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► **To cite this version:**

Theu Dinh, Stéphane Goutte, Khuong Nguyen, Thomas Walther. Economic drivers of volatility and correlation in precious metal markets. 2022. halshs-03672469

**HAL Id: halshs-03672469**

**<https://shs.hal.science/halshs-03672469v1>**

Preprint submitted on 19 May 2022

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# Economic drivers of volatility and correlation in precious metal markets

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## Abstract

We investigate the time-varying dynamics of the precious metal markets. We employ a mixed data sampling technique to identify the impact of macroeconomic and financial drivers from G7 and BRICS countries on the daily volatility and pairwise correlation of Gold, Silver, Platinum, and Palladium. We find that the U.S. and Chinese economies in particular influence the precious metal markets, but in opposite directions. The stock markets and trade balance of both G7 and BRICS countries, as well as the consumer confidence of G7 countries, are the key drivers for the volatility of precious metals. The most influential drivers for correlation are stock markets, money supply, and the inflation rate. Surprisingly, the economic policy uncertainty does not affect the dynamics as much as expected. Lastly, the global financial crisis in 2008 affected the direction of most of the macroeconomic and financial drivers.

*Keywords:* Precious metals, long-term volatility, long-term correlation, macroeconomic drivers, financial drivers, economic policy uncertainty, mixed data sampling

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## 1. Introduction

In the global economy, the trade war between the U.S. and China, the two largest economies in the world, has been becoming more complicated, triggering fears of a global economic slowdown. Many experts have strongly warned that the prolonged U.S.-China trade war could lead to another global financial crisis (GFC). As a consequence of market shocks, investors prefer to keep safe assets and stay away from risky assets, known as the ‘flight to quality’ phenomenon in financial markets (Bernanke et al., 1994). Precious metals, which are considered safe investment assets, outperform traditional assets, such as stocks or bonds, especially in times of high uncertainty (Hillier et al., 2006; Baur and McDermott, 2010; Lucey and Li, 2015). In addition, precious metals became a key in the trade war between the U.S. and China due to the fact that between 2014 and 2017 around 80% of the precious metals used by the U.S. were imported from China.<sup>1</sup> The resilience of precious metals to financial crises has also been highlighted in recent studies (Baur and McDermott, 2010; Ciner et al., 2013; Agyei-Ampomah et al., 2014; Lucey and Li, 2015; Batten et al., 2015). As a result, the dynamics of precious metal markets in the current global economic situation and their dynamic trends around times of market turmoil have attracted the special attention of many scholars (Figuerola-Ferretti and McCrorie, 2016; Klein, 2017).

Because the precious metal markets are highly volatile and difficult to predict, the proper modelling of the volatility and correlation dynamics is crucial in these markets. Investors and portfolio managers can make better investment decisions if they are provided with a more accurate depiction of the dynamics, including the volatility as well as the correlation, of precious metals markets. Many studies find that the volatility and correlation of commodities markets in general and precious metals markets in particular are not only related to supply and demand dynamics, but are also associated with changes in economic activities (Anson, 2008; Belousova and Dorfleitner, 2012). Macroeconomic and financial variables are well-known as

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<sup>1</sup><https://www.reuters.com/article/us-usa-trade-china-rareearth-explainer-idUSKCN1TS3AQ>

the key potential drivers of dynamic movements in precious metal markets (Tully and Lucey, 2007a; Batten et al., 2015; Mo et al., 2018). Another important economic variable linked to high volatility markets, such as precious metal markets, is Economic Policy Uncertainty (EPU), which has also attracted considerable attention (Li and Lucey, 2017; Huynh, 2020).

30 To date, various methods have been applied to measure the impact of economic sources on financial assets' time-varying volatility and correlation, such as modified Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models (Hammoudeh et al., 2011; Pan et al., 2017), popular classes of multiple-equation models including Vector Autoregression- (VAR, Andersen et al., 2003; Apergis et al., 2014), Vector Error Correction Model-based  
35 approaches (Kucher and McCoskey, 2017), and different Dynamic Conditional Correlation (DCC) models (Fernandez-Diaz and Morley, 2019), among others. However, these studies predominantly investigate only the separated effect of a single driver or focus solely on a small number of given macro-finance variables.<sup>2</sup> One of the reasons for this may arise from the problem of the low frequency of economic data while the analyses of time-varying movements  
40 of precious metals are mainly based on high-frequency data.

In this study, by applying the generalized autoregressive conditional heteroskedasticity mixed data sampling model (GARCH-MIDAS, Engle et al., 2013) and the dynamic conditional correlation mixed data sampling model (DCC-MIDAS, Colacito et al., 2011), we can effectively solve the frequency mismatch problem. The main advantage of GARCH-MIDAS and DCC-  
45 MIDAS models is that they disentangle the long-term component from the short-term component of the volatility and correlation, respectively. In particular, advancements in GARCH- and DCC-MIDAS models allow for considering the impact of exogenous variables on the respective long-term component (Conrad et al., 2014; Asgharian et al., 2015).

Our study's primary objective is to analyze the individual impact of the most important

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<sup>2</sup>It is worth noting that some authors propose new techniques for measuring the impact of a large number of predictors jointly, e.g., dynamic factor analysis (Ludvigson and Ng, 2009), quantile regression (Christiansen et al., 2012), data-rich forecast methodology (Aslanidis and Christiansen, 2014), Bayesian Model Averaging (Díaz et al., 2021), or component-wise gradient boosting techniques (Mittnik et al., 2015).

50 economic and financial drivers on the time-varying volatility and correlation of precious metals. Our results indicate the inverse impact of economic drivers from highly developed (Group of Seven, G7) and emerging (Brazil, Russia, India, China, South Africa, BRICS) economies, most notably between the U.S. and China. Among our considered economic and financial factors, stock market returns, interest rates, and consumer confidence are identified as the  
55 most helpful predictors for modelling volatility and correlation. In addition, the trade balance growth is the most important variable in driving dynamic volatility whereas money supply and inflation rate are important determinants of long-term correlation between precious metals. Finally, we find the GFC of 2008 had a significant impact on the influence of economic and financial drivers on the dynamics of the precious metals markets, as many drivers changed  
60 the direction of their impact after the crisis.

