional upper tail dependence ω_U^{SJC} is positively no significant and the conditional lower tail dependence ω_L^{SJC} is positively significant implying that there is a higher possibility of joint extreme events during bear markets rather than bull markets.

Overall, our empirical results on the dependence structure between precious metals spot and future markets can be summarized as follows:

- (1) The linkage between all spot-future pairs is characterized by time varying dependence structure. This dependence is generally strong on average.
- (2) The dependence between all spot-future pairs is characterized by tail dependence which is relatively strong.

1.5.4 Copula- based Granger causality test results

In order to further justify the use of the Grange causality in distribution test, the behavior in terms of nonlinearity of the variables under consideration was examined. To assess the existence of nonlinearity, the BDS test of serial independence proposed by Broock et al. (1996) was employed on the residuals of the AR (1)-GJR-GARCH (1,1) model for spot and future precious metals returns. The test statistics for the BDS test are presented in Table 1. 5. The results clearly reject the null hypothesis that the variables of interest are independently and identically distributed (*iid*) across various dimensions (from 2 to 6) and at 1% level of significance). Hence, the phenomenon of nonlinearity is strongly evident in not only precious metals spot and future returns, but also in their relationship. Therefore, the linear Granger causality tests may lead to misspecification. (Babalos and Balcilar, 2016; Bekiros et al., 2016). In light of the nonlinearity BDS test results, we proceed with the nonparametric causality in distribution test, which can be relied upon to deal with the above-mentioned econometric problem.

Table 1. 5: BDS Test results

	Dimension				
	2	3	4	5	6
Spot returns					
Gold	8.407***	8.557***	6.887***	3.743***	1.133
Silver	5.409***	4.894***	4.867***	1.206	4.293***
Platinum	2.535***	4.029***	5.222***	3.286***	9.675***
Implied Spot returns					
Gold	4.106***	4.461***	2.562***	4.616***	2.431***
Silver	8.521***	8.213***	7.334***	7.087***	6.057***
Platinum	4.329***	4.630***	6.768***	4.922***	6.352***
Notes: This table reports the test statistics for the BDS test. *** Indicates the rejection of the BDS null hypothesis at the 1% level of significance.					

Our study period covers several periods of instabilities (e.g., the energy crisis (2000-2003), the global financial crisis (2007 - 2008), the great recession (2008 - 2009) and the European debt crisis (2010-2013)). During this period the number of transactions in the commodity market increased rapidly. To conduct the causality over time, we split the period of study into 12 subsamples of 5 years each and the subsample shifts forward by 1 year. Details on the subsamples are listed in Table 1. 6 below.

Table 1. 6: Description of data sets and subsamples

Subsample	Period	Obs.	Subsample	Period	Obs.
1	Jan 02- Dec 06	1263	7	Jan 08- Dec 12	1263
2	Jan 03- Dec 07	1264	8	Jan 09- Dec 13	1262
3	Jan 04- Dec 08	1265	9	Jan 10- Dec 14	1262
4	Jan 05- Dec 09	1264	10	Jan 11- Dec 15	1262
5	Jan 06- Dec 10	1265	11	Jan 12- Dec 16	1263
6	Jan 07- Dec 11	1264	12	Jan 13- Jan 17	1020

The GCD analysis is conducted for each sub-sample from Table, assuming that a preceding variable is a logarithmic rate of return lagged by 1.

For each spot-future pair, each sub-sample and each conditional lag, distribution was modelled with the use of univariate AR(1)-GARCH(1,1), in which standardized residuals follow Student's t-distribution.¹⁴Causality between pairs is tested using a multivariate

¹⁴ The order of AR terms and the lag orders of the GARCH model are all specified to be 1, as (Brooks, 2002) stated that a GARCH-family model with lag order of 1 can sufficiently describe volatility clustering in asset returns, and higher-order models are rarely used in financial literature.

independence test based on the empirical copula. Obtained values of Cramér-Von Mises statistic for GCD are presented in Table 1.7 and Table 1.8 for all analysed sub-periods.

a) Is there a causal impact of spot precious metals returns on their future returns?

The results of GCD based on the Cramér-Von Mises statistic are presented in Table 1. 7. As we can see, gold spot returns do not Granger cause gold future returns in all sub-periods except for the first and second sub-periods (the p-value of the Cramér-Von Mises statistic is below the 5% significance level). For platinum, spot returns Granger-cause future returns only in the first five sub-periods (from 2002 to 2010). Meanwhile, silver spot returns do not Granger cause the silver future returns in all sub-periods. These results indicate that past information from the spot returns does not improve forecasts of future returns.

Table 1. 7: GCD testing results (S→F)

	Gold		Silver		Platinum	
	S→F	S→F	S→F	S→F	S→F	S→F
Subsample	CM	P-value	CM	P-value	CM	P-value
1	0.0715	0.0154	0.0283	0.3361	0.1074	0.0024
2	0.0631	0.0354	0.0312	0.2842	0.1653	0.0005
3	0.0501	0.0894	0.0402	0.1523	0.1013	0.0094
4	0.0437	0.1113	0.0374	0.1713	0.0907	0.0064
5	0.0493	0.0914	0.0356	0.2122	0.0638	0.0334
6	0.0421	0.1283	0.0293	0.3011	0.0260	0.3921
7	0.0334	0.2542	0.0280	0.3691	0.0192	0.6838
8	0.0341	0.2152	0.0194	0.6438	0.0189	0.6698
9	0.0211	0.5759	0.0233	0.4890	0.0182	0.7117
10	0.0277	0.3361	0.0169	0.7617	0.0156	0.8356
11	0.0392	0.1533	0.0259	0.3991	0.0203	0.6258
12	0.0387	0.1663	0.0327	0.2642	0.0195	0.6338

Notes: S and F refer, respectively, to spot returns and future returns.

b) Is there a causal impact of future precious metals returns on their spot returns?

The results of GCD for testing causality from precious metals future returns to spot returns are presented in Table 1. 8. The results show that in all sub-periods precious metals future returns Granger-cause spot returns (the p-value of the Cramér-Von Mises statistic is below the 5% significance level). Thus, this implies that information is first disseminated in the future market and then later reflected in the spot market. This result is mainly due to the higher

liquidity and lower transaction costs of the future market. Such advantages attract traders and make the futures market react first to market information. Hence, the future prices lead the spot market prices.

Table 1. 8: GCD testing results (F→S)

	Gold		Silver		Platinum	
	F→S	F→S	F→S	F→S	F→S	F→S
Subsample	CM	P-value	CM	P-value	CM	P-value
1	0.3742	0.0005	6.6240	0.0005	0.4004	0.0005
2	0.2387	0.0005	6.2864	0.0005	0.2836	0.0005
3	0.1889	0.0005	5.7153	0.0005	0.3971	0.0005
4	0.4106	0.0005	5.1615	0.0005	0.6165	0.0005
5	0.3741	0.0005	4.9677	0.0005	0.7883	0.0005
6	0.4129	0.0005	4.3598	0.0005	1.1114	0.0005
7	0.4955	0.0005	4.2037	0.0005	1.430	0.0005
8	0.4520	0.0005	3.7569	0.0005	1.4047	0.0005
9	0.2195	0.0005	3.2684	0.0005	1.3396	0.0005
10	0.1983	0.0005	2.7189	0.0005	1.3910	0.0005
11	0.1195	0.0015	2.6716	0.0005	1.3019	0.0005
12	0.0735	0.0284	1.8993	0.0005	0.9200	0.0005

Notes: S and F refer, respectively, to spot returns and future returns.

1.5.5 Discussion and policy implications

By leading this study, additional contributions are made to the literature debate on the causality between spot and futures markets, focusing on the dynamic and the nonlinear causal relationship between precious metals futures and spot returns. This relationship was characterized by a time-varying dependence structure on average and tail dependence during extreme market conditions.

On one hand, by examining the dependence structure between spot-future pairs of precious metals returns, evidence of a strong dependence between all pairs are found. This close relationship between spot and futures precious metals markets makes the information transmission faster between the two markets. This is due to the absence of arbitrage opportunity (AAO) hypothesis implying that if there is a price shift in a market, there is a price shift in the other market to preserve the AAO. This is classical in derivative markets. For instance, in option market, it corresponds also to arbitrage activities, but also to covering

covered warrants, making synthetic options etc. Efficient markets should display such a strong dependence.

On the other hand, our results reveal a causal relationship from future to spot market for all pairs and all subsamples which tend to be bidirectional for gold and platinum during some subsamples that refer to crisis periods.

The unilateral causality from derivatives to spot can be explained by the fact that the derivative markets are more professional, and react more instantaneously to shocks from spot markets, whereas spot market investors look less at what is going on in the derivatives markets. Thus, a shock in the derivatives market needs time to impact the spot market, making a (temporal) causality. During crisis periods, the markets seem to be less efficient since even shocks in spot markets take time to impact the derivatives markets.

Most empirical studies of the price discovery mechanism support the hypothesis that changes in futures prices lead those in spot prices. However, this is not always the case, and our study confirms this stylized fact. Our results are somehow in line with previous researches and suggest that futures markets dominate spot markets. Although in some subsample periods, our GCD test reveals bi-directional causality between spot-future pairs of gold and platinum. These subsamples cover the energy crises and the global financial crisis.

In general, for all spot-future precious metals pairs, futures returns lead changes in spot returns across all sample sub-periods. Indeed, financial markets are imperfect; frictions including transaction costs and asynchronous trading create a lead-lag relationship between the future market and its underlying spot market so one market responds more quickly to new information than the other market. In reality, the spot market is imperfect; frictions including transaction costs, cash constraints, as well as storage costs for the physical metal create a lead-lag relationship between the future market and its underlying spot market so the spot market responds slowly to new information. In contrast, transactions in the futures market can be implemented immediately by hedgers and speculators who react more swiftly to new information due to lower transaction costs, greater liquidity and flexibility.

Additionally, the spot market is influenced by the speculation, hedging and arbitrage activities in the futures market. Indeed, speculators are interested in earning profit from variations in the market value, so they opt for futures contract rather than physical precious metals.

Meanwhile, hedgers who haven't capacity to store physical metals will opt for futures contracts for hedging purposes. As a matter of fact, both speculators and hedgers will respond to news by operating in the futures markets instead of spot markets.

During the first and second sub-samples, we find bidirectional causality between pairs of spot-futures gold returns, which means that both spot and futures prices react simultaneously to new information. This period spans from Jan 2002 to Dec 2007 including the energy crisis and the beginning of the global financial crisis, when we recorded the highest and sharpest gold price increase. During crisis periods, on one hand the large shocks are more correlated, and on the hand these shocks are not completely transmitted instantaneously to the other market, probably because of the uncertainty of the prediction, and perhaps because of psychological behavior.

1.6 Conclusion

The study attempts to evaluate the dependence structure and the Granger causality in distribution between spot-future returns pairs of precious metals namely gold, silver, and platinum. There are two main findings in this study.

First, the static and time varying copulas estimation results show a strong dynamic dependence between spot and future returns of precious metals. Regarding the dependence during extreme market conditions, we find strong symmetric tail dependence described by the t -copula for gold and platinum spot-future pairs and the SJC copula for silver spot-future pair. Second, the assessment of Granger causality in distribution was carried out with the use of the non-parametric independence test based on the empirical copula. Our results reveal a unidirectional causality in distribution from future precious metal returns to spot precious metal returns during normal periods. So, we can say that during normal times spot returns of precious metals depend on past values of future returns, which means that the future market leads the spot market. However, the causal effect seems to be bi-directional in times of crises for gold (from 2002 to 2007) and platinum (from 2002 to 2010) due to the high demand in the physical market in such periods. Hence, during time of instabilities the precious metals future and spot returns show the cause-and-effect relationship.

Our findings are important to traders and investors since understanding market conditions is a central issue as it will help to provide an idea about trading strategies.

In this study, we only focused on an in-sample analysis between the spot and futures precious metals markets by using a non-linear and nonparametric causality test based on empirical copula. Further research might analyze the out-of-sample forecasting of spot and futures precious metals markets.

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Appendices

1.8 Appendix: Static copulas estimation

Table 1. 9: Static copula estimation

	Gold	Silver	Platinum
Gaussian			
ρ	0.8181729 (0.0041)	0.383397 (0.006)	0.7050 (0.002)
AIC	-4190.27	-598.13	-2598.39
BIC	-4184.03	-591.88	-2592.15
LL	2096.14	300.06	1300.2
Student			
ρ	0.8240 (0.005)	0.3800 (0.014)	0.7085 (0.008)
ϑ	3.1745 (0.25)	10.3346 (1.99)	6.1495 (0.735)
AIC	-4532.76	-630.08	-2712.81
BIC	-4520.28	-617.59	-2700.32
LL	2268.38	317.04	1358.4
Clayton			
θ	0.5328 (0.007)	0.2055 (0.009)	0.4086 (0.008)
AIC	-3653.2562	-541.0745	-2153.8714
BIC	-3647.0139	-534.8323	-2147.6292
LL	1827.628	271.537	1077.936
Gumbel			
θ	2.5012 (0.041)	1.2834 (0.014)	1.9110 (0.02)
AIC	-4125.13	-508.36	-2476.18
BIC	-4118.89	-502.11	-2469.94
LL	2063.57	255.18	1239.09
Clayton-Gumbel (BB1)			
θ_1	0.4333 (0.037)	0.1458 (0.028)	0.3759 (0.035)
θ_2	2.1654 (0.043)	1.2324 (0.019)	1.6668 (0.031)
AIC	-4486.1	-643.41	-2696.12
BIC	-4473.61	-630.93	-2683.64
LL	2245.05	323.71	1350.06
SJC			
τ^U	0.6325 (0.008)	0.1417 (0.022)	0.4917 (0.017)
τ^L	0.6850 (0.010)	0.2455 (0.010)	0.5324 (0.014)
AIC	-4402.2437	-638.3618	-2644.5951
BIC	-4389.7593	-625.8773	-2632.1106
LL	2203.122	321.181	1324.298

Notes: (.) contains the corresponding Standard Error. Bold denotes the minimum AIC and BIC values.

1.9 Appendix: Time varying copulas estimation

Table 1. 10: Time varying copula estimation

	Gold	Silver	Platinum
DCC-G			
α	0.0294 (0.007)	0.0081 (0.002)	0.0147 (0.009)
β	0.9616 (0.010)	0.9870 (0.004)	0.9795 (0.019)
AIC	-4575.7280	-630.8277	-2650.7560
BIC	-4563.2436	-618.3433	-2638.2715
LL	2289.864	317.414	1327.378
DCC-t			
ϑ	5.3047	10.7340 (2.071)	6.5655 (0.780)
α	0.0240	0.0084 (0.002)	0.0140 (0.012)
β	0.9760	0.9878 (0.004)	0.9795 (0.025)
AIC	-4767.9912	-663.4257	-2750.5081
BIC	-4749.2645	-644.6990	-2731.7814
LL	2386.996	334.713	1378.254
tvClayton			
ω	0.1346 (0.042)	-0.3053 (0.151)	0.4302 (0.057)
α	-0.6833 (0.202)	-1.8060 (0.305)	-1.7699 (0.232)
β	0.9524 (0.017)	0.2057 (0.141)	0.4070 (0.098)
AIC	-3941.9980	-588.6755	-2236.4757
BIC	-3923.2713	-569.9488	-2217.7490
LL	1973.999	297.338	1121.238
tvSJC			
ω_U^{SJC}	1.2187 (1.891)	-0.0930 (0.447)	2.9010 (0.485)
α_U^{SJC}	-0.2331 (0.197)	-8.5676 (3.001)	-9.9962 (2.613)
β_U^{SJC}	-4.0124 (0.763)	-0.5252 (0.238)	-0.6934 (0.130)
ω_L^{SJC}	1.3336 (2.644)	0.8014 (0.993)	3.3111 (0.573)
α_L^{SJC}	-0.2226 (0.837)	-7.9071 (3.879)	-9.9986 (3.136)
β_L^{SJC}	-4.2186 (1.323)	-0.7081 (0.146)	-0.7770 (0.135)
AIC	-2208.4831	-652.9044	-2690.7123
BIC	-2171.0297	-615.4511	-2653.2589
LL	1110.242	332.452	1351.356

Note: (.) contains the corresponding Standard Error. The parameters ω , α and β are given by Eq.(1.10). The parameters ω_U^{SJC} , α_U^{SJC} and β_U^{SJC} are given by Eq.(1.13). The parameters ω_L^{SJC} , α_L^{SJC} and β_L^{SJC} are given by Eq.(1.14). Bold denotes the minimum AIC and BIC values.

Chapter2

Is the role of precious metals as precious as they are? A vine copula and BiVaR approaches

This chapter, published in *Resources Policy*, investigates the international evidence on hedge, safe haven, and diversification properties of precious metals—namely gold, silver, and platinum—for the G-7 stock markets. Therefore, this study proposes a multivariate vine copula-based GARCH model to assess the hedge and safe haven properties of precious metals and a Bivariate Value at Risk-based copula (BiVaR) measure to analyse the diversification potential of precious metals. Our empirical results suggest that; (1) gold is the strongest hedge and safe haven asset in almost all the G-7 stock markets, (2) silver and platinum results show that they may act as weak hedge assets, (3) silver bears the potential of a strong safe haven role only for Germany's and Italy's stock markets; however, platinum provides a weak safe haven role for most developed stock markets, (4) precious metals appear as interesting assets for diversifying a portfolio for G-7 stock markets investors. Overall, our findings provide noteworthy practical implication for investors.

Keywords: Precious metals, G-7 stock markets, hedge, safe haven, diversification, vine copula, BiVaR.

2.1 Introduction

In the aftermath of the Global Financial Crisis, the interest in holding precious metals has been increased, triggering a rise in their prices. This interest is due to the role of precious metals, practically gold, as important stores of value and in diversifying risk (Adrangi et al., 2003; Lucey and Tully, 2006). The literature on the hedging and safe haven potentials of precious metals, especially gold, is among the faster growing fields of the financial literature since the turmoil period of the last decade. Therefore, the aim of this study is to move forward the academic debate on the precious metals-stock markets nexus by examining the hedge, safe haven and diversification properties of precious metals, namely gold, silver, and platinum for the G-7 countries using more flexible copula-based models, named vine copula, that allows a finer analysis. We also deepen the analysis of our results using the BiVaR method.

The existing literature provides evidence that gold may serve as a hedge asset against stock market in normal periods and as a safe haven during turmoil periods (e.g., Baur and Lucey, 2010; Baur and McDermott, 2010; Ciner et al., 2013; Reboredo, 2013; Beckmann et al., 2015, among others). Recently, attention has been shifted from gold in favour of other precious metals, which have often similar properties to gold. Precious metals may serve as hedge assets against various market risks such as exchange rates (e.g., Ciner et al., 2013; Reboredo, 2013b; Bedoui et al., 2019; Nguyen et al., 2020), inflation (e.g., Hoang et al., 2016; Salisu et al., 2019), oil prices (e.g., Rehman et al., 2018) and stock market indices (e.g., Hood and Malik, 2013; Mensi et al., 2015; Ali et al., 2020). Some other studies have documented the stochastic properties of precious metals, their dynamic interlinkages, and their volatility spillover (e.g., Lucey and Li, 2015; Balcilar and Ozdemir, 2019; Talbi et al., 2020). These studies are of key importance regarding information about hedging strategies for investors.

Prior studies on the hedge and safe-haven properties of precious metals for stock markets highlights a heterogeneous role of precious metals against equity movement. A number of papers including Baur and Lucey (2010), Baur and McDermott (2010), Hood and Malik (2013), Ciner et al. (2013), Bredin et al. (2015) and Shahzad et al. (2017) has particularly focused on gold which is traditionally accepted as hedge and safe haven asset. While recent studies have expanded the set of potential hedges and safe havens to other precious metals (e.g., Lucey and Li 2015; Low et al., 2016; Li and Lucey 2017; Ali et al., 2020). On the whole, although the literature has documented the role of precious metals, the results are quite mixed for different markets. This is somewhat to be expected, given the use of different

market variables, different countries, different time periods and different methods. Therefore, this incites *us to further explore* this topic.