Our study makes several contributions to the existing literature. Firstly, to the best of our knowledge, our paper is the first work that analyses macroeconomic and financial drivers of the dynamic correlation within the precious metal markets, although many previous studies have investigated the determinants of dynamic correlations between precious metals and other  
65 assets, such as stocks (Mensi et al., 2013; Jain and Biswal, 2016; Klein and Walther, 2022), oil (Šimáková, 2011), exchange rates (Pal et al., 2014; Apergis, 2014), or cryptocurrencies (Klein et al., 2018). There are a few papers that analyze the time-varying correlation between the precious metals themselves (Sensoy, 2013; Klein, 2017), but they do not consider their drivers. Secondly, in an attempt to answer the question of whether the impact of the economic drivers  
70 on the dynamic volatility and correlation of precious metals changes between tranquil and turbulent times, we split the full sample into three sub-periods, namely the pre-crisis period (March 1998—August 2007), the crisis period (September 2007–December 2010) and the post-crisis period (January 2011—August 2018). This helps to provide valuable recommendations to policymakers, investors and portfolio managers for addressing any GFC in the future.  
75 Thirdly, we contribute by investigating the different impact of a set of 19 economic and financial variables from 12 countries (G7 and BRICS) on the volatility and correlation of

precious metals. Most of the aforementioned studies only focus on U.S.-based determinants (Batten et al., 2015).

The rest of the article is organized as follows. Section 2 gives an overview of the existing literature. Section 3 describes the methodology. Our data and the results will be explained in Section 4. Section 5 concludes and discusses the implications of our research.

## 2. Literature review

The issue of what determines precious metal prices has been addressed in a range of studies, especially after the GFC of 2008 (Radetzki, 1989; Kucher and McCoskey, 2017). However, the factors that determine the volatility of the market for precious metals are less well known. In addition, a study on the determinants of pair-wise correlation within in precious metal markets is lacking.

Among the existing literature, the first strand focuses on the role of macroeconomic fundamentals in the dynamic movements of the volatility and correlation of precious metal markets. Batten et al. (2015) investigate the monthly price volatility of precious metals based on the macroeconomic determinants including the business cycle, monetary environment and financial market sentiment. They conclude that whereas monetary variables can explain the volatility of Gold, they cannot explain the volatility of Silver. Moreover, the same macroeconomic factors do not jointly influence the price series of all four precious metals. The impact of macroeconomic fundamentals seems much stronger on Palladium than on other precious metals.

In addition, Mo et al. (2018) find that the economic activities and the monetary environment (GDP, Inflation Rate and M2) show a significant and positive relation with precious metals in both China and India. Moreover, the authors show that the volatility of macroeconomic variables causes an increase in the volatility of precious metal futures.

Contrary to the two above-mentioned studies, Fang et al. (2018b) solely pay attention to identifying the economic drivers of the long-term volatility of the Gold futures market in the

U.S. by employing the GARCH-MIDAS method. The results show that the macroeconomic variables have a significant impact on Gold volatility during and after the GFC of 2008. More specifically, Economic Policy Uncertainty, Employment Rate and Inflation Rate have a positive effect on the long-run volatility of Gold futures while the effects of Capacity Utilization, Diffusion Index, New Consumer Goods and Materials Orders, and Consumer Confidence are negative and significant.

Similarly, [Nguyen and Walther \(2020\)](#) also apply the GARCH-MIDAS approach to investigate the time-varying volatility patterns of some major commodities, including Gold, Silver, and Platinum. The authors find that the long-term volatility is significantly affected by the level of Global Real Economic Activity, as well as changes in Consumer Sentiment, Industrial Production, and Economic Policy Uncertainty. Moreover, they find that the Industrial Production has a negative impact on the long-term volatility of Gold and Silver.

The rest of the related studies pay more attention to studying the impact of a specific aspect of macroeconomics on precious metal markets, such as GDP ([Radetzki, 1989](#)), Money Supply ([Bailey, 1988](#)), Business Cycle ([Kucher and McCoskey, 2017](#)), Macroeconomic News ([Smales, 2017](#)), Industrial Production ([Tully and Lucey, 2007b](#)), Inflation ([Gorton and Rouwenhorst, 2006](#)), Private Inventories ([Radetzki, 1989](#)), Capacity Utilization and Unemployment Rates ([Apergis et al., 2014](#)).

The second strand of literature focuses on the impact of financial variables on the dynamic movements of the volatility and correlation of precious metal markets. Among the financial factors, the short-term interest rate, which is an important tool of monetary policy, affects precious metal returns and volatility through multiple channels ([Hammoudeh and Yuan, 2008](#)). Therefore, a strong relationship between precious metals and interest rates has been reported in the literature ([Fortune, 1987](#); [Cai et al., 2001](#); [Hammoudeh and Yuan, 2008](#)). In general, most studies conclude that high interest rates reduce the demand for storing precious metals ([Hammoudeh et al., 2015](#)) and have calming effects on the volatility of precious metals markets ([Hammoudeh and Yuan, 2008](#); [Cai et al., 2001](#)).

130 In terms of the relationship between exchange rates and precious metals, [Ghosh et al. \(2004\)](#) and [Akram \(2009\)](#) show that commodity prices can be attributed to the influence of changes in exchange rates, especially with respect to the U.S. dollar. [Sari et al. \(2010\)](#) study the relationship between and information transmission among the spot prices of precious metals and the U.S. dollar/euro exchange rate. The authors find evidence of a weak long-term  
135 equilibrium relationship but strong co-movement in the short run.

Another line of research focuses more specifically on the impact of stock markets on the dynamics of precious metals, but the related literature provides inconclusive findings. [Tully and Lucey \(2007b\)](#) and [Creti et al. \(2013\)](#) find that stock returns negatively affect Gold returns and that this impact becomes slower with a decline in equity prices over time. In  
140 contrast, [Boako et al. \(2019\)](#) find a positive association between stock prices and Gold.

With the aim of investigating the effects of multiple economic and financial factors on metals price movements, [Liberda et al. \(2017\)](#) use mixed data sampling methodology to simultaneously study eight possible macroeconomic and financial drivers with various frequencies in a single model. The results show that the financial variables including Interest  
145 Rate, Exchange Rate, Stock Returns, and Crude Oil Returns affect precious metal markets more than macroeconomic variables, such as GDP growth, Inflation, and Industrial Production. Among the financial variables, the equity index has the most significantly negative impact on the metals returns. In addition, the financial variables are better at explaining the movement of the prices of Platinum and Palladium than that of Gold and Silver.