To examine the interactions between precious metals and stock markets, various econometric methods have been used, which can be divided into generalized autoregressive conditional heteroskedasticity (GARCH)-type models (e.g., Hood and Malik 2013; Low et al. 2016; Li and Lucey 2017 and Wu and Chiu 2017), vector autoregression (VAR)-type models (e.g., Wan and Kao 2015), wavelet models (e.g., Bredin et al. 2015), bivariate copulas (e.g., Nguyen et al. 2016) and quantile regression methods (e.g., Shahzad et al. 2017 and Ali et al. 2020).

In particular, the contribution of this present research consists of three main aspects. Firstly, we extend the analysis of precious metals hedging and safe haven properties by modelling the multivariate dependence using vine copula- based GARCH model to study whether precious metals are strong or weak safe haven and/or hedge for the stock markets. The use of copula in higher dimensions is challenging, where standard multivariate copulas, such as the multivariate Gaussian or Student-t copulas, suffer from inflexibility in modelling the dependence structure among larger numbers of variables and exhibit a problem of parameters restriction so they do not allow for different dependency structures between pairs of variables. Hence, the use of vine copulas overcomes the restrictive characteristics of the bivariate copulas by providing flexible and conditional dependence structure between the variables (Brechmann and Czado 2013; Ji et al. 2018). Therefore, the vine copula approach has been widely used in the context of time series models, risk management and so on (see the review about the financial applications of vine copulas provided by Aas (2016)). Nevertheless, in this paper we use the information of dependence on average and in times of extreme market conditions provided by the vine copula to assess, respectively, for the hedge and safe haven properties of precious metals. Secondly, we propose a new definition of “strong safe haven” property. In fact, the copula can test only for weak safe haven since it provides a non-zero probability of extreme price movements to test for uncorrelated series. So, to overcome this limitation, we propose to use simulated data from the best-fitting copula model to compute the tail correlation to rigorously test for strong safe haven property of precious metals. Finally, a BiVaR novel method proposed by Bedoui et al. (2018), will be employed to check for the diversification potential of precious metals for G-7 investors. As far as we know, we are the first to apply the BiVaR based copula method. The importance of this measure remains in combining the copula and the VaR techniques. In fact, the use of copulas allows to construct a level graph of two-dimensional Value at Risk and examine for a risk level, the marginal rate

of substitution (TMS) between the Value at Risk of precious metal and the stock index. So, this method illustrates the level graph of a two-dimensional Value at Risk in a graphical way which enable us to have a clearer vision on the dependence structure between variable and their positioning with regard to the independence, comonotonicity and anti- monotonicity cases which enable as to analyse the diversification property.

The remainder of this chapter is structured as follows: Section 2.2 presents the state of the art. Section 2.3 develops the data and the methodology. Section 2.4 reports and discusses the empirical results of our analysis. Finally, Section 2.5 concludes.

2.2 Literature review

In the recent literature, a stream of research emerges focusing on the role of gold and other precious metals as hedges, safe haven and diversifier assets for stock markets. Notwithstanding the vast existing literature on precious metal markets, the gold market has received the most extensive study.

As defined in Baur and Lucey (2010) who provide the first operational definition of hedge and safe haven, an asset is considered to be a strong (weak) hedge instrument when it is negatively correlated (uncorrelated) on average with another asset. For safe haven property, an asset is considered to be a strong (weak) safe haven instrument when it is negatively correlated (uncorrelated) during the extreme market conditions. However, these hypotheses are based on linear models which generally look at linear correlation and cannot capture rare events on the tails of distributions.

In their paper, they examine the static and time-varying relations between United States (US), United Kingdom (UK), and German stock return and gold return using daily data from 1995 to 2005 to evaluate gold as a hedge and a safe haven. They find that gold serves as an effective hedging tool for stocks and has a role as a safe haven in extreme stock market conditions. As an extension of Baur and Lucey (2010)'s work, Baur and McDermott (2010) study the relationship between gold and stock markets in developed and developing countries using multiple-frequency data from 1979 until 2009. They apply rolling window regression to analyse the time-varying relationship between gold return and the world portfolio index. They find that gold serves as a hedge and safe haven only in European and US markets but not in the BRICs markets (Australia, Canada and Japan). Adopting the same methodology, Hood and Malik (2013) study the role of precious metals (gold, silver, and platinum) relative to the Volatility Index (VIX) as a hedge and safe haven against the US stock market; and they find that, unlike gold, platinum and silver serve neither as a hedge nor as a safe haven for the US

stock market. Similarly, Arouri et al. (2015) use a bivariate VAR-GARCH model to study return and volatility spillovers between world gold prices and the Chinese stock market over the period from 22 March 2004, through 31 March 2011. They find significant return and volatility cross effects between the variables, and gold may serve as a safe haven for the Chinese stock market.

Shen et al. (2013) investigate the dependence structure among gold price, stock price index of gold mining companies, and the Shanghai Composite Index in China using bivariate copula based GARCH models and find that the gold return price has positive correlation with stock market returns, which differs from the findings of other research (gold price typically has negative correlation with stock market returns).

Kumar (2014) investigates the mean and volatility transmission between gold and Indian industrial sectors. Using a generalised VAR-ADCC-BVGARCH model, he finds unidirectional and significant return spillover from gold to stock sectors and claims that gold can be considered a valuable asset class that can improve the risk-adjusted performance of a well-diversified portfolio of stocks and acts as a hedge against different markets.

Applying the Dynamic Conditional Correlation (DCC) Multivariate GARCH Model, Lucey and Li (2015) study the safe haven properties of four precious metals (gold, silver, platinum, and palladium) using daily data from 1989 to 2013. They find evidence that in some periods of time, silver and platinum can act as safe haven when gold does not, and the effect can sometimes be stronger.

Nguyen et al. (2016) investigate the role of gold as a safe haven in seven countries: UK, US, Indonesia, Japan, Malaysia, Philippines, Singapore, and Thailand. Using bivariate copulas, they find that gold may be a safe haven asset during a market crash for the cases of Malaysia, Singapore, Thailand, the UK and US markets but not for the Indonesian, Japanese, and the Philippine markets.

Expanding the work of Lucey and Li (2015), Li and Lucey (2017) examine the safe haven properties of precious metals versus equity market movements across a wide variety of countries using daily data from January 1994 to July 2016. Applying the standard approach as outlined in Baur and Lucey (2010) and Baur and McDermott (2010), they find that each metal may play a safe haven role against the stock market during tail events.

Klein (2017) examines the connection of developed markets and precious metal prices using daily data from Jan 2000 to Dec 2016. Applying DCC-GARCH model, he finds that gold and

silver act as safe haven assets while platinum serves as a temporal surrogate safe haven in extreme market conditions.

He et al. (2018) re-examines whether gold is a safe haven asset for UK and US investors. Applying a Markov-switching CAPM (Capital asset pricing model) approach, they find that gold is consistently a hedge but that no distinct safe haven state exists between gold and UK or US stock markets.

Junttila et al. (2018) study the hedging property of gold and oil against stock market risk in times of financial crisis. They find that stock and gold markets become negatively correlated during times of financial crises. Thus, the gold market provides a better hedge than the oil market against stock market risks.

Recently, Ali et al. (2020) re-examine the safe haven, hedge, and diversification potentials of 21 commodities (including precious metals) for 49 international stock markets. Using the cross-quantilogram approach (the quantile dependence across the whole range of quantiles), they find that precious metals in general and gold in particular provide strong safe havens for developed and frontier stock markets.

Table 2. 1 summarises leading works, covering the period 2010 to 2020, that dealt with the hedge, safe haven, and diversification properties of precious metals. In the existing literature, linear models, GARCH-type models, and quantile regressions are frequently used methods. Our contribution to the literature is two-fold. First, we apply a vine copula to analyse the hedge and safe haven properties. Then, we propose a novel method, the BiVaR measure, to examine the diversification potential of precious metals.

Table 2. 1: Literature review summary

Authors	Precious metal	Stock markets data	Examined Property	Model	Findings
Baur and Lucey (2010)	Gold	Germany, US and UK	Hedge and safe haven	Asymmetric GARCH	Gold is a hedge and a safe haven
Baur and McDermott (2010)	Gold	Developed and emerging markets	Hedge and Safe haven	Quantile regression approach	Gold is a hedge and a safe haven in Europe and the US and strong safe haven in developed countries
Ibrahim and Baharom (2011)	Gold	Malaysia	Diversifier, Hedge and safe haven	EGARCH model	Gold is a diversifier
Ciner et al. (2013)	Gold	US and UK	Safe haven	DCC model	Gold is a safe haven
Hood and Malik (2013)	Gold, silver and platinum	US	Hedge and safe haven	GARCH model	Gold serves as hedge and weak safe haven
Flavin et al. (2014)	Gold	US	Safe haven	Regime-switching Model	Gold is a safe haven
Bredin et al. (2015)	Gold	Germany, US and UK	Hedge and safe haven	Wavelet analysis	Gold is a hedge and a safe haven
Arouri et al. (2015)	Gold	China	Diversifier, hedge and safe haven	VAR-GARCH	Gold is a hedge and a safe haven
Lucey and Li (2015)	Precious metals	US	Safe haven	DCC model	Silver, platinum and palladium serve as safe haven assets
Chkili (2016)	Gold	BRICS	Hedge and safe haven	Asymmetric DCC model	Gold is a hedge and a safe haven
Mensi et al. (2016)	Gold	Gulf	Hedge and safe haven	Quantile regression and wavelet decomposition	Gold is a strong hedge and safe haven at various investment horizons.
Low et al. (2016)	Gold, silver, platinum and palladium	Brazil, Australia, China, Germany, France, UK and US	Hedge and safe haven	GJR-GARCH model	Gold, silver, platinum and palladium serve as hedges and safe haven assets

Table 2. 1 (Continued)

Authors	Precious metals data	Stock markets data	Examined Property	Model	Findings
Nguyen et al. (2016)	Gold	Japan, Singapore, Malaysia, Thailand, Philippines,US and UK	Hedge and safe haven	Copula	Gold serve as a safe haven asset for US, UK, Singapore and Thailand
Li and Lucey (2017)	Gold, sikver, platinum and palladium	Developed and emerging markets	Safe haven	Asymmetric GARCH	Precious metals serve as safe haven assets for all countries under study clustered during some periods.
Shahzad et al. (2017)	Gold	Developed and Eurozone	Diversifier, hedge and safe haven	Quantile-on-quantile method	Gold is a strong hedge and a diversifier asset
Bekiros et al. (2017)	Gold	BRICS	Diversifier, hedge and safe haven	Multi-scale wavelet copula-GARCH	Gold is a diversifier asset
Wu and Chiu (2017)	Gold	US	Diversifier and safe haven	Asymmetric GARCH model	Gold is a safe haven
Wen and Cheng (2018)	Gold	BRICS, Chechnya, Malaysia, Thailand	Safe haven	Copula	Gold is a safe haven for emerging markets
Raza et al. (2019)	Gold	Developed, emerging markets Europe, Asia Pacific and Islamic stock markets	Hedge and diversifier	DCC model	Gold serves as a hedge and diversifier asset
Ali et al. (2020)	Gold, sikver, platinum and palladium	49 international stock markets	Safe haven, hedge, and diversification	Cross-quantilogram approach	Precious metals and gold in particular provide strong safe havens for developed and frontier stock markets.

2.3 Data and methodology

2.3.1 Data description

This study considers daily prices data for precious metals and stock indices. The precious metals include PM fixing of London of the US\$/Troy ounce for gold,¹⁵ the PM fixing of London Platinum price in US\$/Troy ounce, and the silver price in US\$/kilogram fixed by the London Bullion Market (LBMA). We consider the following G-7 stock market indices: S&P/TSX Composite (Canada), CAC 40 (France), DAX (Germany), FTSE MIB (Italy), Nikkei 225 (Japan), FTSE 100 (UK) and the S&P 500 (US). The study period runs from 01 January 2002 through 05 February 2018, which covers several turbulent periods and crises, including the energy price instability period and 2008–2009 GFC. All data were extracted from DataStream, a division of Thomson Reuters, and priced in US dollars. All variables are transformed into logarithmic returns, which are defined as the first difference in the natural logarithm of the daily prices, such that $R_t = \ln(P_t) - \ln(P_{t-1})$, where R_t are returns at time t , and P_t and P_{t-1} are the current price and one-period lagged price, respectively.

Figure 2. 1 displays the dynamics between precious metals and the S&P 500 index prices during the sampling period.¹⁶ It reflects that precious metals and the US stock market are poorly correlated. The same is true for the other markets shown in Figure 2.A in the Appendix. For almost all countries, a falling stock market results in a rise in precious metals demand.

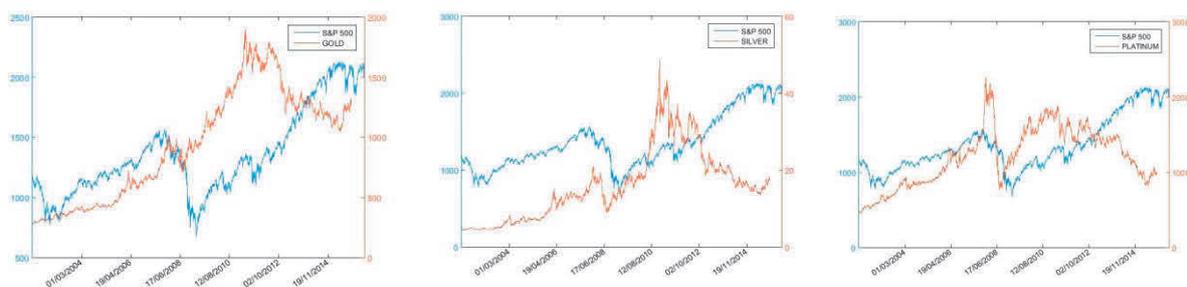


Figure 2. 1: Precious metals and S&P500 dynamics

¹⁵ The fixing occurs twice a day, except for silver, which is fixed at noon each day. The price fixing done in the morning is called the AM Fix, while the afternoon fixing is called the PM Fix.

¹⁶ Plots of precious metals and other stock market indexes are reported in Appendix 2.9, in Figure 2. 3.

2.3.2 Vine copulas

Copulas have found many successful applications in a various empirical works to model joint distributions of random variables.¹⁷ In his theorem, Sklar (1959) states that any n -dimensional multivariate distribution can be decomposed into n marginal distributions and a unique copula. More formally:

$$F(x_1, x_2, \dots, x_n) = C(F_1(x_1), F_2(x_2), \dots, F_n(x_n)) \quad (2.1)$$

where F is a joint distribution of x_1, x_2, \dots, x_n with marginal distributions $F_i = F_i(x_i)$ for $i = 1, 2, \dots, n$, and $C: [0,1]^n \rightarrow [0,1]$ is a copula function. Suppose that F_i and C are differentiable. Then, the joint density function is defined as:

$$f(x_1, x_2, \dots, x_n) = \prod_{i=1}^n f_i(x_i) c(F_1(x_1), F_2(x_2), \dots, F_n(x_n)) \quad (2.3)$$

where $f_i = f_i(x_i)$ is the (unconditional) density of F_i and c is the density of the copula.

Hence, the copula function separates the joint distribution into two contributions: the marginal distributions of each variable and the copula that combines these marginal distributions into a joint distribution.

Given the rich variety of bivariate copulas, they are limited to only one or two parameters to describe the dependence structure among variables. Hence, even though it is simple to generate multivariate Elliptical or Archimedean copulas, they cannot adequately capture the dependence in the multivariate scale.¹⁸ Therefore, we may go beyond these standard multivariate copulas by using vine copula approach, which is a more flexible alternative measure to capture the dependence structure among assets. (Joe, 1997; Bedford and Cooke, 2001, 2002; Kurowicka and Cooke, 2006; Aas et al., 2009)

Technically, a vine copula consists of building a multivariate joint distribution from a cascade of unconditional and conditional bivariate copulas. It is well known that any multivariate density function can be represented as a product of unconditional and conditional densities:

$$f(x_1, \dots, x_n) = f(x_1) \cdot f(x_2|x_1) \cdot f(x_3|x_1, x_2) \dots f(x_n|x_1, \dots, x_{n-1}) \quad (2.4)$$

Bedford and Cooke (2002) introduced two types of vine copulas: canonical vine copulas (C-vine) and drawable vine copulas (D-vine).

In the C-Vine copula one variable plays a pivotal role. The general n -dimensional C-vine copula can be written as:

$$c(x_1, \dots, x_n) = \prod_{i=1}^{n-1} \prod_{j=1}^{n-i} c_{i,i+j|1,\dots,i-1} \left(F(x_i|x_1, \dots, x_{i-1}), F(x_{i+j}|x_1, \dots, x_{i-1}) \right) \quad (2.5)$$

¹⁷ We refer the reader to Joe (1997) and Nelson (2006) for more details about copulas.

¹⁸ The main characteristics of copula functions used in this study are summarised in Table 2. 10 in Appendix 2.7.

For instance, a 4-dimensional C-vine density decomposition and its hierarchical tree structure are represented as follows:

$$\begin{aligned}
f(x_1, x_2, x_3, x_4) &= f_1(x_1) \cdot f_2(x_2) \cdot f_3(x_3) \cdot f_4(x_4) \\
&\cdot c_{1,2}(F_1(x_1), F_2(x_2)) \cdot c_{1,3}(F_1(x_1), F_3(x_3)) \cdot c_{1,4}(F_1(x_1), F_4(x_4)) \\
&\cdot c_{2,3|1}(F_{2|1}(x_2 | x_1), F_{3|1}(x_3 | x_1)) \cdot c_{2,4|1}(F_{2|1}(x_2 | x_1), F_{4|1}(x_4 | x_1)) \\
&\cdot c_{3,4|1,2}(F_{3|1,2}(x_3 | x_1, x_2), F_{4|1,2}(x_4 | x_1, x_2)).
\end{aligned} \tag{2.6}$$

Similarly, D-vine copulas are also constructed by choosing a specific order for the variables in which variables are connected in a symmetric way. The general n -dimensional D-vine copula can be written as:

$$c(x_1, \dots, x_n) = \prod_{i=1}^{n-1} \prod_{j=1}^{n-i} c_{j,j+i|j+1, \dots, j+i-1}(F(x_j | x_{j+1}, \dots, x_{j+i-1}), F(x_{j+i} | x_{j+1}, \dots, x_{j+i-1})). \tag{2.7}$$

We illustrate an example of 4-dimensional D-vine density decomposition and its hierarchical tree structure as follows:

$$\begin{aligned}
f(x_1, x_2, x_3, x_4) &= f_1(x_1) \cdot f_2(x_2) \cdot f_3(x_3) \cdot f_4(x_4) \\
&\cdot c_{1,2}(F_1(x_1), F_2(x_2)) \cdot c_{2,3}(F_2(x_2), F_3(x_3)) \cdot c_{3,4}(F_3(x_3), F_4(x_4)) \\
&\cdot c_{1,3|2}(F_{1|2}(x_1 | x_2), F_{3|2}(x_3 | x_2)) \cdot c_{2,4|3}(F_{2|3}(x_2 | x_3), F_{4|3}(x_4 | x_3)) \\
&\cdot c_{1,4|2,3}(F_{1|2,3}(x_1 | x_2, x_3), F_{4|2,3}(x_4 | x_2, x_3)).
\end{aligned} \tag{2.8}$$

For the selection of the appropriate vine tree structure, pair-copula families and their parameter values, we follow the sequential procedure proposed by Dissmann et al. (2013), which is summarised in Table 2. 2.

Table 2. 2: Sequential method to select a vine copula model

Algorithm. Sequential method to select a vine copula model
1- Calculate the empirical Kendall's τ for all possible variable pairs.
2- Select the tree that maximises the sum of absolute values of Kendall's τ .
3- Select a copula for each pair and fit the corresponding parameters.
4- Transform the observations using the copula and parameters from Step 3. To obtain the transformed values.
5- Use transformed observations to calculate empirical Kendall's τ 's for all possible pairs.
6- Proceed with Step 2. Repeat until the vine copula is fully specified.