150 A third strand of literature is concerned with the relationship between the time-varying volatility and correlation of precious metals market with Economic Policy Uncertainty. Due to the fact that precious metals can act as a hedge or safe-haven for stock investment ([Baur and Lucey, 2010](#); [Baur and McDermott, 2010](#)), precious metals become a key investment possibility when the degree of policy uncertainty in world financial markets grows ([Białkowski et al., 2015](#); [Balcilar et al., 2016](#)). In particular, [Fang et al. \(2018a\)](#) and [Nguyen and Walther \(2020\)](#)  
155 find that GEPU positively affects the volatility of precious metals. More specifically, [Nguyen](#)



and Walther (2020) show that the changes in GEPV positively affect the long-term volatility of Gold and Platinum, but not of Silver. Similarly, Prokopczuk et al. (2019) find a strong co-movement between commodity market volatility and economic uncertainty, especially during recession periods.

Zhou et al. (2018) also use DCC-MIDAS, based on the mixed data sampling technique, combining the threshold VAR model in order to provide international evidence on the impact of macroeconomic policy uncertainty on the correlation between Gold and the U.S. dollar. The authors conclude that the Gold-dollar relationship has not remained constant over time and greatly depends on unpredictable political or economic uncertainty. Moreover, due to the different sources of economic uncertainty, the impacts are varied. The results also show that both Gold and the dollar, in return, can influence the economic uncertainty of the U.S. Europe, Russia, and China.

As a very limited literature that provides international evidence on the impact of extreme events such as the 9/11 terrorist attack, the GFC, the European Debt Crisis, and the Brexit vote on the inter-correlation among precious metals, the contributions of Klein (2017) and Klein and Walther (2022) are noteworthy. The authors point out the significant differences in correlation structures between the pair Gold/Silver and the pair Palladium/Platinum in connection to market shocks. This study also concludes that Gold and Silver act as safe-havens. However, this result does not hold after 2013. Specially, Platinum seems to serve as temporal surrogate safe-haven during periods of market turmoil.

### 3. Methodology

In the following, we present our two-step methodology. The first step relates to the heteroskedasticity process of the return series with the GARCH-MIDAS model (Engle et al., 2013) and its extended models for assessing the impact of the economic drivers of the conditional volatility of precious metals. The next section gives an overview of the DCC-MIDAS model (Colacito et al., 2011) and its modifications for analyzing the effect of economic

determinants on the dynamic correlations between precious metals themselves.

### 3.1. GARCH-MIDAS model with economic variables

185 In order to analyze the volatility drivers, we employ the GARCH-MIDAS model proposed by Engle et al. (2013), which disentangles the volatility into a short-term (daily) and a long-term (monthly) component.

We consider  $r_{i,t}$  as the (logarithmic) return, where  $i$  and  $t$  denotes short- and long-run indexes, respectively, e.g.,  $i$  for day and  $t$  for month, quarter or half-year. The mean equation of this return is as follows:

$$r_{i,t} = \mu + \sqrt{\tau_t g_{i,t}} \varepsilon_{i,t} \quad \forall i = 1, \dots, N_t \quad (1)$$

In which  $N_t$  is the number of trading days in the period  $t$  and  $\varepsilon_{i,t} | \Phi_{i-1,t} \sim \mathcal{N}(0, 1)$  with  $\Phi_{i-1,t}$  is the information set up to day  $(i - 1)$  of period  $t$ . The factors  $\tau_t$  and  $g_{i,t}$  are the long- and short-run variance components, respectively. According to Engle and Rangel (2008),  $g_{i,t}$  follows a standard GARCH(1,1) model with unit variance:

$$g_{i,t} = (1 - \alpha - \beta) + \alpha \frac{(r_{i-1,t} - \mu)^2}{\tau_t} + \beta g_{i-1,t} \quad (2)$$

with non-negativity and stationary conditions  $\alpha, \beta \geq 0$  and  $\alpha + \beta < 1$ .

Compared to the original GARCH model, which has a constant baseline variance, the GARCH-MIDAS model allows the baseline variance to change slowly over time. We follow Engle et al. (2013) and model the long-term component  $\tau_t$  as a slowly varying function of an exogenous variable  $X_t$ :

$$\log(\tau_t) = m + \theta \sum_{k=1}^K \varphi_k(\omega_1, \omega_2) X_{t-k}, \quad (3)$$

which we denote as GARCH-MIDAS-X. Here,  $K$  is the number of lags and  $m$  is an intercept of long-term trend. The Beta-weighting scheme  $\varphi_k$  is determined by a beta lag polynomial

(Ghysels et al., 2007) as follows

$$\varphi_k(\omega_1, \omega_2) = \frac{(k/K)^{\omega_1-1}(1-k/K)^{\omega_2-1}}{\sum_{j=1}^K (j/K)^{\omega_1-1}(1-j/K)^{\omega_2-1}}. \quad (4)$$

Depending on the parameters  $\omega_1, \omega_2 > 1$ , the Beta scheme can depict increasing, decreasing,  
 190 or hump-shaped weights, which sum up to unity.

Eventually, we estimate the parameters by Quasi-Maximum-Likelihood-Estimation (QMLE, Engle et al., 2013).

### 3.2. DCC-MIDAS model with economic variables

The DCC-MIDAS model proposed by Colacito et al. (2011) is a natural extension and  
 195 combination of the DCC model (Engle, 2002) and the GARCH-MIDAS model that allows us to decompose the short- and long-run correlation components by the mixed data sampling approach.

We assume that the  $n$ -dimensional vector of returns  $r_t$  follows the process

$$\begin{aligned} r_t &\stackrel{\text{i.i.d.}}{\sim} \mathcal{N}(\mu, C_t), \\ C_t &= D_t \Omega_t D_t, \end{aligned} \quad (5)$$

where  $\mu$  is the vector of unconditional means,  $C_t$  is the conditional covariance matrix,  $D_t$  denotes a diagonal matrix with standard deviations on the diagonal, and  $\Omega_t$  represents the conditional correlation matrix of returns on time  $(t-1)$  information:

$$\begin{aligned} \Omega_t &= E_{t-1}[\eta_t \eta_t'], \\ \eta_t &= D_t^{-1}(r_t - \mu), \end{aligned} \quad (6)$$

where  $\eta_t$  is the standardized residuals. Hence,  $r_t = \mu + C_t^{1/2} \eta_t$  with  $\eta_t \stackrel{\text{i.i.d.}}{\sim} \mathcal{N}(0, I_n)$ .

It is clear that Equation (5) suggests a two-step model specification strategy. It means

that we first specify  $D_t$  by estimating the GARCH-MIDAS model as in Equation (2), from which we obtain the standardized residuals  $\eta_{i,t}$ . After that, we estimate the DCC-MIDAS parameters. To be more specific, we initially calculate the conditional statistics, which are denoted as  $q_{ij,t}$  (e.g. the short-run correlation between asset  $i$  and asset  $j$  at time  $t$ ). The  $q_{ij,t}$  are the elements of the  $(n \times n)$ -dimensional quasi-correlation matrix  $Q_t$ :

$$q_{ij,t} = \bar{\rho}_{ij,t}(1 - a - b) + a\eta_{i,t-1}\eta_{j,t-1} + bq_{ij,t-1}, \quad (7)$$

where  $\bar{\rho}_{ij,t}$  is the slowly moving long-term correlation between asset  $i$  and asset  $j$ . Here, we follow [Conrad et al. \(2014\)](#) and model the long-term correlation using a Fisher- $z$  transformation:

$$\bar{\rho}_{ij,t} = \frac{\exp(2z_{ij,t}) - 1}{\exp(2z_{ij,t}) + 1}, \quad (8)$$

where  $z_{ij,t}$  is driven by an exogenous variable  $X_t$ :<sup>3</sup>

$$z_{ij,t} = c + \gamma \sum_{k=1}^K \varphi_k(\omega_1, \omega_2) X_{t-k}. \quad (9)$$

The weighting scheme  $\varphi_k(\omega_1, \omega_2)$  is defined as the Equation (4) of Section 3.1. The parameter  $\gamma$  measures the effect of the exogenous variable on the long-run correlations between the precious metals.

Finally, the conditional correlation matrix is given as

$$\Omega_t = \text{Diag}(Q_t)^{-1/2} Q_t \text{Diag}(Q_t)^{-1/2}. \quad (10)$$

We also follow [Colacito et al. \(2011\)](#) and [Conrad et al. \(2014\)](#) in terms of estimation and use the QMLE to estimate the coefficients of the dynamic correlation model.

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<sup>3</sup>We do not present the formula from the realized correlation framework of [Colacito et al. \(2011\)](#) here, as we focus on the effects of macroeconomic and financial drivers on the dynamic correlation only.

## 4. Empirical Application

### 205 4.1. Data and variables

#### 4.1.1. Precious metals data

Our data consist of daily spot and futures (one month) price series of Gold, Silver, Platinum, and Palladium, which are obtained from Thomson Reuters Datastream.<sup>4</sup> Table 1 summarizes the descriptive statistics for the daily spot and futures returns (Panel A and panel 210 B, respectively) divided into a full sample period and the financial crisis-related sub-periods. The results show that the mean and standard deviation values of the spot returns of each precious metals are similar to those of their futures returns. We can see that the mean is small and positive for most return series in both full sample and sub-samples, with the exception of Platinum and Palladium during the GFC. Interestingly, Gold returns exhibit the highest 215 mean but the lowest volatility during the crisis, reflecting the safe-haven role (Baur and McDermott, 2010). Table 1 also reports the results of skewness and kurtosis. The skewness is negative while the kurtosis values are above three for the majority of return series, indicating a non-normally, leptokurtic distribution, which is also confirmed by a Jarque-Bera statistical test.

220 In addition to the descriptive statistics, the  $p$ -values of Ljung-Box (LB) statistics of order 15 for the returns series show the existence of auto-correlation in most of them. For the squared returns series, however,  $p$ -values of LB are highly significant, which reveals a long-range serial dependence. This result is confirmed by the results of the ARCH test, hence motivating our decision to use the GARCH-model to filter the daily returns.

#### 225 4.1.2. Exogenous variables

Following our literature review in Section 2, we select a set of exogenous variables with respect to data availability. We divide the exogenous variables into three categories:

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<sup>4</sup>We use both, spot and futures prices to account for their different dynamics (Pindyck, 2001).

Macroeconomic variables, Financial variables, and Economics Policy Uncertainty (see Table 7 in the Appendix).<sup>5</sup>

230 The monthly data for the macroeconomic and financial variables are retrieved for 12 countries (G7 and BRICS) from March 1998 to August 2018 from Thomson Reuters Datastream, the FRED database at the Federal Reserve Bank of St. Louis, OECD database, and World Bank database. Additionally, monthly data for EPU indices is collected from <https://www.policyuncertainty.com>. In order to ensure consistency between countries  
235 and to remove the potential adverse impact of different currencies, the macroeconomic variables used in the study are index variables calculated according to the same formula, or transformed in terms of growth variables.

#### *4.2. Results and discussions*

We begin our analysis by testing the impact of various macroeconomic and financial  
240 drivers on the conditional volatility of each precious metal and six pairs of correlations of four major precious metals<sup>6</sup> in our sample by employing the GARCH-MIDAS-X model and DCC-MIDAS-X.

In the first step, we estimate standard and asymmetric GARCH and GARCH-MIDAS variants in order to check whether a decomposition in short- and long-term volatility components  
245 is actually useful. For all metals, we find that the GARCH-MIDAS model using monthly realized volatility as a driver of the long-term volatility outperforms the other variants in terms of the Bayesian Information Criterion (BIC). For Platinum only, the GJR-MIDAS-RV has a slightly better BIC. We report the results in Table 6 in the Appendix. Additionally, we determine that  $K = 36$ , i.e. three years of monthly observations, is the optimal lag-length for  
250 the MIDAS component with regards to the BIC.

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<sup>5</sup>We note that the distinction between economic and financial variables is not mutually exclusive as some of the financial variables can also be regarded as economic variables and vice versa (e.g. the EPU or the exchange rates).

<sup>6</sup>Gold-Silver (G-S), Gold-Platinum (G-Pl), Gold-Palladium (G-Pa), Silver-Platinum (S-Pl), Silver-Palladium (S-Pa) and Platinum-Palladium (Pl-Pa).