The estimation of vine copulas is a two-step separation procedure which is called the inference functions for the margin method (IFM). It implies that the joint log-likelihood is

simply the sum of univariate log-likelihoods, and the copula log-likelihood is given as follows:

$$l(x) = \sum_{i=1}^n \ln(f_i(x_i)) + \ln\left(c(F_1(x_1), \dots, F_n(x_n))\right). \quad (2.9)$$

2.3.3 Vine copula based GARCH model

In this study, an AR(1)-GARCH(1,1) model is adopted for the marginal distributions according to the AIC and BIC information criteria for possible values ranging from zero to four.¹⁹ The model can be written as:

$$R_t = \mu + \phi_1 R_{t-1} + \varepsilon_t, \quad (2.10)$$

$$\varepsilon_t = Z_t \sqrt{\sigma_t}, Z_t \sim \text{Student} - t(\vartheta), \quad (2.11)$$

$$\sigma_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2, \quad (2.13)$$

where $\omega > 0$, $\alpha_1, \beta_1 \geq 0$, and R_t are the logarithmic returns at time t, μ is a constant term of the return equation, ε_t represents the return residuals, and Z_t are the standardised residuals which have a student-t distribution with ϑ degrees of freedom.

The Vine copula based GARCH model is estimated following a two-step procedure. First, we estimate the parameters for the univariate marginal models in Equations (2.10) -(2.13) by the maximum likelihood method. Second, we obtain the parameters of the vine copula using the sequential maximum likelihood estimation procedure described in Table 2.2 that consists of estimating pair-copula parameters sequentially and conditioning on the parameters of the preceding levels of the vine structure, choosing the best pair-copulas using the AIC and BIC information criteria.²⁰

2.3.4 Testing for hedge and safe haven properties

The use of copulas is crucial since it gives us information about both the average dependence and the dependence in times of extreme market movements (independent from how the marginal distributions are modelled). On one hand, the average dependence is given by correlation measures (Kendall's tau or Spearman's rho) which are obtained from the dependence parameter of the copula. On the other hand, the dependence in terms of extreme market movements is obtained from the copula tail dependence coefficients.

¹⁹ The order of AR terms and the lag orders of the GARCH model are all specified to be 1, which is in line with Brooks, 2008 who stated that a GARCH-family model with lag order of 1 can sufficiently describe volatility clustering in the data, and higher-order models are rarely used in financial literature.

²⁰ The pair copulas functions are reported in Appendix 2.7, in Table 2. 11

On the basis of copula dependence information, we can formulate the conditions under which a precious metal is characterised as a strong (weak) hedge and/or strong (weak) safe haven for the stock indexes under study as in Table 2. 3.

Table 2. 3: Hypothesis testing

Conditions	Conclusion
$\rho_{PM,I} < 0$	Precious metal is a strong hedge
$\rho_{PM,I} = 0$ or strongly near to 0	Precious metal is a weak hedge
$\lambda_L = 0$	Precious metal is a weak safe haven
$\lambda_L = 0$ and $\rho(PM, I I < I_q) < 0$	Precious metal is a strong safe haven

Notes: $\rho_{PM,I}$ is the average dependence measure (given by the copula parameter or the Kendall tau) between precious metals (PM) and stock market indexes (I) and λ_L is the lower tail dependence coefficient for the joint distribution of precious metals and stock market indexes. We define $\rho(PM, I|I < I_q)$ as the correlation between precious metals (PM) and stock market indexes (I) at the lower tail of stock returns distribution, where I_q denotes the q^{th} percentile of I.

Based on the values of Kendall's tau, the precious metal serves as a strong hedge when the value of Kendall's tau is negative or equal to zero. Meanwhile, if Kendall's tau is positive and near to zero, the precious metal is considered as a weak hedge. Then, based on the lower tail dependence coefficient λ_L , the precious metal is a weak safe haven asset when it shows zero lower tail dependence ($\lambda_L = 0$) with the stock market index. This means that in this case investors will not experience a loss in their precious metal holdings when the stock market crashes. And, if $\lambda_L > 0$, this implies that there is a positive probability of concurrent losses in precious metal and stock market indexes during periods of turmoil. However, positive lower tail dependence does not strictly signify a null probability of positive precious metal returns during the time of significant equity downturns since λ_L is only a conditional probability measure rather than a tail correlation. The reason is that it is more reasonable to compute the value of correlation between stock market (I) and precious metal (PM) returns at the lower tail of the stock returns distribution. Hence, the precious metal is a strong safe haven asset for the stock market if $\lambda_L = 0$ and $\rho(PM, I|I < I) < 0$ at the same time.

2.3.5 BiVaR based copula model

Based on the dependence structure computed using copulas, the bivariate Value at Risk (BiVaR) risk measure is implemented to examine the diversification benefits of precious metals. Copulas allow us to draw the level curves of the two-dimensional Value at Risk and examine, for a given threshold level ($\alpha=5\%$), the marginal rate of substitution (TMS) between the VaR of the two univariate risks. Hence, for a given marginal distribution of precious

metals and stock returns, it is possible to draw the contours corresponding to the minimum copula (anti-monotonicity case), maximum copula (comonotonicity case), and the independence copula.

Let r_X and r_Y be the precious metal and stock market index return series with univariate distribution functions, F_X and F_Y , respectively. Hence, \forall the threshold $\alpha \in [0,1]$, we have:

$$\{(r_X, r_Y); F_X(r_X) \cdot F_Y(r_Y) = \alpha\}, \text{ independence case} \quad (2.14)$$

$$\{(r_X, r_Y); \max(F_X(r_X) + F_Y(r_Y) - 1, 0) = \alpha\}, \text{ anti-monotonicity case} \quad (2.15)$$

$$\{(r_X, r_Y); \min(F_X(r_X), F_Y(r_Y)) = \alpha\}, \text{ comonotonicity case} \quad (2.16)$$

The level curves from the empirical copula are given by:

$$\{(r_X, r_Y); \mathbf{C}(F_X(r_X), F_Y(r_Y)) = \alpha\}. \quad (2.17)$$

The level curves are used to determine the TMS between the two univariate VaR. The higher the level of the empirical curves (approaching the anti-monotonicity case), the more that dependence between the precious metals and stock market indices returns is negative. Hence, there is the presence of a compensation effect. However, the closer the curves are to their lower limit, corresponding to the case of comonotonicity (positive dependence) where the returns tend to move in the same direction, the more the correlation between losses is therefore extremely high. Regarding the curves of multiplication, they correspond to the diversification case (see Cherubini and Luciano, 2001; Bedoui and Ben Dbabis, 2009).

2.4 Empirical results and discussions

This section discusses the empirical results of this study. The preliminary analyses results are firstly presented. Then, we discuss our main results about the hedge, safe haven and diversification potentials of precious metals for the G-7 stock markets.

2.4.1 Preliminary analyses results

The descriptive statistics for the daily returns of precious metals and equity indexes are reported in

. Results show that all the means are close to zero, and the standard deviations are small, which means that all series are around the mean. Likewise, among the precious metals, silver has the highest standard deviation, while gold has the lowest, which implies that silver is the most volatile. Moreover, asymmetry and fat tails in the returns were evident for all series.

Thus, the results for the skewness and the excess of kurtosis reinforce the rejection of normality. The Jarque–Bera (JB) test rejects the normality hypothesis, while the Ljung-Box (LB) statistic confirmed the absence of serial correlation, except for the Nikkei 225, gold, and platinum. Likewise, the ARCH effect test indicates the presence of ARCH effects in all series.

Table 2. 4: Descriptive statistics for log-returns

	CAC40	DAX	FTSE 100	FTSE MIB	NIKKEI 225	S&P\ TSX	S&P500	Gold	Silver	Platinum
Mean(10^{-2})	0.0102	0.0255	0.0054	-0.0016	0.0211	-0.1195	0.0232	0.0370	0.0270	0.0178
Std. Dev	0.0155	0.0156	0.0134	0.0167	0.0140	0.0983	0.0115	0.0110	0.0200	0.0148
Max	0.1214	0.1236	0.1221	0.1238	0.1164	0.0992	0.1095	0.0684	0.1828	0.0843
Min	-0.117	-0.0960	-0.1150	-0.1542	-0.1211	-6.6025	-0.0947	-0.0960	-0.3535	-0.1728
Skewness	0.0926	0.0573	-0.0203	-0.1592	-0.4742	-0.5417	-0.2356	-0.3902	-1.7524	-0.9114
Kurtosis	8.8223	8.2855	10.7229	9.1053	9.6310	11.2394	11.3305	7.5531	31.2669	12.1964
JB stat	4757,6*	3918,7*	8362,7*	5240,3*	6291,1*	9682,9*	9761,1*	2992*	113751*	12323,7*
Q(20)	63.41*	40.09*	81.20*	46.17*	22.31	68.80*	73.77*	26.53	84.10*	20.89
LM stat	198.79*	171.45*	354.85*	114.19*	243.51*	345.60*	365.35*	40.81*	117.90*	155.82*

Notes: Std. Dev denotes the standard deviation, JB denotes the Jarque–Bera statistic for normality testing. Q (20) denotes the Ljung-Box statistic for autocorrelation testing, LM stat denotes Engle’s LM test statistic for heteroskedasticity testing. (*) indicates rejection of the null hypothesis at the 5% level.

2.4.2 Main results

In the first step, we filter the returns using GARCH model, aiming to obtain the residuals since copula model request independent and identically distributed (i.i.d) uniform data. Then, we filter the standard innovation by t- distribution. Thereafter, we apply the vine copula to the transformed standardized residuals of each asset returns, mainly the C-vine and D-vine copulas.²¹ The empirical estimates of the marginal model for returns given by equations (2.10) – (2.13) are reported in Table 2. 5. The results of the volatility estimates show that the α_1 coefficients, which measure the adjustment to past shocks, and the β_1 coefficients, which measure the volatility persistence of the process, are significant for all series, which indicates that the conditional volatility is persistent over time and is past-dependent. As usual, all series are described by significant GARCH effects. Finally, the results for the goodness-of-fit of our marginal models are reported in the last row of Table 2. 5. The Ljung-Box (Q statistic) and ARCH (LM statistic) statistics indicate that neither autocorrelation nor ARCH effects remained in the residuals of the marginal models. We also checked the adequacy of the

²¹ Before estimating copula models, we calculate the empirical Kendall’s τ for all possible pairs of variables to select the tree that maximises the sum of absolute values of Kendall’s τ . (Appendix 2.8, Table 2. 12) The results shows that platinum has the strongest dependency in terms of the empirical value of pairwise Kendall’s tau; hence, we consider platinum as the first root node. Thereby, the order of variables is as follows. For France, Canada, and US, the order of variables should be the following: Platinum (order 1), Gold (order 2), Silver (order 3), and the Stock Index (order 4). And for the rest of countries, the order is: Platinum (order 1), Silver (order 2), Gold (order 3), and the Stock Index (order 4).

Student-t distribution model, testing the null hypothesis that the standardized model residuals were uniform (0,1) by comparing the empirical and theoretical distribution functions using the Kolmogorov-Smirnov test. The p -values for those tests, reported in the last row of Table 2. 5, indicate that the null hypothesis could not be rejected at the 5% significance level for either of the marginal models. Hence, the marginal models are correctly specified, and the copula model can correctly capture dependence between precious metals and equity markets.

Table 2. 5 : Parameter estimates for marginal models of precious metals and stock market returns

	CAC40	DAX	FTSE100	FTSE MIB	NIKKEI 225	S&P\TSX	S&P500	Gold	Silver	Platinum
Mean equation										
μ (10^{-4})	7.1327 (3.76)	9.9147 (5.19)	5.0729 (3.47)	6.6756 (3.53)	7.5689 (3.57)	7.1591 (5.49)	7.9312 (5.57)	6.3487 (3.79)	5.8014 (2.04)	4.9329 (2.51)
ϕ_1	-0.041 (-2.25)	-0.013 (-0.71)	-0.0350 (-1.89)	-0.056 (-2.27)	-0.0411 (-2.39)	0.0202 (1.13)	-0.0562 (-3.01)	-0.0079 (-0.458)	-0.0906 (-5.58)	-0.02073 (-1.186)
Variance equation										
ω (10^{-6})	2.0475 (3.44)	1.7323 (3.25)	1.7199 (3.96)	8.4475 (2.60)	3.8797 (3.84)	9.6567 (3.38)	1.5845 (3.78)	1.3191 (3.15)	0.0406 (3.59)	3.3138 (3.83)
α_1	0.0887 (8.58)	0.0870 (8.59)	0.1101 (9.11)	0.0712 (8.58)	0.0977 (8.73)	0.0818 (7.89)	0.101 (8.43)	0.0398 (6.11)	0.0406 (6.64)	0.0705 (7.48)
β_1	0.9055 (87.28)	0.9092 (89.48)	0.8813 (73.29)	0.9288 (118.5)	0.8889 (70.76)	0.9121 (88.99)	0.8919 (74.90)	0.9517 (123.33)	0.9510 (141.88)	0.9153 (84.41)
ϑ	7.9602	8.0630	9.1590	7.3602	9.3696	6.5160	6.3356	5.5135	4.9273	5.9475
LL	9861.6	9810.3	10692.9	9709.3	9648.3	11145.8	10764.01	10440.4	8523.7	9855.2
Q(20)	19.55 [0.486]	23.98 [0.243]	16.87 [0.66]	18.50 [0.55]	8.326 [0.989]	13.768 [0.84]	23.39 [0.27]	23.53 [0.2635]	11.171 [0.941]	14.18 [0.821]
Q(20) ²	18.30 [0.567]	30.41 [0.063]	6.47 [0.998]	15.12 [0.769]	17.67 [0.609]	15.19 [0.765]	24.13 [0.236]	7.96 [0.99]	7.99 [0.99]	23.29 [0.274]
ARCH- LM stat	0.55 [0.456]	0.02 [0.883]	1.7510^{-5} [0.996]	0.004 [0.944]	2.50 [0.113]	0.44 [0.505]	1.44 [0.229]	0.62 [0.430]	4.69 [0.030]	5.58 [0.018]
Goodness of fit of the marginal distribution model										
K-S test	[0.58]	[0.108]	[0.68]	[0.27]	[0.206]	[0.15]	[0.07]	[0.29]	[0.35]	[0.15]

Notes. This table reports the ML estimates and z-statistic (in brackets) for the parameters of the marginal distribution model defined in Eqs. (2.10)-(2.13). The $Q(20)$ and $Q(20)^2$ are the Ljung-Box statistics for serial correlation in the model's standardised residuals and standardised squared residuals, respectively, using 20 lags. ARCH is Engle's LM test for the ARCH effect in the standardised residuals up to 10th order. K-S denotes the Kolmogorov-Smirnov test. The reported p values (in square brackets) below 0.05 indicate the rejection of the null hypothesis that the model distribution is correctly specified.

Table 2. 6 presents the best vine copula model that fits our data using the Log Likelihood (LL) values, AIC, and BIC criteria. The results show that the D-vine structure for Canada, Japan, UK, and US markets is more appropriate than the C-vine, whereas the latter is more suitable for France, Germany, and Italy than the former.

Table 2. 6: Vine copula model selection

Country	Criteria	C-vine	D-vine	Choice
France	LL	1774.82	1773.219	C-vine
	AIC	-3529.64	-3526.438	
	BIC	-3468.428	-3465.226	
UK	LL	1788.083	1791.184	D-vine
	AIC	-3554.167	-3559.85	
	BIC	-3486.834	-3491.96	
Italy	LL	1772.113	1737.825	C-vine
	AIC	-3524.61	-3513.65	
	BIC	-3463.015	-3446.317	
Germany	LL	1773.678	1774.566	C-vine
	AIC	-3527.356	-3459.798	
	BIC	-3466.144	-3459.798	
Japan	LL	1763.845	1766.714	D-vine
	AIC	-3505.69	-3511.429	
	BIC	-3438.357	-3444.096	
Canada	LL	1698.796	1699.391	D-vine
	AIC	-3375.592	-3378.782	
	BIC	-3308.259	-3317.57	
US	LL	1631.687	1741.68	D-vine
	AIC	-3461.136	-3459.617	
	BIC	-3393.803	-3398.405	

Notes: The LL denotes the Log Likelihoods. Bolds denote maximum of LL values and minimum of AIC and BIC values.

Table 2. 7 and Table 2. 8 represent, respectively, results of the parameter estimation of the selected C-vine and D-vine copulas for each of the G-7 stock markets.

For France, Germany, and Italy, the first tree of Table 2. 7 shows symmetric upper and lower tail dependence between all pairs, indicating similar dependence during upward and downward periods and an average dependence near to zero, particularly, between platinum and the stock market indexes. This result indicates that platinum may serve as a weak hedge for French, German, and Italian investors. Taking the second tree, results show that gold may serve as both hedge and safe haven on the stock market of France, and silver may have the role of a hedge and a safe haven asset in the stock markets of Germany and Italy. Finally, the third tree shows zero upper tail for France, Germany, and Italy, a weak dependence on average for France, and negative dependence on average for Germany and Italy. This result reveals that silver is a weak hedge and safe haven asset for French investors, and gold serves as a strong hedge and a safe haven asset for German and Italian investors.

Table 2. 7: Results of estimated parameters for C-vine copulas

France							
#Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,G}$	t-Student	0.4	0.5938	9.1616	0.1381	0.1381
	$C_{P,S}$	t-Student	0.39	0.5804	8.6912	0.1408	0.1408
	$C_{P,I}$	t-Student	0.09	0.1344	14.7521	0.0032	0.0032
2	$C_{G,S P}$	t-Student	0.24	0.3655	12.2644	0.0272	0.0272
	$C_{G,I P}$	Rotated Gumbel	-0.08	-1.0926	0	0	0
3	$C_{S,I P,G}$	Clayton	0.02	0.0308	0	0.0168e-8	0
Germany							
#Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,S}$	t-Student	0.39	0.5814	8.7670	0.1397	0.1397
	$C_{P,G}$	t-Student	0.4	0.5932	9.0857	0.1394	0.1394
	$C_{P,I}$	t-Student	0.08	0.1288	15.7353	0.0023	0.0023
2	$C_{S,G P}$	t-Student	0.24	0.3637	12.2559	0.0269	0.0269
	$C_{S,I P}$	Rotated Joe	-0.01	-1.0212	0	0	0
3	$C_{G,I P,S}$	Rotated Gumbel	-0.09	-1.0968	0	0	0
Italy							
#Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,S}$	t-Student	0.39	0.5812	8.8180	0.1385	0.1385
	$C_{P,G}$	t-Student	0.41	0.5951	9.5462	0.1313	0.1313
	$C_{P,I}$	t-Student	0.08	0.1290	12.071	0.0073	0.0073
2	$C_{S,G P}$	t-Student	0.24	0.3637	12.276	0.0268	0.0268
	$C_{S,I P}$	Rotated Joe	-0.02	-1.0297	0	0	0
3	$C_{G,I P,S}$	Rotated Gumbel	-0.08	-1.0851	0	0	0

Notes: P= platinum, G=gold, S=silver and I= stock index for each country. $C_{P,G}$ denotes copula between platinum and gold. $C_{G,S|P}$ denotes copula between gold and silver given platinum. τ is the Kendall's tau of the specified copulas, θ is the copula parameter and ϑ is the degree of freedom.

In the first tree of Table 2. 8, we observe symmetric upper and lower tail dependence given by the t-copula. We also observe a dependence on average strongly near to zero between silver and stock market indexes for Canada and US and between gold and stock market indexes for UK and Japan, indicating that silver (gold) is only a weak hedge asset for Canadian and American (UK and Japanese) investors. In the second tree, results indicate that gold may serve as a strong hedge and a safe haven asset ($\lambda_L = 0$) against the stock markets of Canada and US. However, silver is only a weak hedge for Japan and UK. Finally, the third tree shows weak dependence on average between platinum and stock market indexes, confirming the role of platinum as a weak hedge for the Canada, US, UK, and Japan stock markets. Regarding lower tail dependence, results indicate zero tail dependence for Canada and US, arguing that platinum is a safe haven for Canadian and American investors.