Table 1: Descriptive statistics and stationary tests of four precious metals

	Mean	Stdev	Skewness	Kurtosis	J.B.	Q(15)	Q <sup>2</sup> (15)	ARCH(15)
<b>Panel A: Spot return</b>								
<i>Full sample</i>								
Gold	0.032	1.073	0.085	6.226	0.000	0.010	0.000	0.000
Silver	0.032	1.803	-0.523	6.573	0.000	0.012	0.000	0.000
Platinum	0.023	1.406	-0.296	4.950	0.000	0.035	0.000	0.000
Palladium	0.049	2.092	0.016	5.091	0.000	0.000	0.000	0.000
<i>Pre-crisis</i>								
Gold	0.038	0.985	0.183	7.786	0.000	0.009	0.000	0.000
Silver	0.038	1.568	-0.907	6.443	0.000	0.041	0.000	0.000
Platinum	0.058	1.379	-0.004	6.009	0.000	0.010	0.000	0.000
Palladium	0.040	2.264	0.295	5.934	0.000	0.001	0.000	0.000
<i>Crisis</i>								
Gold	0.091	1.793	0.300	2.099	0.000	0.129	0.000	0.000
Silver	0.028	2.839	-0.147	3.878	0.000	0.441	0.005	0.000
Platinum	-0.057	2.316	-0.795	2.347	0.000	0.209	0.000	0.000
Palladium	-0.120	2.641	-0.532	3.004	0.000	0.319	0.022	0.000
<i>Post-crisis</i>								
Gold	0.018	1.023	-0.227	4.872	0.000	0.006	0.000	0.000
Silver	0.026	1.835	-0.416	5.523	0.000	0.030	0.000	0.000
Platinum	0.001	1.257	-0.138	1.810	0.000	0.058	0.000	0.000
Palladium	0.081	1.809	-0.235	2.252	0.000	0.057	0.000	0.000
<b>Panel B: Futures one month return</b>								
<i>Full sample</i>								
GoldF	0.032	1.088	0.049	6.815	0.000	0.004	0.000	0.000
SilverF	0.033	1.867	-0.628	6.919	0.000	0.235	0.000	0.000
PlatinumF	0.024	1.458	-0.957	7.542	0.000	0.004	0.000	0.000
PalladiumF	0.049	2.085	-0.014	5.383	0.000	0.000	0.000	0.000
<i>Pre-crisis</i>								
GoldF	0.038	0.999	0.336	7.839	0.000	0.040	0.000	0.000
SilverF	0.039	1.625	-0.882	7.711	0.000	0.058	0.000	0.000
PlatinumF	0.059	1.441	-1.665	5.283	0.000	0.000	0.000	0.000
PalladiumF	0.040	2.232	0.185	6.607	0.000	0.001	0.000	0.000
<i>Crisis</i>								
GoldF	0.090	1.733	0.297	2.631	0.000	0.049	0.000	0.002
SilverF	0.027	2.863	-0.311	3.432	0.000	0.239	0.000	0.000
PlatinumF	-0.058	2.363	-0.591	1.964	0.000	0.294	0.000	0.000
PalladiumF	-0.122	2.635	-0.339	3.347	0.000	0.204	0.000	0.000
<i>Post-crisis</i>								
GoldF	0.018	1.056	-0.385	6.198	0.000	0.015	0.000	0.000
SilverF	0.028	1.914	-0.558	6.095	0.000	0.077	0.000	0.000
PlatinumF	0.001	1.301	-0.100	1.669	0.000	0.013	0.000	0.000
PalladiumF	0.082	1.835	-0.183	2.211	0.000	0.217	0.000	0.000

Note: The table shows the descriptive statistics for daily returns series of four precious metals over full sample period (Mar 02, 1998 to Aug 31, 2018) and three sub-sample periods including pre-crisis (Mar 02, 1998 to Aug 31, 2007), crisis (Sept 03, 2007 to Dec 31, 2010) and post-crisis (Jan 03, 2011 to Aug 31, 2018), respectively. J.B. refers P-value of the Jarque-Bera test for normality. Q(15) and Q<sup>2</sup>(15) denote the Ljung-Box Q-test statistics for auto-correlation in the return and squared return series, respectively, up to 15 lag. Furthermore, ARCH(15) is the Engle (1982) LM test for ARCH effects up to 15 lags.

In the following sub-sections, we analyze the impact of the various macroeconomic and financial variables on the volatility and correlation of precious metals. To this end, we focus on the statistical significance of coefficients  $\theta$  in Equation (3) and  $\gamma$  in Equation (9) which determine the size and direction of the impact of an exogenous variable on the long-term volatility and inter-correlation of precious metals, respectively. Following this, the signs of  $\theta$  and  $\gamma$  reveal whether an upside or downside trend in the long-term volatility and correlation can be caused by an increase in the respective economic variables.<sup>7</sup>

#### *4.2.1. Macro-finance drivers of precious metals volatility and correlation - opposite evidence between the U.S. and China*

Due to the escalating tension between the U.S. and China after 2018 and its subsequent persistent headwind for all financial markets, we start our analysis with a focus on these two countries.

In general, the results in Tables 2 and 3 show that Chinese economic drivers have less impact on volatility and correlation among precious metals pairs than their U.S. counterparts. In addition, the long-term volatility of Gold and long-term correlations of the Gold-Silver and Platinum-Palladium pairs appear to be the most affected by economic variables. This is consistent with the findings of Klein (2017), who concludes that there are significant differences in correlation structures for two groups of precious metals: (1) Gold and Silver as investment assets and (2) Palladium and Platinum as mainly industrial metals.

Interestingly, the results reveal a totally contrary scenario between the U.S. and China in terms of the impact of almost all macro and financial drivers on the precious metals return volatility and their pairwise correlations. A few exceptions have a similar directional impact for volatility: EPU growth (positive impact), Exchange rate (negative impact), and Gold & Foreign Reserves growth (positive impact); and on correlation: import growth.