Table 2. 8: Results of estimated parameters for D-vine copulas

Canada							
Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,G}$	t-Student	0.41	0.5955	8.5439	0.1523	0.1523
	$C_{G,S}$	t-Student	0.4	0.5859	10.732	0.1062	0.1062
	$C_{S,I}$	t-Student	0.01	0.0163	14.714	0.0013	0.0013
2	$C_{P,SI}$	t-Student	0.23	0.3575	12.055	0.0272	0.0272
	$C_{G,IS}$	Rotated Joe	-0.01	-1.0234	0	0	0
3	$C_{P,IS,G}$	Survival Clayton	0.01	0.0176	0	0	7.87e-18
UK							
Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,S}$	t-Student	0.39	0.5806	8.5573	0.1438	0.1438
	$C_{S,G}$	t-Student	0.4	0.5865	10.788	0.1056	0.1056
	$C_{G,I}$	t-Student	0.02	0.0319	7.4344	0.0216	0.0216
2	$C_{P,GI}$	t-Student	0.25	0.3889	11.811	0.0339	0.0339
	$C_{S,IG}$	Survival Gumbel	0.06	1.0609	0	0.0780	0
3	$C_{P,IS,G}$	t-Student	0.11	0.1704	20.132	0.0008	0.0008
US							
Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,G}$	t-Student	0.41	0.5951	8.5441	0.1521	0.1521
	$C_{G,S}$	t-Student	0.4	0.5851	10.732	0.1058	0.1058
	$C_{S,I}$	t-Student	0.02	0.0314	10.334	0.0073	0.0073
2	$C_{P,SI}$	t-Student	0.23	0.3579	12.055	0.0273	0.0273
	$C_{G,IS}$	Rotated Joe	-0.02	-1.0354	0	0	0
3	$C_{P,IS,G}$	Gaussian	0.09	0.1342	0	0	0
Japan							
Tree	Blocks	Family	τ	Parameter		λ_L	λ_U
				θ	ϑ		
1	$C_{P,S}$	t-Student	0.39	0.5805	8.1081	0.1540	0.1540
	$C_{S,G}$	t-Student	0.4	0.5842	10.601	0.1074	0.1074
	$C_{G,I}$	t-Student	0.02	0.0379	8.7998	0.0133	0.0133
2	$C_{P,GI}$	t-Student	0.25	0.3883	11.645	0.0350	0.0350
	$C_{S,IG}$	Survival Gumbel	0.06	1.0617	0	0.0789	0
3	$C_{P,IS,G}$	t-Student	0.09	0.1433	19.984	0.0007	0.0007

Notes: P= platinum, G=gold, S=silver and I= stock index for each country. $C_{P,G}$ denotes copula between platinum and gold. $C_{P,SI}$ denotes copula between platinum and silver given gold. τ is the Kendall's tau of the specified copulas, θ is the copula parameter and ϑ is the degree of freedom.

In the next step, we estimate the tail correlation between precious metals and stock market index returns to find out if precious metals are strong safe haven assets or just weak safe haven assets for the stock markets under study. For that end, we performed a Monte Carlo simulation with $N = 10^5$ simulations from the joint distributions characterised by the best fitting copula functions for each country where precious metals are shown to be weak safe

haven assets. Then, we compute the correlation between precious metals and stock market index returns at the 1% tail of stock market returns.

Table 2. 9 : Correlation between stock and precious metals returns at 1% tail of stock returns

		Copula	Tail correlation	Conclusions
France	Gold	Clayton	-0.0005	Strong safe haven
Germany	Gold	Rotated Gumbel	-0.0001	Strong safe haven
	Silver	Rotated Joe	-0.0003	Strong safe haven
Italy	Gold	Rotated Gumbel	-0.0021	Strong safe haven
	Silver	Rotated Joe	-0.0014	Strong safe haven
	Platinum	Student-t	0.0021	Weak safe haven
Canada	Gold	Rotated Joe	-0.0010	Strong safe haven
	Platinum	Survival Clayton	0.0002	Weak safe haven
US	Gold	Gaussian	-0.0001	Strong safe haven
	Platinum	Rotated Joe	0.0042	Weak safe haven

As shown in Table 2. 9, the tail correlation is negative only for gold and silver. Hence, based on our definition of a strong safe haven asset, we conclude that gold may act as a strong safe haven instrument against extreme losses in France, Germany, Italy, Canada, and US stock markets. Silver is a strong safe haven asset in Germany and Italy. However, platinum is a weak safe haven asset against extreme losses in Canada and US stock markets.

Table 2. 10 summarizes our empirical findings regarding hedge and safe haven properties of precious metals.

Table 2. 10: Hedge and safe haven analysis results summary

		Copula	Hedge	Safe haven
France	Gold	Rotated Gumbel	Strong	Strong
	Silver	Clayton	Weak	No
	Platinum	Student-t	Weak	No
Germany	Gold	Rotated Gumbel	Strong	Strong
	Silver	Rotated Joe	Strong	Strong
	Platinum	Student-t	Weak	No
Italy	Gold	Rotated Gumbel	Strong	Strong
	Silver	Rotated Joe	Strong	Strong
	Platinum	Student-t	Weak	No
UK	Gold	Student-t	Weak	No
	Silver	Survival Gumbel	Weak	No
	Platinum	Student-t	Weak	No
Japan	Gold	Student-t	Weak	No
	Silver	Survival Gumbel	Weak	No
	Platinum	Student-t	Weak	Weak
Canada	Gold	Rotated Joe	Strong	Strong
	Silver	Student-t	Weak	No
	Platinum	Survival Clayton	Weak	Weak
US	Gold	Gaussian	Strong	Strong
	Silver	Student-t	Weak	No
	Platinum	Rotated Joe	Weak	Weak

In Figure 2. 2 we present the 95% level curves of the BiVaR between precious metals and the S&P500 index. As we can see, the 95% level curve of the empirical copula is closer to the level curve of multiplication or independence, which means that the losses for precious metals and the stock market are uncorrelated.

As we expected before, the low correlations between the precious metals and equity market indices support the diversification properties of metals. Thus, in order to guarantee benefit from diversification, it is preferred to put precious metal and equity indexes in the same portfolio. This result is similar for the other stock markets.²²

²² The others level curves of the BiVaR are contained Appendix 2.10, in Figure 2. 4.

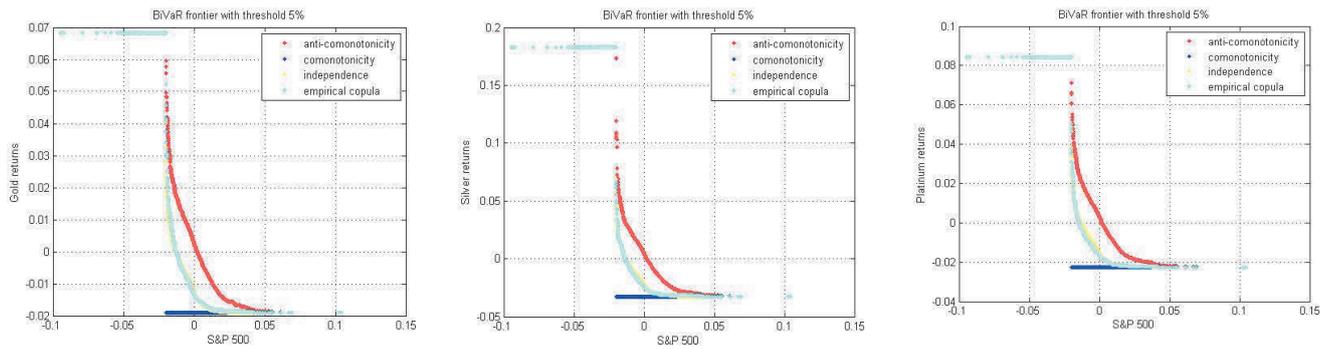


Figure 2. 2: BiVaR level curves between S&P 500 and Precious metals

2.4.3 Discussion

By leading this study, additional insights are made regarding the literature debate on the interaction between precious metals and stock markets with a special concern on the valuable roles of precious metals; namely gold, silver and platinum as hedge, safe haven and diversification assets. Indeed, this study adopts the combination of copulas and VaR techniques. On one hand, we apply vine copulas to assess for the hedge and safe haven properties of precious metals for the G-7 stock markets and propose a new definition of “strong safe haven” asset by computing the tail correlation using simulated data from the best-fitting copula model. Our estimation results show that gold serves as a strong hedge and safe haven for European countries as well as the US and Canada, but only weak hedge for UK and Japan. These findings are in line with previous studies Baur and McDermott, 2010 and Bredin et al., 2015.

Gold is considered as safe haven asset for several reasons. To start with, gold served historically as a currency and still remains a monetary asset. Second, it is the most liquid precious metal and easiest to trade. Also, our results confirm that gold does not comove with stocks during extreme market conditions. Last but not least, it is an international asset, and its value is independent of the decision of a particular State.

Regarding silver, our results reveal that it may acts as strong hedge and safe haven asset in German and Italian stock markets, which means that it may be suitable and affordable alternative safe haven since it is cheaper than gold. However, silver is not considered as a safe haven asset for the rest of G-7 stock markets since it is more thinly traded, making it more volatile and illiquid. For the case of platinum, it is a weak hedge for all G-7 stock markets and only a weak safe haven for American, Canadian, and Japanese stock markets. As we know, an

asset is considered to be a safe haven when its market is extremely liquid, and platinum is relatively illiquid. This can explain the fact that platinum cannot be a safe haven for most of the G-7 stock markets. However, it is a cheap alternative to gold and may be profitable for investors if the price of gold continues to rise. On the other hand, we apply a novel method—the BiVaR based copula method—to analyse the diversification potential of precious metals. Our findings confirm that precious metals provide a useful means of diversification for G-7 investors.

Overall, our results suggest that there is some degree of heterogeneity regarding the role of precious metals between the G7 countries, which is due to the fact that each country has its own financial risk exposure.

To sum up, even though gold acts as a better hedge and safe haven for the G-7 stock markets, investors can find a valuable investment benefit in silver and platinum with different degrees (weak or strong).

2.5 Conclusions

In this study, we analyse the hedge, safe haven, and diversification potential of precious metals—namely gold, silver, and platinum—for the G-7 stock markets. Indeed, the vine copula method is used to test the hedge and safe haven hypotheses and the BiVaR is applied to assess the diversification benefits of precious metals. Our empirical results show that precious metal hedge and safe haven behaviors vary by country.

First, gold provides the strongest safe haven property for all G-7 countries, which is consistent with previous literature. This result means that gold may be used to offset losses in equity markets during turmoil periods. Also, silver bears the potential of a strong safe haven role for German and Italian stock markets. However, platinum provides a weak safe haven role for most developed markets. Furthermore, in line with existing studies, our study suggests that gold has a strong hedging property in developed stock markets. For silver and platinum, results show that they may act as weak hedge assets. Finally, the results of the BiVaR analysis argue that all precious metals exhibit diversification benefits for G-7 stock markets investors. Our findings provide a noteworthy practical implication for investors in the G-7 countries in building their investment strategies. We suggest that investors may hedge their equity investments in normal times by investing in these precious metals and ensure their portfolios from losses during periods of turbulence by investing in gold.

Further research might analyze the out-of-sample forecasting of expected returns in precious metals and how precious metals investment should fit into a diversified portfolio.

2.6 Acknowledgment

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Appendices

2.7 Appendix: Bivariate copula functions

Table 2. 11: Bivariate copula functions

Copula	Function	Parameter	Tail dependence
Gaussian	$C(\mathbf{u}, \mathbf{v} \rho) = \Phi(\Phi^{-1}(\mathbf{u}), \Phi^{-1}(\mathbf{v}))$	$\rho \in [-1, 1]$	No tail dependence
t-copula	$C(\mathbf{u}, \mathbf{v}; \rho, \vartheta) = T(t^{-1}(\mathbf{u}), t^{-1}(\mathbf{v}))$	$\rho \in [-1, 1]$	Symmetric tail dependence
Clayton	$C^C(\mathbf{u}, \mathbf{v}; \theta) = (\mathbf{u}^\theta + \mathbf{v}^\theta - 1)^{-\frac{1}{\theta}}$	$\theta \in (0, \infty)$	Lower tail dependence
Gumbel	$C^G(\mathbf{u}, \mathbf{v}; \theta) = \exp(-((-\ln(\mathbf{u}))^{\frac{1}{\theta}} + (-\ln(\mathbf{v}))^{\frac{1}{\theta}})^\theta)$	$\theta \in [1, \infty)$	Upper tail dependence
Joe-Clayton	$C^{JC}(\mathbf{u}, \mathbf{v} \tau^U, \tau^L) = 1 - (1 - \{[1 - (1 - \mathbf{u})^k]^{-\gamma} + [1 - (1 - \mathbf{v})^k]^{-\gamma} - 1\})^{1/k}$	$\tau^U \in (0, 1)$ $\tau^L \in (0, 1)$	$\tau^u = \wedge \left(\omega_u^{SJC} + \beta_u^{SJC} \tau_{t-1}^u + \alpha_u^{SJC} \frac{1}{q} \sum_{i=1}^q u_{t-i} - v_{t-i} \right)$ $\tau^l = \wedge \left(\omega_l^{SJC} + \beta_l^{SJC} \tau_{t-1}^l + \alpha_l^{SJC} \frac{1}{q} \sum_{i=1}^q u_{t-i} - v_{t-i} \right)$
Rotated version of copula			
There are three rotated forms, with angles 90 degrees, 180 degrees, and 270 degrees, defined as follows:			
$C_{90}(\mathbf{u}, \mathbf{v}) = \mathbf{v} - C(\mathbf{1} - \mathbf{u}, \mathbf{v})$			
$C_{180}(\mathbf{u}, \mathbf{v}) = \mathbf{u} + \mathbf{v} - 1 + C(\mathbf{1} - \mathbf{u}, \mathbf{v})$			
$C_{270}(\mathbf{u}, \mathbf{v}) = \mathbf{u} - C(\mathbf{u}, \mathbf{1} - \mathbf{v})$			
Survival version of copula			
$\bar{C}(\mathbf{u}, \mathbf{v}) = \mathbf{u} + \mathbf{v} - 1 + C(\mathbf{1} - \mathbf{u}, \mathbf{1} - \mathbf{v})$			
Dependence measures			
The Kendall's tau can be written as a function of the copula as follows: $\theta_\tau = 4 \int_0^1 \int_0^1 C(\mathbf{u}, \mathbf{v}) d(\mathbf{u}, \mathbf{v}) - 1$,			
The upper (right) and lower (left) tail dependence measures are, respectively, $\lambda_U = \lim_{u \rightarrow 1} \Pr [X \geq F_X^{-1}(u) Y \geq F_Y^{-1}(u)] = \lim_{u \rightarrow 1} \frac{1 - 2u + C(u, u)}{1 - u}$ and $\lambda_L = \lim_{u \rightarrow 0} \Pr [X \leq F_X^{-1}(u) Y \leq F_Y^{-1}(u)] = \lim_{u \rightarrow 0} \frac{C(u, u)}{u}$			
Notes: λ_U and λ_L denote the lower and upper tail dependence, respectively. For the Gaussian copula $\Phi^{-1}(\mathbf{u})$ et $\Phi^{-1}(\mathbf{v})$ are the standard normal quantile functions and Φ is the bivariate standard normal cumulative distribution function with correlation parameter ρ . For the t-copula $t^{-1}(\mathbf{u})$ and $t^{-1}(\mathbf{v})$ are the quantile functions of the univariate Student-t distribution and T is the bivariate Student-t cumulative distribution function with ϑ the degree-of-freedom and ρ the correlation parameter. For the SJC copula, $k = \frac{1}{\log(2 - \tau^U)}$ and $= \frac{-1}{\log \tau^L} \cdot \tau^U$ and τ^L denote the upper and lower tails of the SJC and the Joe-Clayton copulas.			

2.8 Appendix: Empirical Kendall's tau matrices for G-7 counties

Table 2. 12: Empirical Kendall's tau matrices for G-7 counties

France				
	CAC 40	Gold	Silver	Platinum
CAC 40	1	-0.02249074	0.03375731	0.08429327
Gold	-0.02249074	1	0.39800740	0.41186940
Silver	0.03375731	0.39800740	1	0.39854344
Platinum	0.08429327	0.41186940	0.39854344	1
Sum	1,14054132	1,83236754	1,830308	1,89470611
Germany				
	DAX	Gold	Silver	Platinum
DAX	1	-0.02068612	0.04223904	0.08117698
Gold	-0.02068612	1	0.39800740	0.41186940
Silver	0.04223904	0.39800740	1	0.39854344
Platinum	0.08117698	0.41186940	0.39854344	1
Sum	1,14410214	1,8305629	1,83878988	1,89158982
UK				
	FTSE100	Gold	Silver	Platinum
FTSE100	1	0.01770941	0.06112196	0.1128933
Gold	0.01770941	1	0.39800740	0.4118694
Silver	0.06112196	0.39800740	1	0.3985434
Platinum	0.11289327	0.41186940	0.39854344	1
Sum	1,19172464	1,827586	1,8576728	1,923306
Italy				
	FTSE MIB	Gold	Silver	Platinum
FTSE MIB	1	-0.01972463	0.03392975	0.08201692
Gold	-0.01972463	1	0.39800740	0.41186940
Silver	0.03392975	0.39800740	1	0.39854344
Platinum	0.08201692	0.41186940	0.39854344	1
Sum	1,135671	1,829601	1,83048059	1,89242976
Japan				
	NIKKEI225	Gold	Silver	Platinum
NIKKEI225	1	0.02487169	0.05709541	0.09598458
Gold	0.02487169	1	0.39800740	0.41186940
Silver	0.05709541	0.39800740	1	0.39854344
Platinum	0.09598458	0.41186940	0.39854344	1
Sum	1,17795168	1,83474849	1,85364625	1,90639742
Canada				
	S&P/TSX	Gold	Silver	Platinum
S&P/TSX	1	-0.002292608	0.005024797	0.008544629
Gold	-0.002292608	1	0.398007396	0.411869405
Silver	0.005024797	0.398007396	1	0.398543445
Platinum	0.008544629	0.411869405	0.398543445	1
Sum	1,015862034	1,812169409	1,801575638	1,818957479
US				
	S&P500	Gold	Silver	Platinum
S&P500	1	-0.006665807	0.01759668	0.06968461
Gold	-0.006665807	1	0.39800740	0.41186940
Silver	0.017596684	0.398007396	1	0.39854344
Platinum	0.069684607	0.411869405	0.39854344	1
Sum	1,093947098	1,816542608	1,81414752	1,88009745