In particular, the effect of Consumer Confidence on both volatility and correlation can be

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<sup>7</sup>An alternative approach is presented by Walther et al. (2019) for the case of cryptocurrencies. Instead of statistical inference, the authors focus solely on the predictive accuracy of volatility drivers.



observed more clearly. This U.S. indicator has a negative impact on long-term volatility while a positive effect can be seen on the inter-correlation of most precious metals. Meanwhile, the figure for China shows no effect on any precious metals volatility or correlation. In contrast, China's Composite Leading Indicator (CLI) seems to have been an important determinant of precious metals volatility except for Gold, but the U.S. CLI does not indicate any statistically significant effect. Additionally, the long-run volatility of precious metals is significantly affected by the foreign trade of both countries. However, Chinese export growth has more influence on volatility than that of the U.S., whereas the import growth of China has less impact on volatility than that of the U.S. This result can be explained by China's dominance in exporting rare metals. This country produced around 90% of the world's rare earth metals in 2019.<sup>8</sup> Meanwhile, the U.S. remains one of the world's top importers of precious metals, although the U.S. has recently made it a priority to diversify their sources of rare metals in order to reduce its dependence on China.<sup>9</sup>

Notably, all four precious metals (spot and futures) react significantly and negatively to the U.S. stock market returns, while only the long-term volatility of spot precious metal returns has a significantly positive response to the stock returns in China. This result indicates that, in the long-term, an upward trend of stock returns in the U.S. would help to stabilize precious metal markets. However, this is not true for the Chinese stock market because almost all  $\theta$  coefficients of the Chinese stock returns are insignificant. With respect to correlation, Table 3 reveals that the U.S. stock market returns are positively associated with almost all correlation pairs between precious metals spot returns. Meanwhile, their Chinese counterparts do not appear to affect any conditional correlation. These findings are similar to the conclusion of Uddin et al. (2020) in regard to the key role of the largest stock market (i.e., the U.S. market, which has over 5 000 listed firms) in driving the precious metals markets. In contrast, the Chinese stock market shows a poor long-run performance and it has not played a role as

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<sup>8</sup><https://www.investopedia.com/insight/chinese-mining-companies/>

<sup>9</sup><https://www.visualcapitalist.com/chinas-dominance-in-rare-earth-metals/>

prominent as the banking sector in providing financing for firms and promoting economic growth in China and globally. In addition, many companies, including mining companies, are publicly listed, but none of them are listed in the domestic market. Finally, several other factors also show an opposite impact between the U.S. and China on the dynamic correlation levels among precious metal returns (e.g., M1, M2, and inflation).

Table 2: Coefficients  $\theta$  of economics variables of the U.S. and China

Assets	Gold	GoldF	Silver	SilverF	Platinum	PlatinumF	Palladium	PalladiumF
<b>Panel A: United States</b>								
<i>Macroeconomic variables</i>								
M1 Growth		-0.1345**	-0.9366**	-0.8870**		0.1692*		
M2 Growth	0.4923**	0.6750*	0.2682**	0.3155**			0.2331*	
Inflation Rate	0.4079*	0.2641*				0.0989*		0.1749*
Unemployment Rate	0.0974*	0.0858**			0.0663*		-0.1251*	-0.1251*
Saving Ratio	-0.1909**			-0.2569**	-0.0796***	0.0658*		
Capacity Utilisation	-0.0512*						-0.0881*	-0.0881*
Industrial Production	-0.0494**	-0.0411**		-0.1195**	-0.1718***		-0.0710***	-0.0645***
Consumer Confidence	-0.2731***		-0.2762***	-0.3054***	-0.1691**	-0.1754**	-0.2116***	
Composite Leading Indicator							-0.1630*	
Export Growth	0.4668*	-0.0548*			-0.1999**	-0.0762***	-0.1011**	
Import Growth	0.4283*		0.7013*	0.8101*	-0.2011**		0.1029**	
Gold&Foreign Reserves	0.1813**	0.1813**	0.4138**	0.5142**		0.0749**	0.2495**	0.2495**
<i>Financial variables</i>								
Stock market	-0.0775**	-0.0652***		-0.0569**	-0.3542***	-0.2593**	-0.0395***	-0.5079***
Bond market							0.0802*	0.2028**
Interest Rates		0.1978*						
Interbank 3M Rates	0.1677**			-0.3911***			0.1647***	0.1475***
T-bill 3M Rates					0.0923*		0.1685***	
Exchange Rates	-0.0313**	-0.0304**	-0.0492***	-0.0527***			0.0158***	
<i>EPU</i>					0.2242***			
<b>Panel B: China</b>								
<i>Macroeconomic variables</i>								
M1 Growth		0.3164*		-0.0730**		0.3275***		0.1788***
M2 Growth	0.6364**						3.7941***	
Inflation Rate	0.1505***		0.2840***	0.1989**				
Unemployment Rate	1.2893**	1.6245***	2.1366***	2.1216***			2.5641***	2.2086**
Saving Ratio								
Capacity Utilisation								
Industrial Production								
Consumer Confidence								
Composite Leading Indicator			-0.1976***	-0.2054***	-0.1848**	-0.1635*	-0.2376***	-0.1906***
Export Growth	0.2379***	0.2070***	0.4766*	0.5682*	0.0495**			0.0199***
Import Growth			0.6376***	0.6859***				
Gold&Foreign Reserves	0.1892*	0.0638**		0.0897***	0.9346*		-0.0714**	
<i>Financial variables</i>								
Stock market	-0.0230*		0.2049*		0.1382***	0.1567***	-0.0953**	
Bond market								
Interest Rates	0.5162***			-4.0609**		0.2120*		
Interbank 3M Rates								
T-bill 3M Rates								
Exchange Rates	-0.0252***	-0.0219***	-0.0201***					
<i>EPU</i>					0.0489***			

Note: The table reports estimated results for parameters  $\theta$  of macroeconomic and financial variables of the U.S. and China from GARCH(1,1)-MIDAS-X model. The symbols \*\*\*, \*\*, and \* denote statistical significance at the levels of 1%, 5% and 10%, respectively. Otherwise the field is left blank.