2.9 Appendix: Precious metals and stock market indexes dynamics

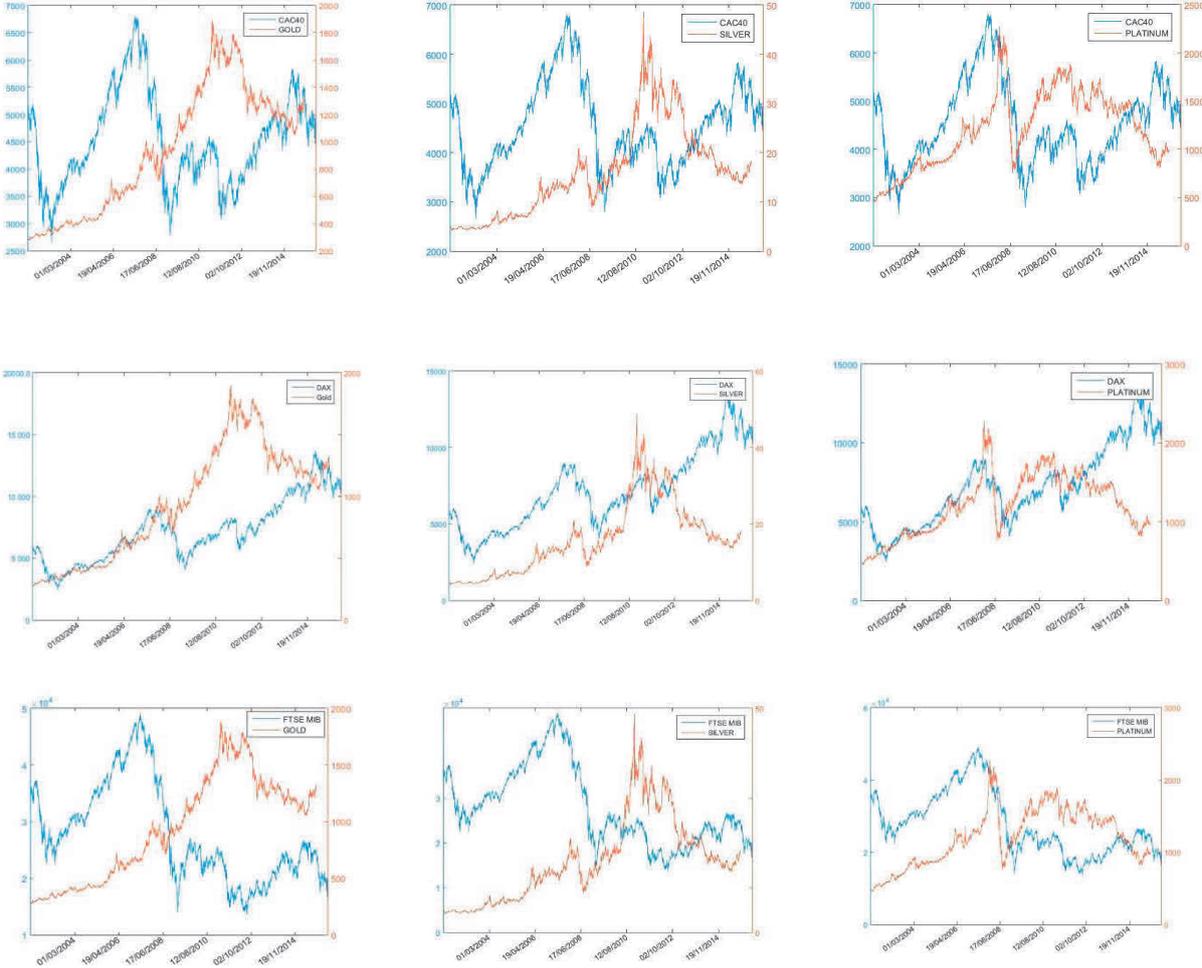


Figure 2. 3: Precious metals and stock market indexes dynamics

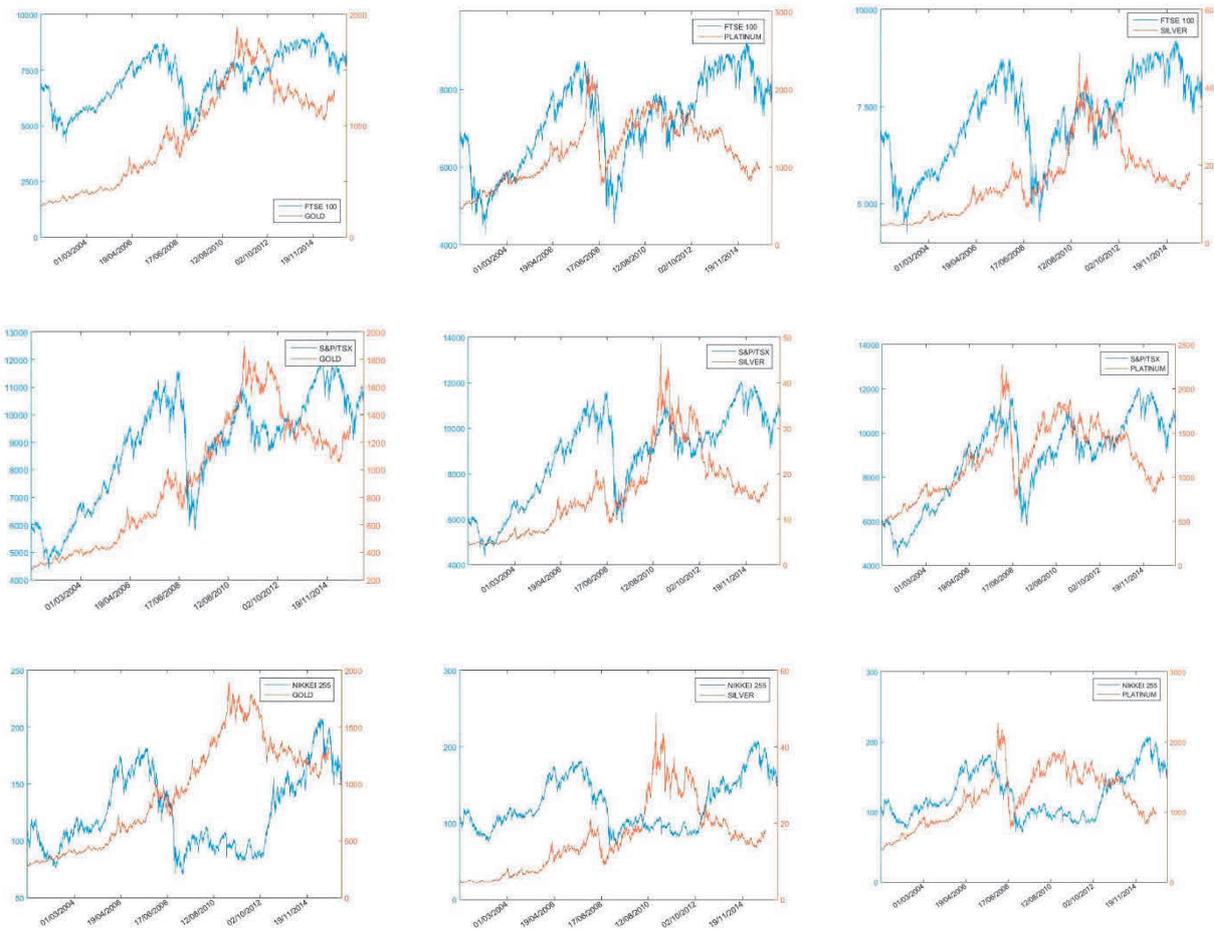


Figure 2. 3 (Continued)

2.10 Appendix: BiVaR level curves between Precious between G-7 stock market-Precious metals

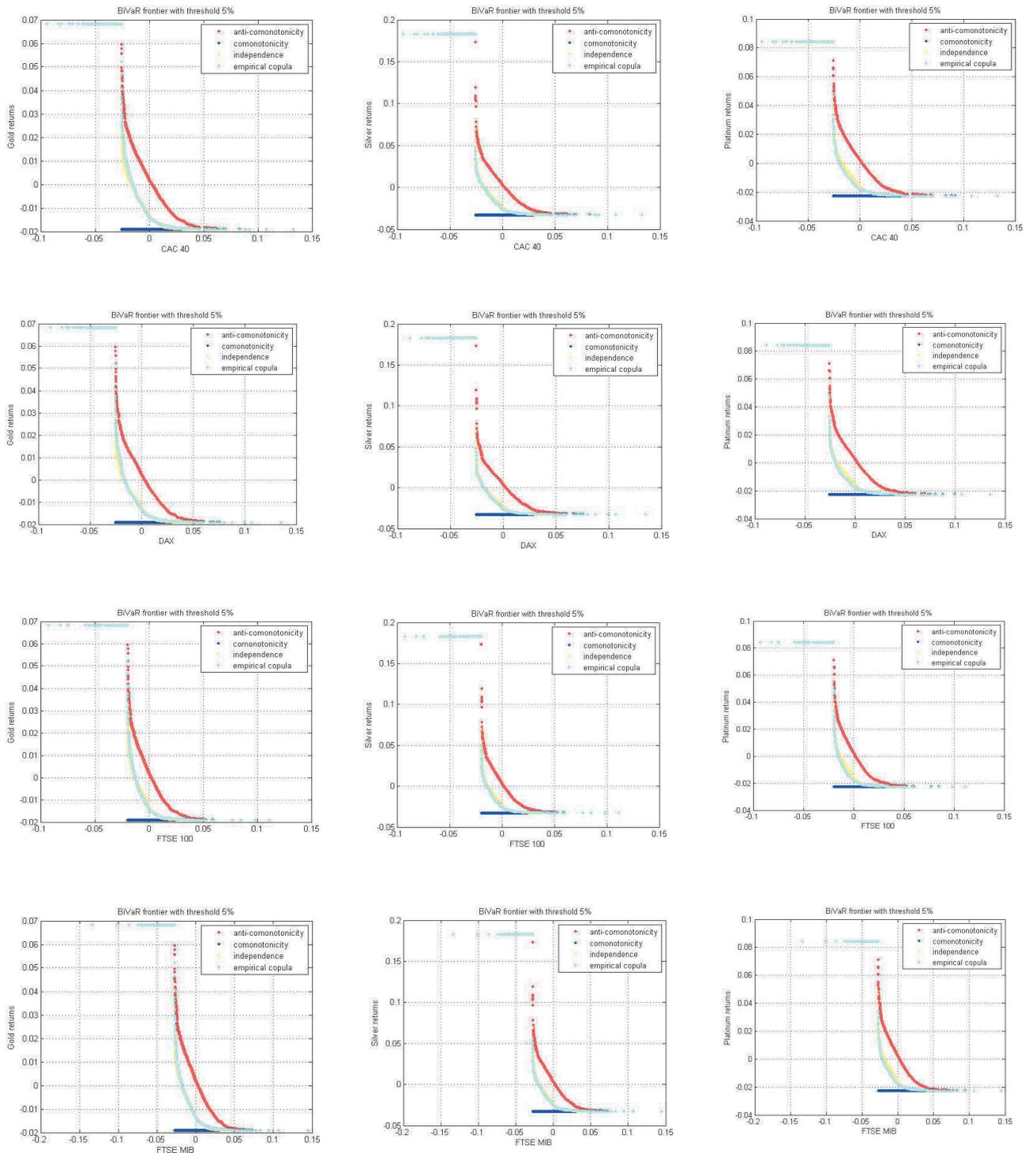


Figure 2. 4: BiVaR level curves between Precious between G-7 stock market-Precious metals

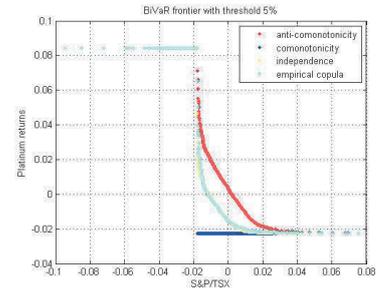
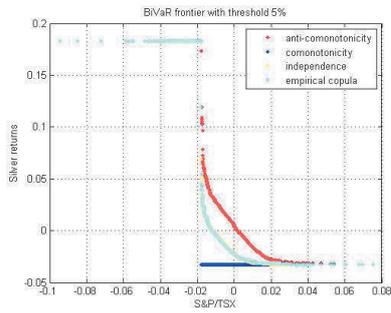
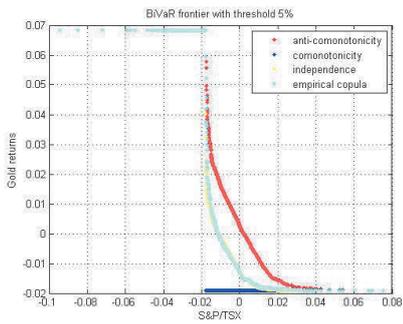
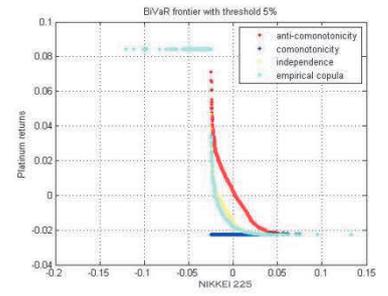
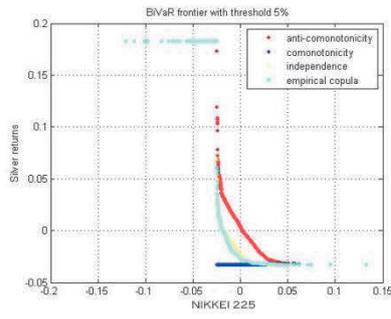
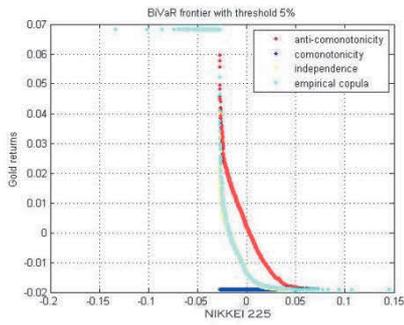


Figure 2. 4 (Continued)

Chapter3

Does economic policy uncertainty matter for the co movements between precious metals and BRICS stock markets? A cross-quantilogram approach

Economic policy uncertainty (EPU) has relevant implications for financial markets. To assess for these implications, this paper aims to investigate how the EPU drives the quantile dependence between precious metals and BRICS stock markets. Applying the cross-quantilogram approach, developed by Han et al. (2016), our results lead to the same findings when controlling or not for the EPU. Indeed, we provide evidence that gold is a perfect hedge in Russia and India. While silver and platinum may be seen as hedge assets only in the China stock market. Adding to that, over the entire sample period, we find that extreme negative stock market returns were followed by extreme positive gold returns for all stock markets except for Brazil and China. Hence, gold is not a safe haven in these stock markets. However, silver is a safe haven only in China stock market and platinum is a safe haven in China and South Africa stock markets.

Keywords: BRICS stock markets, precious metals, Economic Policy Uncertainty, quantile dependence, Cross-quantilogram.

3.1 Introduction

Investment in precious metals has become increasingly important and remarkable, since the commodity prices boom of 2007. From an economic perspective, this rise was due to the fact that precious metals have been considered as an engine of global economic growth because of the significant rise in the GDP and GDP share of commodity exports and commodity prices in developing countries. In 2018, the global production of gold was about \$134 billion (China and Russia are among the top 5 producers). Meanwhile, the global production of silver and platinum was \$13 billion and \$4 billion in 2018, respectively (China and Russia among the top 5 of silver producers while South Africa alone accounts for more than two-thirds of global platinum production).²³

Given the valuable role of precious metals for investors during periods of economic and political uncertainties, there exists a considerable body of literature on the dynamics of precious metals (eg., Lucey et al., 2014; Balcilar and Ozdemir, 2019 and Talbi et al., 2020) and their co-movement with other market factors such as; stock market indices (e.g., Hood and Malik, 2013; Mensi et al., 2015 and Ali et al., 2020), exchange rates (e.g., Ciner et al., 2013; Reboredo, 2013b and Bedoui et al., 2019), inflation (e.g., Hoang et al., 2016 and Salisu et al., 2019), stock market uncertainty captured by the VIX (e.g., Jubinski and Lipton, 2013), and EPU (e.g. Thongkairat et al., 2019 and Badshah et al., 2019). These studies are of key importance regarding the information that they may give about hedging and diversification strategies for investors. Hence, precious metals have become part of portfolio allocation, which contributes to the significant financialization of commodity markets. Therefore, this phenomenon has intensified the connection between precious metals and other financial markets which leads to the overall economic fluctuations. Consequently, since economic policy plays an important role in shaping financial markets, then uncertainty related to economic policies decisions should matter (Adjei and Adjei, 2017).

This uncertainty can be measured by Economic Policy Uncertainty index (EPU, hereafter). Baker et al., (2016) constructed an EPU index to measure the uncertainty related to monetary, fiscal and other relevant policies. This index is based on newspaper coverage frequency and the evidence related to uncertain economic events appearing in the articles such as the USA presidential elections, the Lehman Brothers failure, the 9/11 attacks, the 2011 debt ceiling dispute, among other battles over fiscal policy.

²³ Source: IFM World Economic Outlook, October 2019

There are considerable studies concerning the effect of EPU on the stock market (e.g., Kang and Ratti, 2013; Arouri et al., 2014; Li et al., 2015), the bond market (e.g., Wisniewski and Lambe, 2015) and commodities, including crude oil (e.g., Antonakakis et al., 2014; Wang et al., 2015) and precious metals (e.g., Reboredo and Uddin, 2016; Raza et al., 2018; Thongkairat et al., 2019). More recent studies extend the literature to analyze the impact of EPU on correlations among financial asset classes; on one hand, EPU has a negative effect on U.S. stock -bond market correlations (Fang et al., 2017) and on UK stock market-gold correlations (Gao and Zhang, 2016), on the other hand, it has a positive effect on the long-run oil-stock market correlation (Fang et al., 2018) and on the correlation between US stock market and commodities (Badshah et al., 2019).

Different from previous studies, which were mainly focused on the impact of EPU on precious metals prices and stock market prices separately, this study contributes to the existing literature by introducing a new empirical investigation of the impact of EPU on the dependence between precious metals and BRICS stock markets using the Cross-quantilogram (CQ, hereafter) approach proposed by Han et al. (2016).

While previous studies use econometric methods such as the vector autoregressive (VAR) framework, multivariate GARCH type models, dynamic conditional correlation (DCC), and copulas, we are the first to use the CQ approach in modelling the quantile dependence structure between precious metals and BRICS stock markets. The CQ approach is technically more informative than copulas are since it is a model-free measure able to estimate correlation across quantiles of each distribution. This approach is based on quantile hits and is not reliant on any particular moment condition. However, copulas can only measure a general dependence between variables, so do not include lags. In addition, the CQ approach enables us to use arbitrary quantiles and lags, which allows us to simultaneously detect the direction and the magnitude (positive or negative spillovers) of the dependence between variables.

Motivated by these literature gaps, this study contributes to the emerging literature in two ways. First, as far as we know, no previous study has applied the CQ approach to measure the quantile dependence between precious metals and BRICS stock markets. The CQ approach allows us to check for the valuable role of precious metals, as a safe haven asset, in the BRICS stock markets.²⁴ Second, this is the first study that attempt to investigate the impact of

²⁴ Following the definitions proposed by Baur and Lucey (2010) and Baur and McDermott (2010), the precious metal is not considered as a safe haven when extreme positive stock returns are predicting extreme negative gold returns since this is not a market turmoil situation. Also, if some positive dependence is found across the whole range of quantiles, the precious metal cannot be considered neither a hedge nor a safe haven.

the EPU on the dependence between the BRICS stock markets and precious metals. To that end, we apply the partial cross-quantilogram (PCQ) approach that include the EPU as a control variable in the CQ model.

The remainder of this paper is structured as follows: section 3.2 provides the related literature review. Section 3.3 presents the data and the methodology. Then, section 3.4 discusses the empirical results of our analysis. Finally, section 3.5 contains conclusions.

3.2 Literature review

The academic background on uncertainty and its effect on financial markets has been limited. Although it has overgrown, recently, there are still considerable opportunities for further research, as many questions have not been discussed. In this section, we review the existing literature regarding the EPU measures, the impact of the EPU index on stock markets, the impact of the EPU index on precious metals and the impact of the EPU on the dependence between stock markets and precious metals.

3.2.1 Economic Policy Uncertainty measures

Interest in economic policy uncertainty has grown as it played an important role in the Great Recession and recovery. The International Monetary Fund (2013) argued that uncertainties about taxation, spending, regulatory, and monetary policies were the main contributors to the unusually high decline in economic activity at the onset of the 2007-2009 recession.

The most obvious and widely used uncertainty measure is the standard deviation of stock prices and stock returns. The implied market volatility index (VIX), an index of 30-day option-implied volatility in the S&P500 stock index, has been used for many years as a proxy for firm uncertainties in the stock market. Nonetheless, the VIX index pertains only to uncertainty about equity returns, omitting uncertainty about economic policy.

There exist some works in the literature that focused explicitly on policy uncertainty and consider the detrimental economic effects of monetary, fiscal, and regulatory policy uncertainty. (e.g., Friedman, 1968; Rodrik, 1991; Higgs, 1997 and Hassett and Metcalf, 1999) Then, there is a growing literature on text-based uncertainty measures using newspaper archives. (e.g., Hoberg and Phillips (2010) and Alexopoulos and Cohen (2015))

Using text data from internet search, Da et al. (2015) develop the FEARS index, which is an investor sentiment and fears-based uncertainty index. Likewise, Manela and Moreira (2017) propose the NVIX news-based uncertainty index using text from the Wall Street Journal to find the implied volatility in the 1980s. However, this index captures only the news

component of uncertainty. Others have developed uncertainty measures based on political risks by exploring the uncertainty around election years. (e.g., Julio and Yook, 2012)

Using econometric methods, Jurado et al. (2015) propose new indices for macroeconomic uncertainty based on many economic indicators, particularly, aggregate economic and financial market indicators. Although these uncertainty indices are all commonly used, they still limited to measure only specific types of uncertainty. Also, the application of most of these uncertainty indices is complicated since they are not publicly available. Moreover, some of them cannot be expanded for longer periods or cannot be used in the case of different countries. Hence, researchers are incited to develop new uncertainty measures that take into account all these factors.

Baker et al. (2016) develop the Economic Policy Uncertainty (EPU) index which captures uncertainty from newspapers, policy, market, and economic indicators. The EPU index is an aggregation of all these factors. This index is based on searches for keywords in newspapers' articles that contain words like "economic", "uncertainty", "economy", "policy", "regulation", "legislation," "congress," "legislation," "white house," "regulation" and "federal reserve". The EPU index is highly correlated with events associated with periods of extreme policy uncertainty like wars, the Eurozone crisis and spikes occurring around elections.

3.2.2 The linkage between EPU and stock markets

The linkage between financial markets and EPU has recently been the subject of extensive research. Several studies in the extant literature investigate the policy uncertainty effect on the stock market finding mixed results. So far, many prior works documented the negative relationship between EPU and stock market returns. Antonakakis et al. (2013) investigate the dynamic correlations among 10 S&P500 market returns, VIX index and EPU index. They find a negative conditional correlation between market returns and policy uncertainty over time. Kang and Ratti (2013) investigate the effects of oil price shocks and EPU on US stock markets. They find that an unexpected increase in policy uncertainty leads to a decline in real stock returns. Sum (2013) argues that US EPU negatively granger-cause the Association of Southeast Asian Nations (ASEAN) stock market returns. Arouri et al. (2014) find that EPU has negative effects on the US, Europe, China, and the Gulf Cooperation Council (GCC) stock market returns. Others find no correlation between EPU and stock markets returns. Mensi et al. (2014) find that the U.S. EPU has no impact on the BRICS stock markets. Li et

al. (2015) find absence of causality when examining the causal link between U.S EPU and stock returns in India and China.

3.2.3 The linkage between EPU and precious metals

Extending the literature to the effect of EPU on precious metal markets, prior studies focused the most on gold. Jones and Sackley (2016) examine the relationship between the EPU and gold prices. They find that increases in EPU levels contribute to gold prices appreciation. Reboredo and Uddin (2016) study the impact of policy uncertainty on the price dynamics of energy and metals (gold, silver, copper, platinum and palladium) futures in the USA for the period 1994–2015. Using a quantile regression approach, they find neither co-movement nor Granger causality between commodity futures prices and policy uncertainty. Their results indicate that general stock market uncertainty conditions are not so crucial in determining commodity futures prices. Balcilar et al. (2016b) study the impact of EPU on gold prices, return and volatility. Using, the non-parametric causality-in-quantiles approach, their empirical results of monthly and daily data revealed that uncertainty measures affect gold prices, return and volatility. In contrast, the results of quarterly data showed weak causality and were significant for gold volatility only. Raza et al. (2018) examine the association between EPU and gold prices by using the monthly data from 1995 to 2017. Using the standard linear Granger causality test, they find that no causal association exists between EPU and gold prices. Then, using the nonparametric causality-in-quantiles approach test, they find that EPU causes gold prices in all the examined countries, especially at the low tails. Gao et al. (2019) investigate the time-varying effects of EPU on gold prices from 2006 to 2017. Using a time-varying parameter structural vector autoregression with stochastic volatility (TVP-SVAR-SV) model, they show that the effects of global economic policy uncertainty (GEPU) shocks on gold prices change over time. The changes were positive during 2006–2008 and 2013–2017, while the impacts were negative during 2009–2012, implying that the efficiency of gold as a safe haven is not stable and depends on economic conditions. Thongkairat et al. (2019) examine the effect of EPU on three precious metal markets (Gold, Silver, Platinum) using a Markov-switching model with mixture distribution regimes. Their results confirm the persistence of the relationship between the EPU, and the precious metals returns with different distribution characteristics between high and low economic uncertainty periods in precious metal markets.

3.2.4 The impact of the EPU on precious metals- stock markets nexus

Notwithstanding the vast literature investigating the link between economic policy uncertainty, precious metals and stock markets in separate contexts, there still no sufficient empirical evidence on how EPU simultaneously affects the dynamics between these markets.

In fact, some studies have pointed out that the effect of uncertainty is state dependent (e.g., Han e al., 2019). The reason why, it may be assumed that policies uncertainty may also serve as a channel to explain interactions between different markets.

Gao et al. (2016) investigate the impact of economic EPU on correlations between the UK stock market and gold market. They find that when economic policies become less certain, gold demand increases while stock demands decrease, resulting in a decline in correlations. However, more certain economic policies result in higher correlations.

Recently, Badshah et al. (2019) examine whether EPU has an effect on the dynamic conditional correlations between stock and commodity returns (including gold and silver). Their results show a positive and significant effect of EPU on stock-commodity correlations with particularly stronger effects in the case of energy and industrial metals. This effect is stronger during weak economic conditions. Also, they find a significant effect of EPU on optimal hedge ratios in commodities.

Table 3. 1 summarizes leading works that dealt with the effect of EPU on stock markets, precious metals and correlation between these markets.

In the light of the above-mentioned studies, our study attempts to supplement the literature by examining the effect of U.S. EPU on the quantile dependence between precious metals and BRICS stock markets.

Table 3. 1 : Overview on the impact of the EPU

Impact on	Variable	Geographic zone	Method	Expected sign	Reference
Stock market	Stock market indices	USA	DCC	Negative	Antonakakis et al. (2013)
		USA	Structural VAR	Negative	Kang and Ratti (2013)
		ASEAN	Granger causality tests	Negative	Sum (2013)
		US, Europe, China, and GCC	Panel regressions	Negative	Arouri et al. (2014)
		BRICS	Quantile regression	No impact	Mensi et al. (2014)
		India and China	Granger	No impact	Li et al. (2015)
Precious metals	Gold	US and Europe	Short-run pricing model	Positive	Jones and Sackley (2016)
	gold, silver, copper, platinum and palladium	USA	quantile regression	No impact	Reboredo and Uddin (2016)
	Gold	USA	Non-parametric causality-in-quantiles	Positive	Balcilar et al. (2016b)
	Gold	Canada, China, France, Germany, Japan, Korea, UK and US	Granger causality	No impact	Raza et al. (2018)
	Gold		Nonparametric causality-in-quantiles	Positive	Raza et al. (2018)
	Gold	20 countries	Time-varying structural VAR	positive and negative	Gao et al. (2019)
	Gold, Silver, Platinum	USA	Markov-switching model	Positive	Thongkairat et al. (2019)
Stock-precious metals nexus	Gold	UK	DCC-ARMA-GARCH	Negative	Gao and Zhang (2016)
	Gold and silver	USA	ADCC-GARCH	Positive	Badshah et al. (2019)

3.3 Methodology

3.3.1 Data description

Our dataset consists of daily closing prices of the BRICS stock market indices (Brazil's BOVESPA index, Russia's MOEX index, India's BSE100 index, China's Shanghai SEA index, South Africa's FTSE/JSE index) and the spot prices for the precious metals including the PM fixing of London²⁵ of the US\$/Troy ounce for gold, the PM fixing of London Platinum price in US\$/Troy ounce, and the silver price in US\$/kilogram fixed by the London Bullion Market (LBMA). All these data series are denominated in US dollars and collected from Thomson Reuters DataStream database.

To measure the uncertainty of economic policy, we use the daily U.S. EPU index proposed by Baker et al. (2016), which is obtained from the official website for Economic Policy Uncertainty.²⁶ Our daily data cover the period from 3 January 2002 to 23 October 2020, encompassing the Global Financial Crisis (GFC), the European Sovereign Debt Crisis (ESDC) and the COVID-19 recent crisis. Daily returns are calculated as the logarithmic difference between observations at time t and $t - 1$ as $\ln(P_t) - \ln(P_{t-1})$.

Figure 3. 1 presents the daily evolution of the US EPU index.²⁷ As we can see, EPU captures periods of economic instabilities, such as the Global financial crisis, the European debt crisis and Brexit which affected the global economy and leaved lasting financial scars.

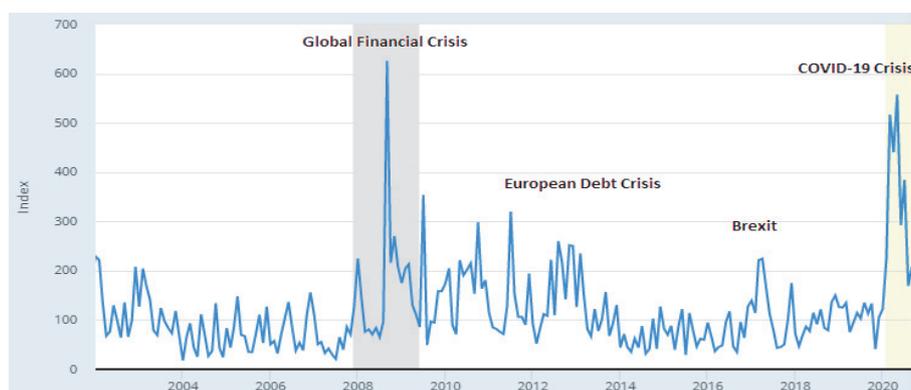


Figure 3. 1: Daily U.S Economic Policy Uncertainty Index dynamics

²⁵ The fixing occurs twice a day, except for silver, which is fixed at 12 noon. The price fixing done in the morning is called the AM Fix while the afternoon fixing is called the PM Fix.

²⁶ EPU data are retrieved from www.policyuncertainty.com

²⁷ Source: Baker et al. (2016), as updated at www.policyuncertainty.com.

3.3.2 Econometric model

In this study, we use the cross-quantilogram (CQ) approach developed by Han et al. (2016) to examine the cross-quantile dependence between precious metals and the BRICS stock markets. The CQ approach is a model-free measure of correlation between variables. Unlike the conventional correlation measures (such as copulas), the CQ estimates the correlation across quantiles of distributions. Hence, it can capture cross-quantile asymmetries in the dependence structure. The CQ requires the stationarity of the data series, that we test using unit root tests. This approach allows us to present the cross-quantile unconditional bivariate correlation between two distributions for different lag lengths in a graphical way to capture the entire dependence structure in the CQ estimations, which is called heatmaps. The quantile distribution [$q = (0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95)$] of two variables is presented in X-axis and Y-axis of the heatmap. In each heatmap, the bivariate quantile combinations of variables are presented by 121 cells, where correlation is indicated by colour scale. And, any statistically insignificant correlation is set to zero. Also, the methods used in the existing literature, such as copulas, do not permit to study the influence of control variables. Since the purpose of this study is to investigate the sensitivity of the dependence structure to EPU, the CQ is the appropriate approach. To that, we estimate the partial cross-quantilogram (PCQ) model by incorporating the EPU index as a control variable.

Let $y_{1,t}, y_{2,t}, \dots, y_{i,t}$ represent stationary time series where $i = 1, 2, \dots, n$ Asset and $t = 1, \dots, T$. We can define the conditional distribution of the series y_{it} given x_{it} as $F_{y_i|x_i}(\cdot | x_{it})$ and the corresponding conditional quantile function as $q_{i,t}(\tau_i) = \inf\{v: F_i(v) \geq \tau_i\}$ for $\tau_i \in (0,1)$ for $i = 1, 2$. First, the cross-quantilogram estimates the quantile-hit (or quantile-exceedance) process, which is essentially the serial dependence between two events, $\{y_{1,t} < q_{1,t}(\tau_1)\}$ and $\{y_{2,t-k} < q_{2,t-k}(\tau_2)\}$. Then, it estimates the cross-correlation between different quantile-hits. The cross-correlation is measured as follow:

$$\rho_\tau(k) = \frac{E \left[\psi_{\tau_1} \left(y_{1,t} - q_{1,t}(\tau_1) \right) \psi_{\tau_2} \left(y_{2,t-k} - q_{2,t-k}(\tau_2) \right) \right]}{\sqrt{E \left[\psi_{\tau_1}^2 \left(y_{1,t} - q_{1,t}(\tau_1) \right) \right]} \sqrt{E \left[\psi_{\tau_2}^2 \left(y_{2,t-k} - q_{2,t-k}(\tau_2) \right) \right]}}, \quad (3.1)$$

where $\psi_{r_i}(y_{i,t} - q_{i,t}(\tau_i)) = 1[y_{i,t} < q_{i,t}(\tau_i)] - \tau_i$ represents the quantile hit process, k indicates the number of lead-lag periods to time t . The quantile-hit process is determined under time $t - k$ and $\rho_\tau(k)$ is the correlation of the quantile-hit process.

In the case of an unconditional cross-correlation, it is measured as follow:

$$\hat{\rho}_\tau(k) = \frac{\sum_{t=k+1}^T \psi_{\tau_1}(y_{1,t} - \hat{q}_{1,t}(\tau_1)) \psi_{\tau_2}(y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2))}{\sqrt{\sum_{t=k+1}^T \psi_{\tau_1}^2(y_{1,t} - \hat{q}_{1,t}(\tau_1))} \sqrt{\sum_{t=k+1}^T \psi_{\tau_2}^2(y_{2,t-k} - \hat{q}_{2,t-k}(\tau_2))}}, \quad (3.2)$$

Moreover, the CQ measures the presence of predictable directionality between the two time series. In the case of two events, $y_{1,t} \leq q_{1,t}(\tau_1)$ and $y_{2,t-k} \leq q_{2,t-k}(\tau_2)$, if $\rho_\tau(k) = 0$ so there is no cross-dependence or directional predictability, while, if $\rho_\tau(k) = 1$ so there is a quantile dependence or directional predictability. Following Han et al. (2016), the quantile version of the Ljung-Box-Pierce test is used to make a statistical inference about the validity of the null hypothesis that conditional correlations are not different from zero ($H_0: \rho_\tau(1) = \dots = \rho_\tau(p) = 0$) against the alternative ($H_1: \rho_\tau(k) \neq 0$ for some $k \in 1, \dots, p$). The Ljung-Box test is defined as follow:

$$\hat{Q}_\tau(p) = T(T+2) \sum_{k=1}^p \frac{\hat{\rho}^2(k)}{T-k}. \quad (3.3)$$

The second contribution of this paper is to study the impact of the EPU on the cross-quantile relationship between precious metals and BRICS stock markets. To that end, following Han et al. (2016), we apply the partial cross-quantilogram (PCQ) model, which is an extended version of the CQ that controls for intermediate events between t and $t - k$ and that measures the relationship between two events $\{y_{1t} \leq q_{1,t}(\tau_1)\}$ and $\{y_{2t} \leq q_{2,t}(\tau_2)\}$. Hence, the PCQ model include control variable to the model (EPU index in our paper) represented by the vector $\mathbf{z}_t \equiv [\psi_{\tau_3}(y_{3t} - q_{3,t}(\tau_3)), \dots, \psi_{\tau_l}(y_{lt} - q_{l,t}(\tau_l))]^\top$ where $l = 3, \dots, n$. The correlation matrix of the hit processes and its inverse matrix are presented as follow:

$$R_{\bar{\tau}} = E[h_t(\bar{\tau})h_t(\bar{\tau})^\top] \text{ and } P_{\bar{\tau}} = R_{\bar{\tau}}^{-1}, \quad (3.4)$$

where $h_t(\bar{\tau}) = [\psi_{\tau_1}(y_{1t} - q_{1,t}(\tau_1)), \dots, \psi_{\tau_l}(y_{lt} - q_{l,t}(\tau_l))]^\top$ is a $l \times 1$ vector of the quantile hit process and $P_{\bar{\tau}}$ is the PCQ presented as follow:

$$\rho_{\bar{\tau}|z} = -\frac{p_{\bar{\tau},12}}{\sqrt{p_{\bar{\tau},11}p_{\bar{\tau},22}}}. \quad (3.5)$$

Thus, $\rho_{\bar{\tau}|z}$ is the cross-quantilogram dependence that is conditional on the control variable z .

Also, $\rho_{\bar{\tau}|z}$ can be defined in the following manner:

$$\rho_{\bar{\tau}|z} = \delta \sqrt{\frac{\tau_1(1-\tau_1)}{\tau_2(1-\tau_2)}}, \quad (3.6)$$

where δ is a scalar parameter derived from the following regression, $\psi_{\tau_1}(y_{1t} - q_{1,t}(\tau_1)) = \delta\psi_{\tau_2}(y_{2t} - q_{2,t}(\tau_2)) + \gamma^\top \mathbf{z}_t + u_t$, with a $(l-2) \times 1$ vector γ and an error term u_t .

3.4 Empirical results and discussion

The empirical results are presented in three subsections. The first one is a presentation of the preliminary analysis. The second subsection reveals the estimation results of the cross-quantile dependence between precious metals and BRICS stock markets. And the final subsection, if this cross-quantile relationship is moderated when the EPU is considered.

3.4.1 Preliminary analysis

The descriptive statistics for the precious metals and stock market indices return series and EPU are reported in Table 3. 2.

The results of Panel A show that the mean average returns are positive for all series. The standard deviation of the Brazilian stock market is the highest regarding other stock markets and the silver is the most volatile metal. All series are negatively skewed, except the Indian stock market index, and have high kurtosis, which means that the presence of asymmetry and fat tails were evidently rejecting the normality of the series. Regarding Panel B, the Jarque–Bera (JB) test reinforces the rejection of the normality hypothesis. Checking for stationarity, the ADF test results show that the EPU is stationary, while precious metals and stock markets indices are stationary in terms of first differences. To eliminate heteroscedasticity, we transform all the variables into logarithmic values.

Table 3. 2: Descriptive statistics for precious metals, stock market indices returns and the U.S. EPU

Panel A: Summary statistics									
	China	Russia	India	S.Africa	Brazil	gold	silver	platinum	EPU
Mean(10^{-4})	2.1787	3.9725	4.6761	3.9471	3.1673	3.0059	2.5681	1.0621	7.9735
Std. Dev	0,0165	0,0213	0,0166	0,0179	0,0252	0,0119	0,0210	0,0145	0.1785
Max	0,0901	0,2020	0,1905	0,1288	0,2201	0,0878	0,1228	0,1601	0.6842
Min	-0,0911	-0,2119	-0,1190	-0,1285	0,1921	-0,0980	-0,1952	-0,0956	-0.6430
Skewness	-0,3661	-0,4086	0,03843	-0,2723	-0,1872	-0,3315	-0,8850	-0,1155	0.5404
Kurtosis	7,5338	13,2910	11,7491	8,0492	8,6452	7,7471	9,9637	10,0678	5.3862
Panel B: Preliminary tests									
J.-B. test	3336.8*	16860.8*	12111.5*	4080*	5064*	3634.9*	8167.85*	7911.67*	51.46*
ADF Test (Level)	-0.095	-0.226	0.304	0.062	-0.472	0.301	-0.508	-0.321	-4.355*
ADF Test (1 st difference)	-61.09*	-55.109*	-58.237*	-59.70*	-62.01*	-62.488*	-62.959*	-59.437*	-3.767*
Panel C: Pearson correlation matrix									
	China	Russia	India	S.Africa	Brazil	gold	silver	platinum	EPU
China	1								
Russia	0,1561	1							
India	0,2077	0,3901	1						
S.Africa	0,178	0,5959	0,4487	1					
Brazil	0,1422	0,35599	0,2716	0,4594	1				
Gold	0,0045	-0,0172	-0,0022	-0,026	-0,0070	1			
Silver	-0,0098	-0,0176	-0,0153	-0,040	0,0070	0,4724	1		
platinum	0,0006	-0,0318	-0,0134	-0,048	0,0035	0,4320	0,4882	1	
EPU	1	0,1561	0,2077	0,1789	0,1422	0,0045	-0,0098	0,0006	1
Notes: The Sdt.Dev denotes the standard deviation, J-B test denotes the Jarque–Bera statistic for normality testing, ADF test presents the Augmented Dickey-Fuller statistic for stationarity testing. (*) indicates rejection of the null hypothesis at the 5% level.									

Figure 3. 2 plots the dynamics of BRICS stock markets and precious metals returns. First and foremost, all the series show similar characteristics in regard to the presence of extreme observations or outliers corresponding to various incidents. An important feature of the data is the association of large negative and positive bases with high volatility periods. Hence, the clustering in the returns is substantial and is easily detected from the log return series, where large (small) price changes tend to be followed by large (small) price changes over consecutive days. Additionally, precious metals have experienced large and persistent fluctuations which cause stress in global economy. Great increases occurred in precious metal price returns especially in periods of financial crises, such as the GFC, the Brexit and the COVID-19 sanitary crisis.