Table 3: Coefficients  $\gamma$  of economics variables of the U.S. and China

Pairs of Assets	Gold–Silver		Gold–Platinum		Gold–Palladium		Silver–Platinum		Silver–Palladium		Platinum–Palladium	
Countries	US	China	US	China	US	China	US	China	US	China	US	China
<b>Macroeconomic variables</b>												
M1 Growth	0.3568**		0.6277***	-1.0963**			0.5191***				0.4717**	
M2 Growth	0.9507*	-1.1396***		-1.1596***	-1.1347*			-0.1537***				-0.6549***
Inflation Rate	-0.1382**	0.8183***	-1.2895***				-0.2543**	0.1238**		0.1377***		
Unemployment Rate								0.8990***	0.9423***			
Saving Ratio												
Capacity Utilisation	0.1139*		0.3390*								0.3466*	
Industrial Production			0.3386**									
Consumer Confidence	1.5113**		1.9844***		1.7165**		1.4700*		1.7635*		2.7214**	-2.7959**
Composite Leading Indicator			1.5281*	1.7337*								1.2851*
Export Growth	-0.1739*				0.1772**			-0.1161**	0.1812**			
Import Growth	-0.1969**	-1.0317***										
Gold&Foreign Reserves		-0.1214**		-0.2788***							0.1599*	0.5301***
<b>Financial variables</b>												
Stock market	0.1486*		0.1774**		0.0996***				0.0854**		0.1019***	1.1359***
Bond market			0.9956***									
Interest Rates	-0.0745**		-0.1362***		-0.1007*		-0.1059**		-0.5612***		-0.2331***	
Interbank 3M Rates	-0.0700**						-0.1102**					
T-bill 3M Rates												
Exchange Rates												0.4757**
<b>EPU</b>	-0.0138***											

Note: The table shows estimation results  $\gamma$  of macro-finance drivers of the U.S. and China from DCC-MIDAS-X model. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise the field is left blank.

#### 4.2.2. The global financial crisis of 2008 and macro-finance drivers of precious metals volatility and correlation

The safe-haven ability of precious metals against market shocks such as the GFC of 2008, is proven in many prior works (Baur and Lucey, 2010; Batten et al., 2015). In addition, Morales and Andreosso-O’Callaghan (2011) suggest that the precious metal markets are less influenced by times of market stress than other financial markets. Therefore, we use a sub-period analysis, still focusing on the U.S. and China, to investigate any change in the role of economic drivers of precious metals across the various phases of the GFC 2008. Tables 4 and 5 report the estimation results of the potential drivers of volatility and correlation in precious metal futures over three periods of the 2008 crisis. This selection arises as the futures contracts on precious metals have become the most-widely used instruments for risk management in more volatile periods, and the U.S. and China have played an important role in global derivatives trading for metals (Klein and Todorova, 2021).

Generally, the period after the 2008 GFC has witnessed a greater number of economic determinants in China affecting the long-term volatility of all four precious metals as well as their correlation compared to other periods (e.g., there are more significant coefficients

Table 4: Coefficients  $\theta$  of economics variables of the U.S. and China over three sub-periods of global financial crisis 2008

Assets Periods	GoldF			SilverF			PlatinumF			PalladiumF			
	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	
<b>Panel A: United States</b>													
<i>Macroeconomic variables</i>													
M1 Growth	0.6574*	0.5116***				-0.5661**		-0.9755***		2.00*	-0.0971***	-4.3327***	
M2 Growth		0.5156*				-2.1543**	1.5155***			2.5460***	5.9999***	0.5708***	
Inflation Rate						-0.2459**			-0.2992**		-5.000***		
Unemployment Rate			0.2545***	0.6734***				-0.1142*		0.7296***	-1.0059***		
Saving Ratio		-0.0956**	1.4900***	0.5112*			0.3332***	0.0845*		0.4423*	-1.0127***	-0.5491***	
Capacity Utilisation		-0.1305***			-0.1175***		-0.4908***	-0.1304***		-0.1813***	-0.1011***		
Industrial Production		-0.1006**	-0.0872**					-0.1005***	0.3610***			0.2344***	
Consumer Confidence	-0.7209***	-0.1070*	-0.3744***				-0.6422***	-0.1069***		-0.9405**			
Composite Leading Indicator		-0.1047*				0.5631***	-0.2758***	-0.1042***				-0.1000***	
Export Growth	-0.1360***	-0.9966***	-0.6751***	1.5884***		-0.2692**	0.1923**	0.5179***	1.1469**	0.2323*	0.4974**	-0.2170***	
Import Growth	-0.0783***	0.9827***				0.1724***		-1.0089**	0.4602**			0.1016**	
Gold&Foreign Reserves	0.0966**					0.2893**	-0.1509***	-0.5357**	-0.2692*	0.7883**	-5.0050***	0.2390***	
<i>Financial variables</i>													
Stock market			-0.4932***					-0.3412***	-0.4945*	-0.3036**		0.5001**	-0.5848***
Bond market						-0.8942***	0.4082*				1.0565***		
Interest Rates		1.0021***	-0.6683***	-0.2628***							-0.2174**		
Interbank 3M Rates		-0.9674*	-0.8399***	-0.2483***					0.9754***		-0.2075**		0.9339**
T-bill 3M Rates		1.0026***		-0.2670***						7.0128**			
Exchange Rates		-0.1365**	-0.0531***		-0.1235***			-0.1364***				-0.1297***	
<i>EPU</i>		-0.1069***		-0.0382**			0.0095***	-0.0969***		0.0116***	-0.1009***		
<b>Panel B: China</b>													
<i>Macroeconomic variables</i>													
M1 Growth		-0.9797**	-0.7815***					5.0030**	-0.6633**	2.8881**	0.4993**	0.0482**	
M2 Growth		-1.0026***						5.0078***	4.4239**				
Inflation Rate	0.2282***		0.3384*	-0.3139**		-0.2140**		-0.1072**	0.3529***				
Unemployment Rate		0.1085***	0.5031***	1.1528***				0.1099**		-0.7097**			
Saving Ratio													
Capacity Utilisation													
Industrial Production													
Consumer Confidence			-0.3606**					-0.1051**				-0.1001***	
Composite Leading Indicator	-0.1041***		-0.3842***			-0.5557***	-0.2022*		-0.9907***			-0.1001***	-1.4815*
Export Growth		0.5091**	0.5005***	0.5141**		0.0990*						-0.0674**	
Import Growth			-0.4602***				-0.1579***	-0.1079*		0.6196***	0.5030***		
Gold&Foreign Reserves	0.1145***	5.0001***	0.1370***	0.2192**	1.0295***	0.5627***	0.1955***	0.4796***	0.4398***		1.0010***	0.9180***	
<i>Financial variables</i>													
Stock market returns		0.0955*	0.1510***			0.3050***		-1.0245***	0.3307***	-0.3608***		-0.0518*	
Bond market returns			-0.6495**			-1.0820***		0.1132***				-0.7091***	
Interest Rates			0.5539***					0.0884***	-0.4786**	1.4465**	0.1397*	-1.0604**	
Interbank 3M Rates													
T-bill 3M Rates													
Exchange Rates		-0.1039***	-0.0368***	-0.1413***								-0.1001***	
<i>EPU</i>	-0.0070**	-0.0979***	-0.0015**				0.0106***	-0.0979*	-0.0050***	-0.0113**			

Note: The table reports estimated results for parameters  $\theta$  of macroeconomic and financial variables of the U.S. and China over three sub-periods of GFC from GARCH(1,1)-MIDAS-X model. Three periods include Pre-crisis (Mar, 1998 to Aug, 2007); Crisis (Sep, 2007 to Dec, 2010), and Post-crisis (Jan, 2011 to Aug, 2018). The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise the field is left blank.