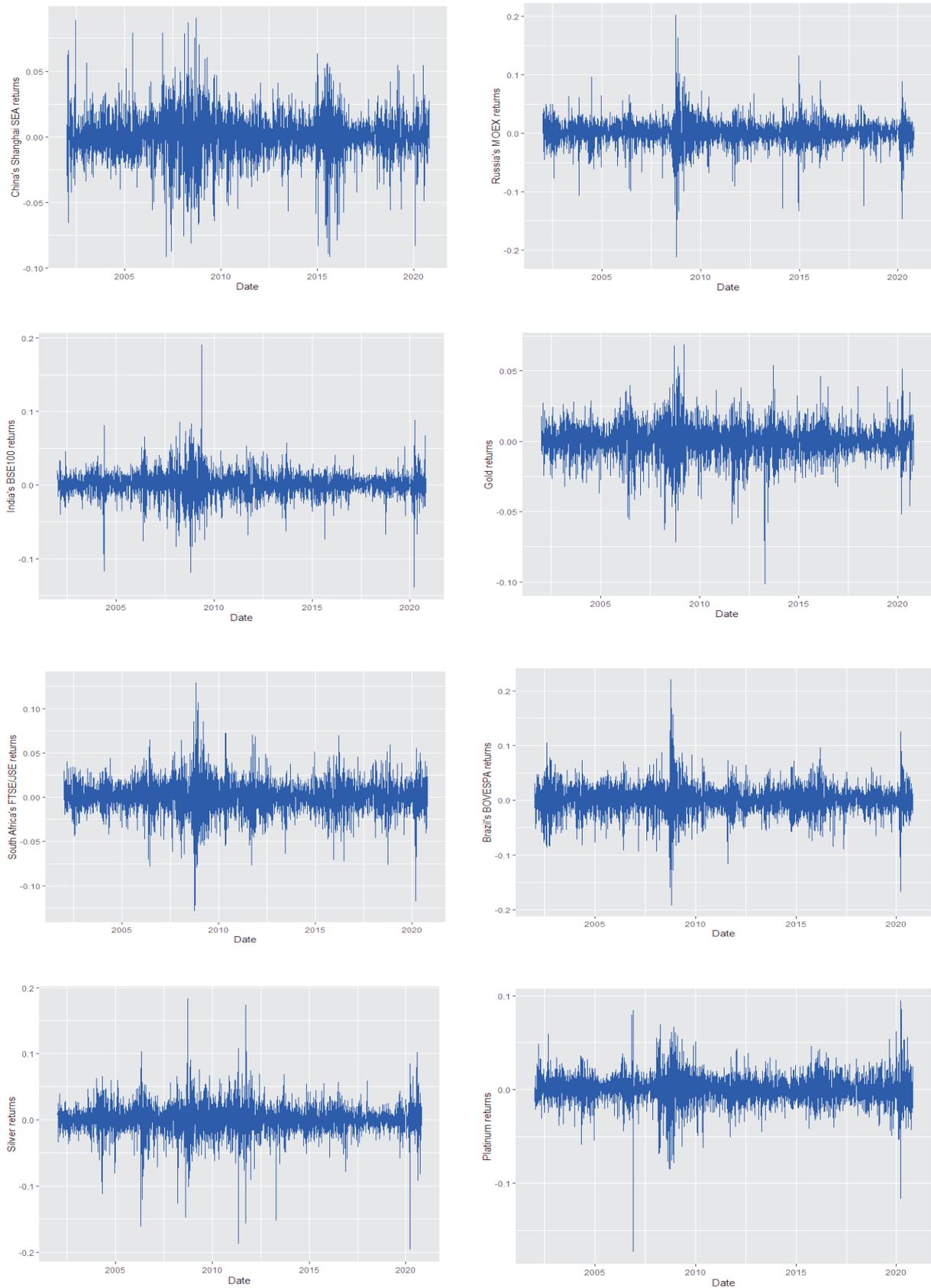


Figure 3. 2: BRICS stock markets and precious metals returns dynamics

3.4.2 Cross-quantilogram model results

The results of the directional predictability from the quantiles of BRICS stock market returns to the returns of each precious metal, gold, silver and platinum, are given in Figure 3. 3. In each heatmap, the X-axis presents the quantiles of precious metals, while the Y-axis presents the quantiles of the BRICS stock markets. The magnitude (positive or negative spillovers) is shown through the colour scale from blue (strongly negative) through light orange (uncorrelated) to red (strongly positive).

Indeed, the cross-quantilogram analysis gives us information about the valuable roles of precious metals as a hedge and safe haven for the BRICS stock markets. Based in the framework of the cross-quantilogram analysis, there is two conditions under which the precious metal may be considered as a safe haven asset: (1) If extreme negative stock returns (i.e., lower quantiles) are followed by future positive gold returns (i.e., upper quantiles); which correspond to a negative CQC in the upper left corner of the heatmap. (2) If there is no dependence across the whole range of quantiles, which means that the heatmap is entirely empty.

Figure 3. 3 shows that extreme negative stock returns are associated with extreme negative precious metals returns for the BRICS stock markets (lower left-corner of all heatmaps). Nonetheless, at the same time and in some cases, extreme negative stock returns are predicting extreme positive precious metals returns. This may seem contrasting, but this can be explained by the fact that the quantile spillover from BRICS stock markets to precious metals has a changing nature, meaning that there are times when extreme negative stock returns are coupled to extreme positive gold returns (safe haven) and times when extreme negative stock returns are followed by extreme negative gold returns. Results for gold show that extreme negative stock returns are predicting extreme positive gold returns in Russia, India and South Africa, which means that gold is a safe haven in Russia, India and South Africa stock markets. Concerning silver, extreme negative stock returns are predicting extreme positive silver returns in China. This result means that silver is a safe haven in China stock market. And, regarding platinum, extreme negative stock returns are predicting extreme positive platinum returns in China and South Africa. Hence, platinum is a safe haven in China and South Africa stock markets. Adding to that, for gold, no dependence across the whole range of quantiles is found in Russia and India. However, for silver and platinum, there is no significant dependence across all combinations of quantiles only in the China stock market. These results imply that these precious metals may provide diversification benefits.

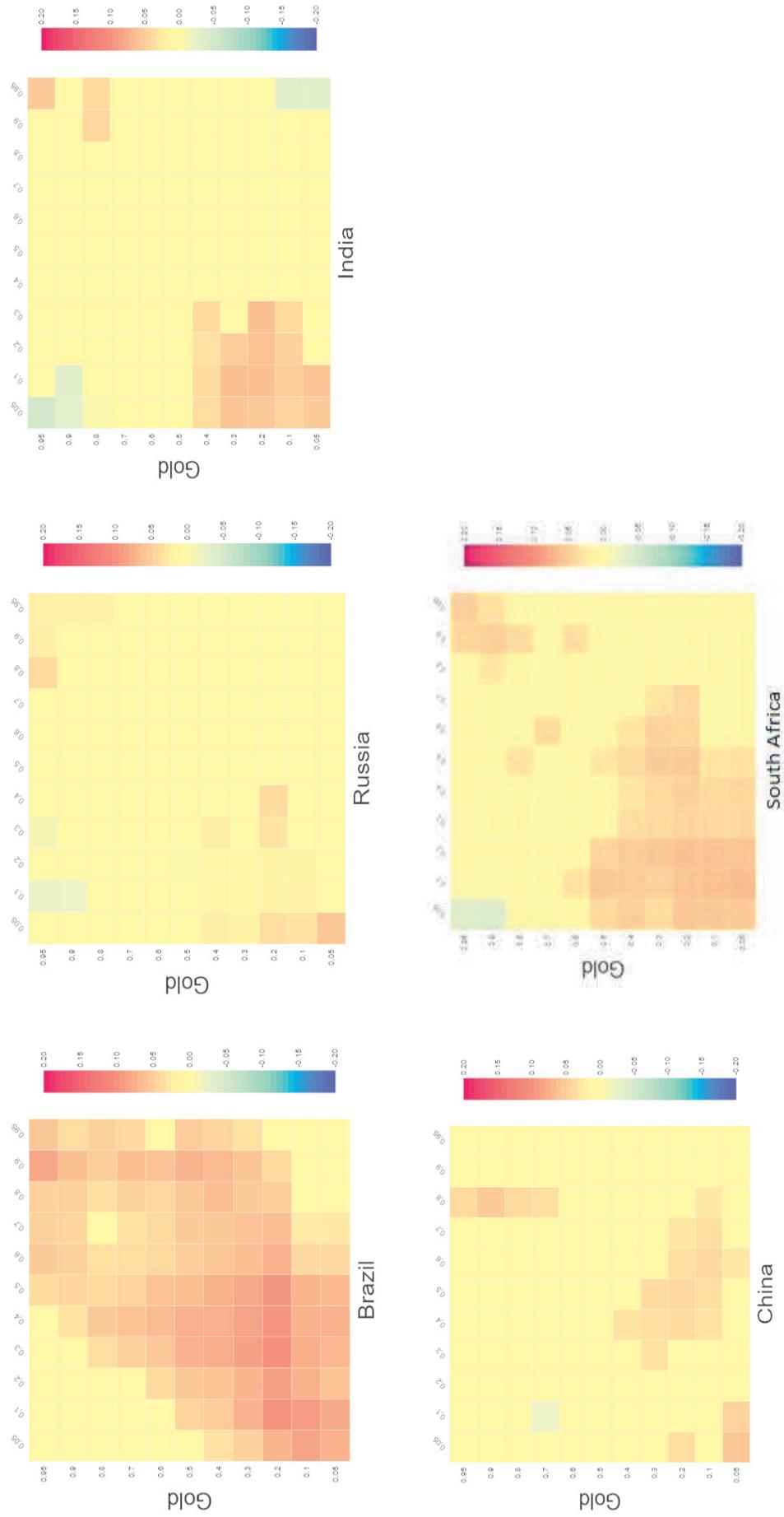


Figure 3.3: Cross-quantile correlation between precious metals and stock returns

Notes: The cross-quantile correlation is estimated using Eq. (3.1) and statistical significance is measured using Box-Ljung test as presented in Eq. (3.2). All insignificant correlation was set to zero. Colour scale indicates the direction of relationship.

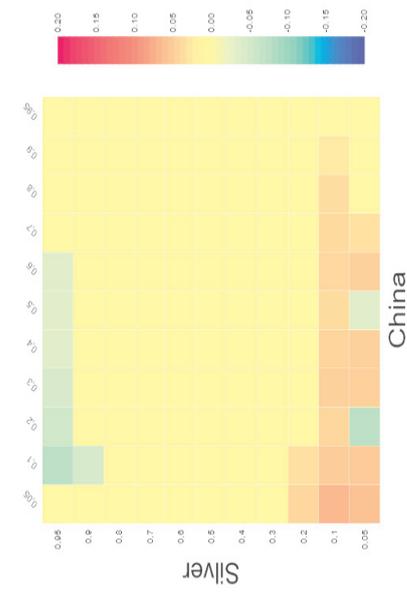
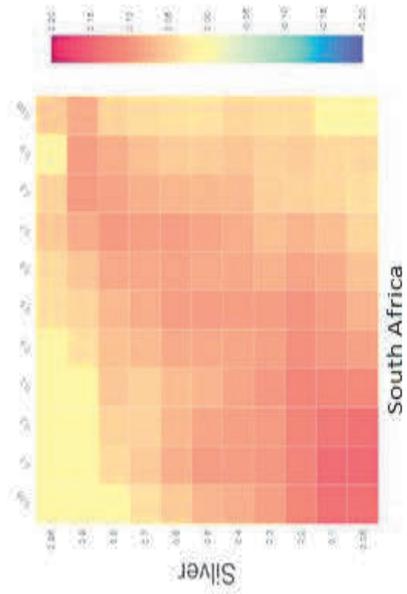
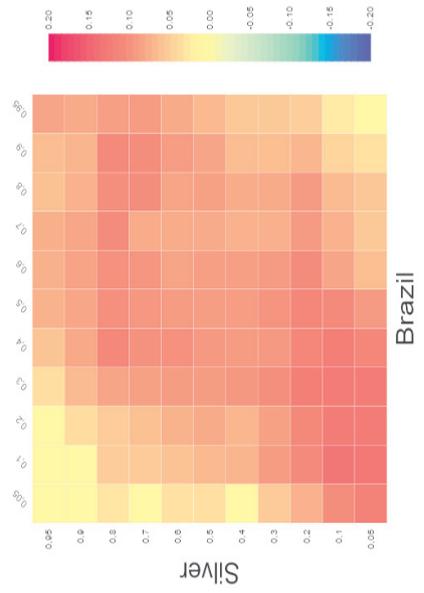
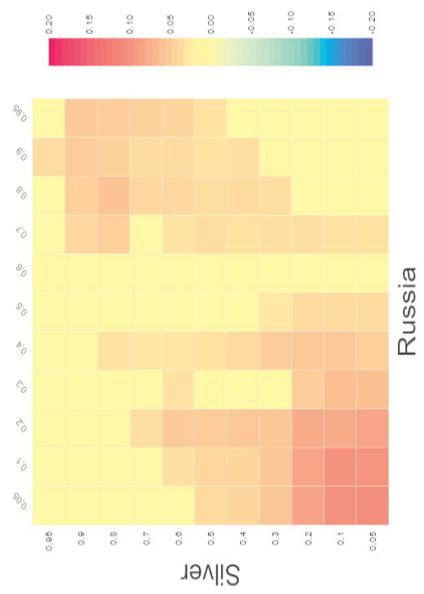
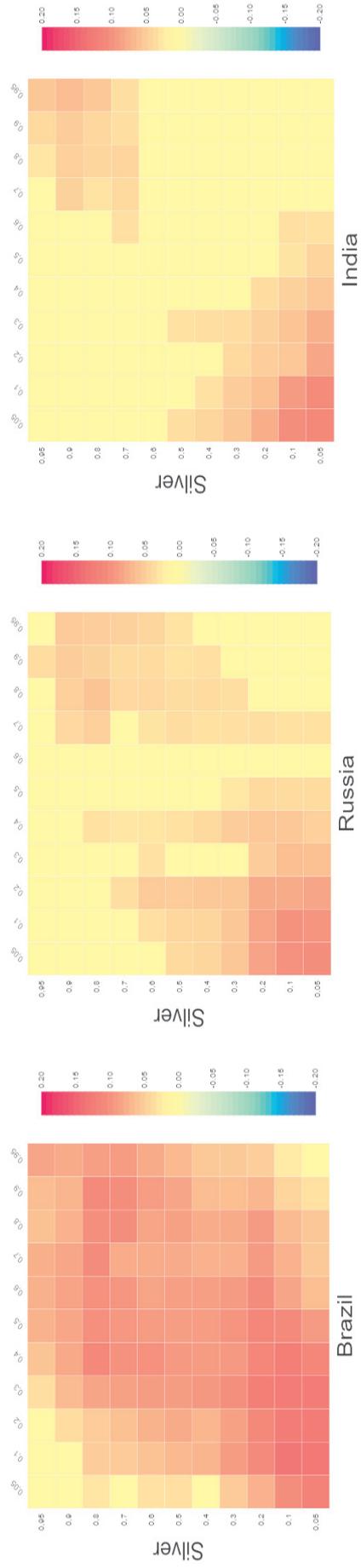


Figure 3. 3: (Continued)

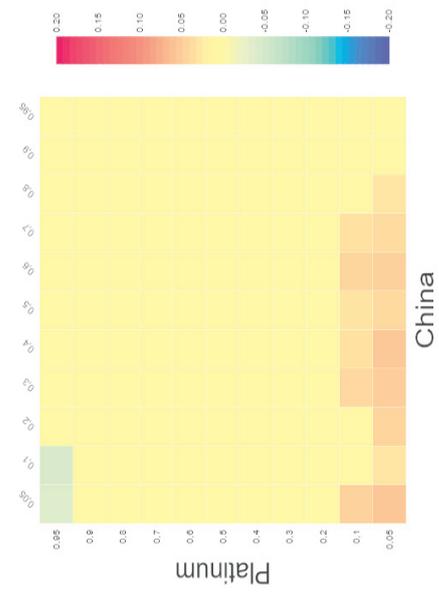
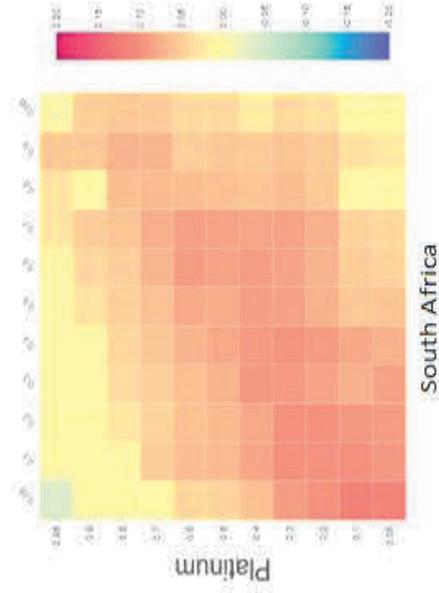
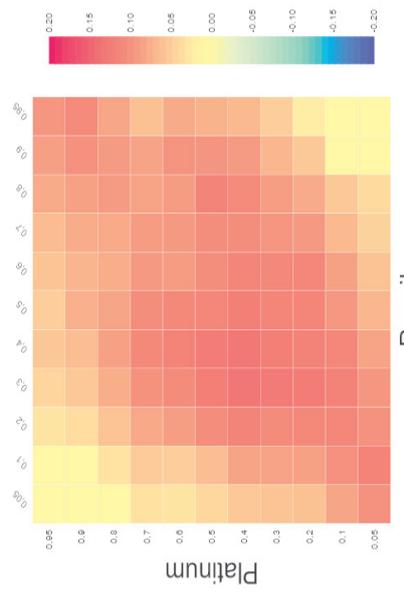
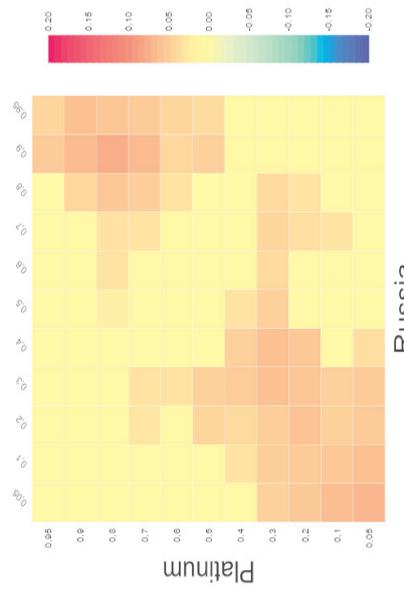
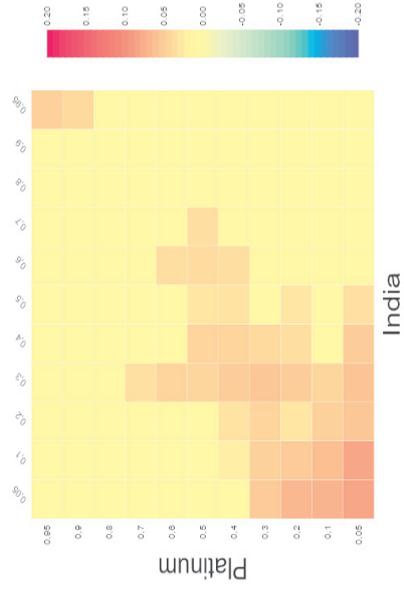


Figure 3. 3: (Continued)

3.4.3 Partial cross-quantilogram model results

In this subsection, we discuss the estimation results of the dependence structure between precious metals and the BRICS stocks markets after controlling for economic policy uncertainty (EPU). As we mentioned in the methodology section, this analysis is based on the PCQ model in which the EPU index is incorporated as a state variable to capture the impact of the changes in EPU. The CQ estimations between precious metals and the BRICS stocks markets controlling for EPU are presented in Figure 3. 4.

Even after controlling for EPU, Figure 3. 4 shows that BRICS stock markets have a positive dependence on precious metals across quantiles, except in the case of opposite quantiles. This result is in line with our findings without considering the EPU in the CQ model.

When comparing the results in Figure 3. 3 to Figure 3. 4, we can clearly notice that there is no remarkable difference. Consequently, we may argue that uncertainty related to the EPU has no or a little impact on the dependence between precious metals and BRICS stock markets. Indeed, gold remain a safe haven in Russia, India and South Africa stock markets; silver a safe haven in China stock market and platinum is a safe haven in China and South Africa stock markets. The reason why the results differ from one country to another, even though they correspond to the same group of countries, is that each country has its own financial risk exposure and business cycle connectedness with different taxes and legislations, etc. Hence, this will affect the reaction of each financial market to economic uncertainty.

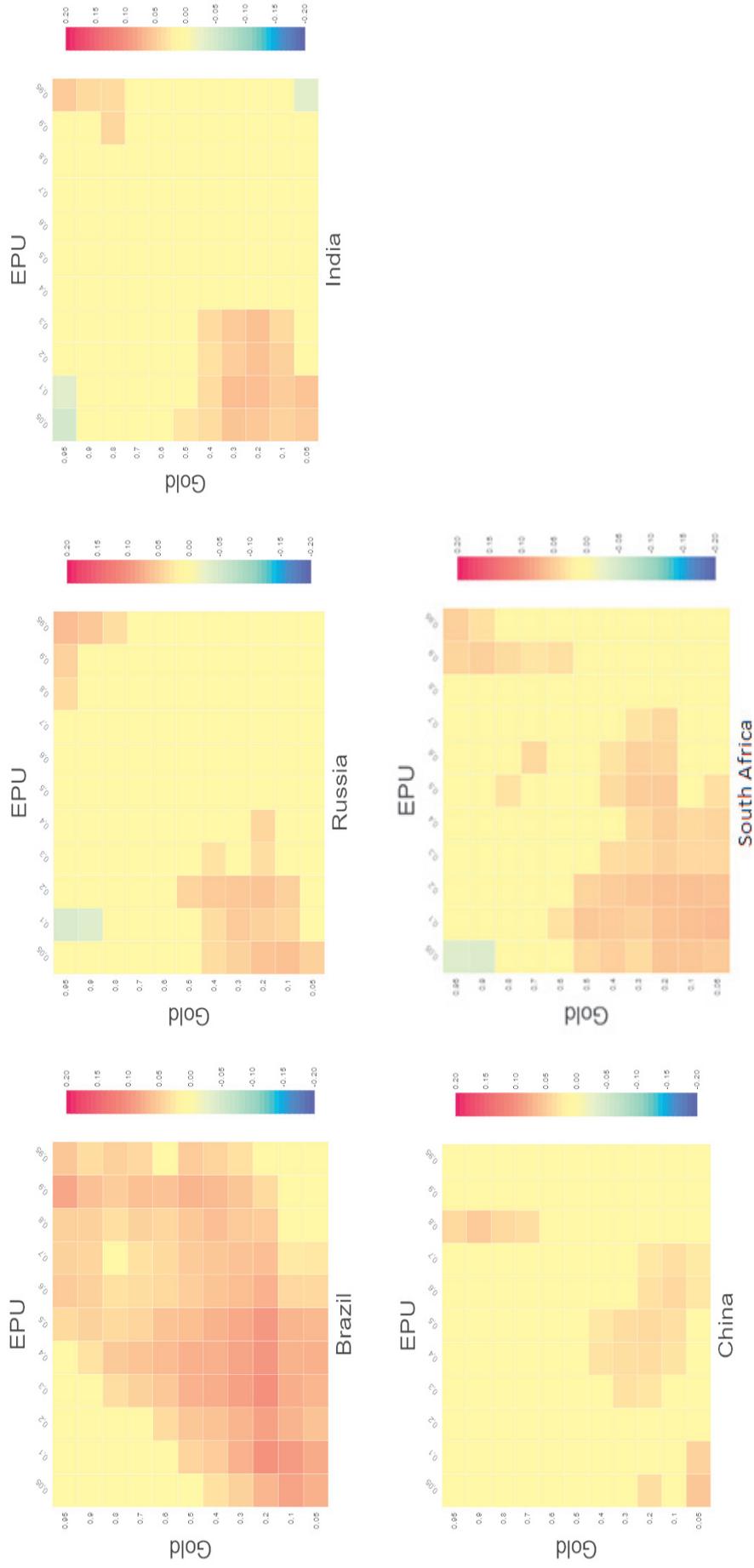


Figure 3. 4: Cross-quantile correlation between BTRICS stock markets and precious metals returns after controlling for EPU index

Notes: The cross-quantile correlation is estimated using Eq. (3.1) and statistical significance is measured using Box-Ljung test as presented in Eq. (3.2). All insignificant correlation was set to zero. Colour scale indicates the direction of relationship

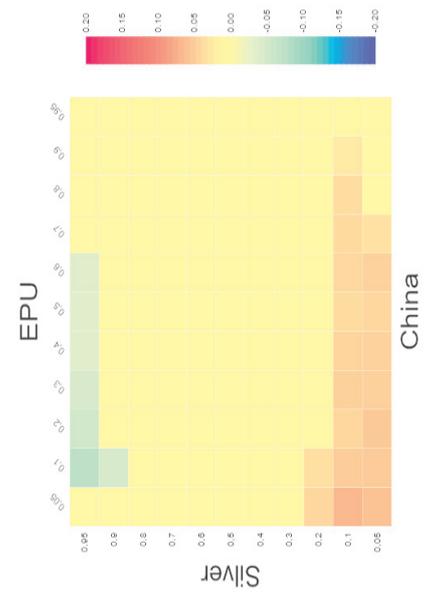
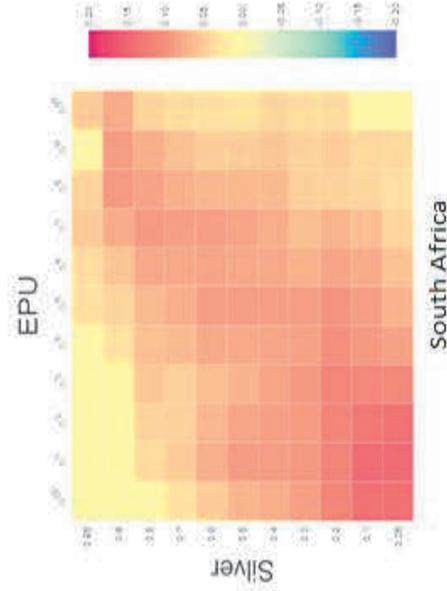
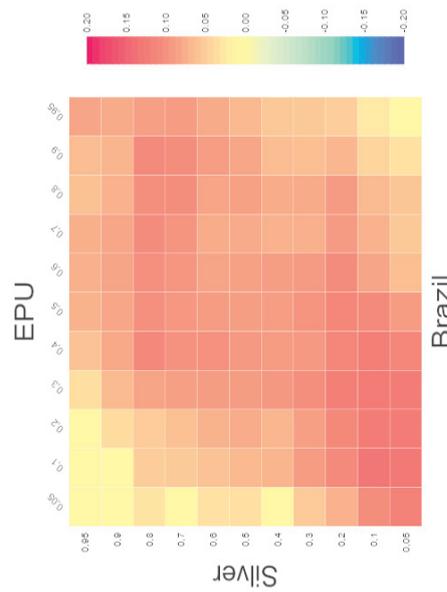
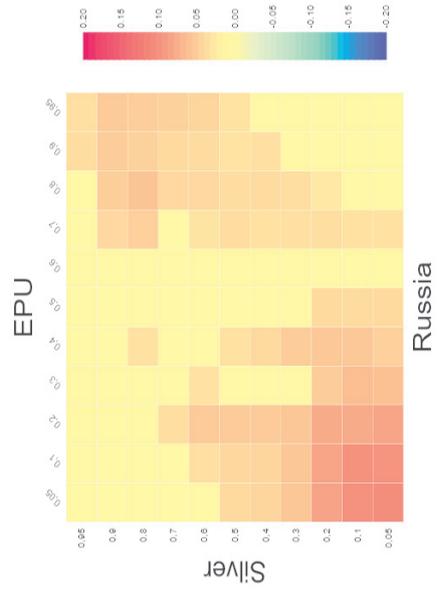
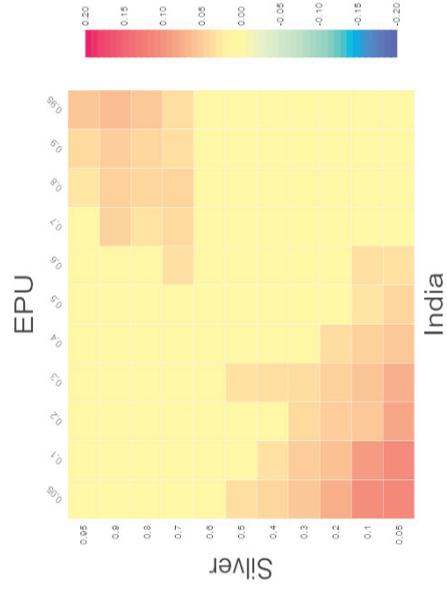


Figure 3. 4: (Continued)

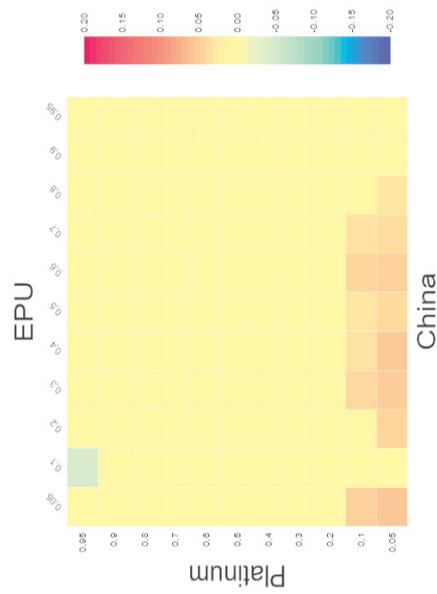
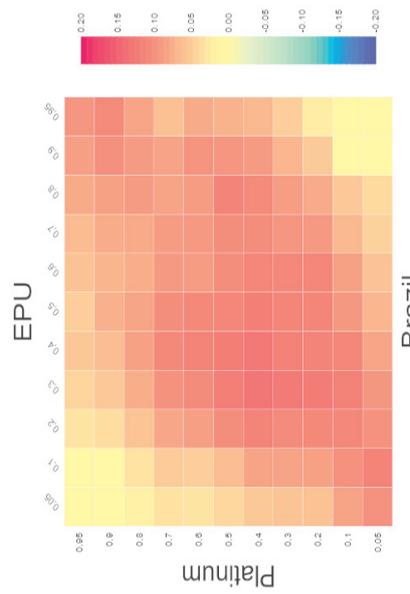
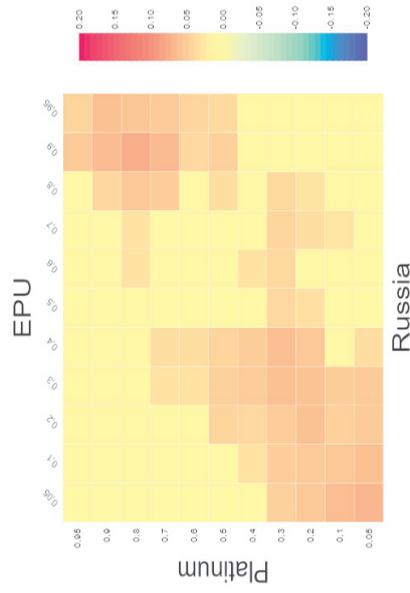
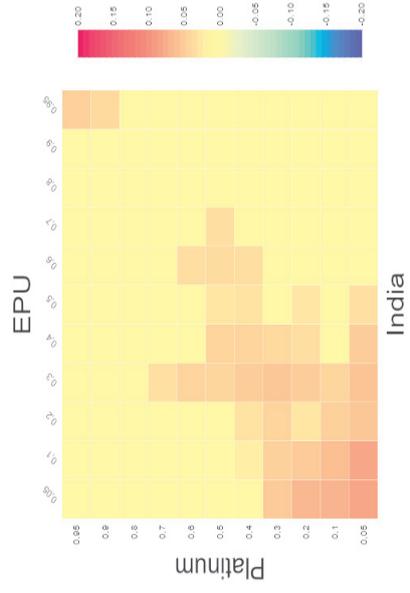


Figure 3. 4: (Continued)

3.5 Conclusions

This study explores how US Economic Policy Uncertainty (EPU) impact the quantile dependence between precious metals and BRICS stock market using the cross-quantilogram approach developed by Han et al. (2016). Overall, the dependence structure across quantiles is found to be consistent, even after controlling for EPU. Indeed, our empirical results could have important implications to different economic actors for different purposes.

First, without controlling for EPU, our empirical results may be useful to investors and portfolio manager to protect their investment portfolio due to the valuable roles of precious metals. For gold, no dependence across the whole range of quantiles is found in Russia and India. While silver and platinum no significant dependence across all combinations of quantiles only in the China stock market. These results imply that these precious metals may provide diversification benefits when combined with these stock market indices in a portfolio. Adding to that, over the entire sample period, extreme negative stock market returns were followed by extreme positive gold returns for all stock markets except for Brazil and China. Hence, gold is not a safe haven in these stock markets. However, silver is a safe haven only in China stock market and platinum is a safe haven in China and South Africa stock markets. Second, when controlling for EPU, our findings may be useful to risk managers to analyse whether EPU is a systematic risk factor in BRICS stock market returns or not. Third, our findings may be useful to policy maker since understanding how the US EPU affect the spillover between BRICS stock markets and precious metals is important in the decision process of economic and financial policies.

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General Conclusion

Over time, the demand for commodities, including precious metals, is more and more important as real assets and as investment assets for investors due to the potential benefits that they may offer in the real economy and in financial markets. Precious metals differ from other commodities in that they present a group of metals with similar investment properties and distinct quality of being both investment and industrial assets.

Due to their importance in terms of portfolio and risk management, researchers restart paying more attention to their inter-linkages, investment properties and their interaction with other financial markets. This thesis consists of three papers on precious metals markets with a special concern on the dependence structure, causality, investment properties and the impact of economic uncertainty in precious metals and stock markets.

Chapter one of this thesis set two main objectives. Firstly, it evaluates the dependence structure between spot-future returns pairs of precious metals (gold, silver, and platinum) using static and time-varying copulas. Then, it analyses the Granger causality in distribution between spot and future returns of precious metals using Granger causality-based copula test. There are two main findings in this study. First, the static and time varying copulas estimation results show a strong dynamic dependence between spot and future returns of precious metals. Regarding the dependence during extreme market conditions, we find strong symmetric tail dependence described by the t -copula for gold and platinum spot-future pairs and the SJC copula for silver spot-future pair. Second, the assessment of Granger causality in distribution was carried out with the use of the non-parametric independence test based on the empirical copula. Our results reveal a unidirectional causality in distribution from future precious metal returns to spot precious metal returns during normal periods. So, we can say that during normal times spot returns of precious metals depend on past values of future returns, which means that the future market leads the spot market. However, the causal effect seems to be bi-

directional in times of crises for gold (from 2002 to 2007) and platinum (from 2002 to 2010) due to the high demand in the physical market in such periods. Hence, during time of instabilities the precious metals future and spot returns show the cause-and-effect relationship. Our findings are important to traders and investors since understanding market conditions is a central issue as it will help to provide an idea about trading strategies.

Chapter two of this thesis examined the hedge, safe haven and diversification potentials of precious metals for the G-7 stock markets. Indeed, the vine copula method is used to test the hedge and safe haven hypotheses and the BiVaR is applied to assess the diversification benefits of precious metals. Our empirical results show, firstly, that gold provides the strongest safe haven property for all G-7 countries, which is consistent with previous literature. This result means that gold may be used to offset losses in equity markets during turmoil periods. In addition, we find that silver bears the potential of a strong safe haven role for Germany and Italy stock markets. However, platinum provides weak safe haven role for most developed markets. Furthermore, in line with existing studies, our study suggests that gold has a strong hedging property in developed stock markets. For silver and platinum, our new results show that they may act as weak hedge assets. Finally, the results of the BiVaR analysis argue that all precious metals exhibit diversification benefits for G-7 stock markets. Our findings provide a noteworthy practical implication for investors in the G-7 countries. We suggest that investors may hedge their equity investments in normal times by investing in these precious metals and ensure their portfolios from losses during periods of turbulence by investing in gold.

Chapter three explores the impact of US Economic Policy Uncertainty (EPU) on the quantile dependence between precious metals and BRICS stock market using the Cross-Quantilegram approach developed by Han et al. (2016). Overall, the dependence structure across quantiles is found to be consistent, even after controlling for EPU. Indeed, our empirical results could have important implications to different economic actors for different purposes. First, our empirical results may be useful to investors and portfolio manager to protect their investment portfolio due to the valuable roles of precious metals. For gold, no dependence across the whole range of quantiles is found in Russia and India. While silver and platinum no significant dependence across all combinations of quantiles only in the China stock market. These results imply that these precious metals may provide diversification benefits when combined with these stock market indices in a portfolio. Adding to that, over the entire sample period, extreme negative stock market returns were followed by extreme positive gold

returns for all stock markets except for Brazil and China. Hence, gold is not a safe haven in these stock markets. However, silver is a safe haven only in China stock market and platinum is a safe haven in China and South Africa stock markets. Second, our findings may be useful to risk managers to analyze whether EPU is a systematic risk factor in BRICS stock market returns or not. Third, our findings may be useful to policy maker since understanding how the US EPU affect the spillover between BRICS stock markets and precious metals is important in the decision process of economic and financial policies.

- **Contributions**

This thesis contributes to the existing literature on precious metals markets in several ways. Firstly, to the best of our knowledge, chapter one of this thesis is the first of its kind to investigate the dynamic and causal relationship between the spot-futures pairs of precious metals returns using causality copula-based model. In addition, seeking robustness, this is the first study considering the real prices of precious metals by taking into account inflation and the interest rate. We therefore consider deflated spot prices and deflated-implied spot prices (rather than future prices).

Secondly, chapter two gives a new insight on the valuable roles of precious metals for the G-7 stock markets. Therefore, it extends the analysis of hedge and safe haven properties of precious metals in the multivariate scale by using vine copula- based GARCH model. The use of vine copula overcomes the restrictive characteristics of standard copulas, such as the multivariate Gaussian or Student-t copulas, which exhibit a problem of parameters restriction and suffer from inflexibility in modelling the dependence structure among larger numbers of variables. Hence, the use of vine copulas provides a flexible and conditional dependence structure between the variables. Adding to that, we propose a new definition of “strong safe haven” property by using simulated data from the best-fitting copula model to compute the tail correlation. Moreover, this chapter propose a BiVaR novel method proposed by Bedoui et al. (2018), to check for the diversification potential of precious metals for G-7 investors.

Finally, different from previous studies, which were mainly focused on the impact of EPU on precious metals prices and stock market prices separately, the third chapter fulfil the literature gap by evaluating the impact of the EPU on the dependence between precious metals and BRICS stock markets. To that end, we applied the Cross-Quantilogram (CQ) approach which is a tow in one method. Firstly, it allows us to check for the valuable role of precious metals using the information provided by the quantile dependence between precious metals and

BRICS stock markets. Second, it enables us to check for the impact of the EPU on the dependence structure using the partial Cross-Quantilogram (PCQ) approach that include the EPU as a control variable in the CQ model.

- **Future research prospects**

To begin with, in the first chapter, we only focused on an in-sample analysis between the spot and futures precious metals markets by using a non-linear and nonparametric causality test based on empirical copula. Further research might analyse the out-of-sample forecasting of spot and futures precious metals markets. Then, in the second chapter, we studied the investment properties of precious metals for the G-7 stock markets using vine copulas and BiVaR approaches. For future research, it would be interesting if we conduct a precious metals portfolio analyses based on the dependence structure information provided by the vine copula.

Finally, in the third chapter, we evaluated the impact of the EPU on the dependence between precious metals and BRICS stock markets. It may be a fruitful idea if we make a comparative study by analysing the impact of other uncertainties such as market uncertainty and investor sentiment.

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