Table 5: Coefficients  $\gamma$  of economics variables of the U.S. and China over three sub-periods of global financial crisis of 2008

Pairs of Assets Periods	GoldF–SilverF			GoldF–PalladiumF			GoldF–PlatinumF			SilverF–PalladiumF			SilverF–PlatinumF			PalladiumF–PlatinumF		
	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.
<b>Panel A: U.S.</b>																		
<i>Macroeconomic variables</i>																		
M1 Growth	-0.5358	0.7505				1.7138		1.6702	1.1398		1.0211		1.1721	1.1312				1.2181
M2 Growth		-2.7528	-0.3771	-1.7955				-0.0953	1.1712				-0.8140		0.5250	-0.5866		0.8350
Inflation Rate					0.9332		-1.0377	-0.1336							0.2356			0.4387
Unemployment Rate																		
Saving Ratio											0.9640							
Capacity Utilisation		1.7927			1.5556	1.3446	-0.1372	1.4774	-0.0963		0.7210		0.3148		-0.2685	0.9914		0.0193
Industrial Production		0.4717			1.8865	1.4699		0.3422			0.8095		0.1577		0.6883			1.6340
Consumer Confidence				-0.5650		1.3006		1.9444		0.3107	1.7336							1.0868
Composite Leading Indicator		48.4845	1.4141	0.5378	0.9870			1.9899	0.4509		0.7966		-0.7738	0.3750		0.0386		
Export Growth			0.1252	0.3972	1.1659			0.4960	1.3114		0.4645			0.4336				3.2115
Import Growth	0.2478	5.6445	0.2018	0.7123	1.3338			0.6336	1.5653					0.6044		0.4464	1.5078	
Gold&Foreign Reserves			0.2192	1.0438				0.6474	-0.0931				1.3503			-0.2093		
<i>Financial variables</i>																		
Stock market																		
Bond market																		
Interest Rates		-12.446			1.0907	0.7091	-27.307				1.9066		3.5705			-0.1527	0.1988	-0.1480
Interbank 3M Rates		0.4258			1.8672		-0.2132	0.0470		-0.3100			-0.1865			-2.8012		-0.1279
T-bill 3M Rates	7.9615	1.6404			-9.2773	0.8577	-23.022	1.3426		-0.3578			-0.2084	0.3164		0.0860	1.2322	
Exchange Rates			-0.2061	-1.1922	0.5773		-0.9044	1.9272				-0.0640				-0.7224		
<i>EPU</i>	-0.6191		0.0912	-0.2343							0.6190	-0.0055			-0.0063	-0.1557	-0.9037	-0.1054
<b>Panel B: China</b>																		
<i>Macroeconomic variables</i>																		
M1 Growth					0.6738	-0.0987		0.7189	-0.0860								1.2647	-0.1537
M2 Growth	-2.6774		-1.2394			1.4732				0.2851			0.3078				-0.3109	0.2315
Inflation Rate				0.2654				0.2592					0.2215			0.1844		
Unemployment Rate				0.7609				0.6690										
Saving Ratio																		
Capacity Utilisation																		
Industrial Production																		
Consumer Confidence				0.6557	-1.4576			-1.5888					-0.4440	-0.1048	-0.2537			
Composite Leading Indicator	0.9995	1.1891		1.0021			1.9121		1.0008	0.6243			-0.0879	0.6952			0.6286	
Export Growth											1.0538		0.4659			0.3466		0.3883
Import Growth			0.1003	-0.1685	0.8596		-0.1730								-0.1466	-2.7245		
Gold&Foreign Reserves		1.7590	-0.3707		0.6474		1.5735	0.7948						1.6200				
<i>Financial variables</i>																		
Stock market																		
Bond market																		
Interest Rates		1.2630					-0.5088	0.8928	0.0376							0.0329	1.0091	-0.1691
Interbank 3M Rates					0.3312		0.9830			0.9922						-1.1517		0.9544
T-bill 3M Rates																		
Exchange Rates			-0.2724	-0.3934	1.4551		-0.0223			-0.2085			-1.5215					
<i>EPU</i>	-0.0642	-0.8463								-0.0358			-0.1518	-0.1042			-1.8683	-0.0614

Note: The table reports estimated results for parameters  $\gamma$  of macroeconomic and financial variables of the U.S. and China over three sub-periods of GFC from DCC-MIDAS-X model. Three periods include Pre-crisis (Mar, 1998 to Aug, 2007); Crisis (Sep, 2007 to Dec, 2010), and Post-crisis (Jan, 2011 to Aug, 2018). The value is given if the parameter  $\gamma$  is statistically significant, i.e. the critical values at significance level is 10%. Otherwise the field is left blank.

of  $\theta$  and  $\gamma$ ). In addition, the opposite trend can be seen between the signs of significant coefficients  $\theta$  and  $\gamma$  of several drivers in China during the crisis and after the crisis. More specifically, some economic drivers of China make pair-correlations turn from positive to  
325 negative (e.g., M1 on the GoldF-PlatinumF and GoldF-PalladiumF) or the reverse (e.g., M2 on PlatinumF-PalladiumF). These findings align with the conclusion of [Agyei-Ampomah et al. \(2014\)](#), who find that the superior role of precious metals is to protect investors' wealth against shocks in the U.S. financial market. One possible explanation is that the precious metals demand increases in emerging countries like China, which have not been strongly affected  
330 by the financial crisis or before. Additionally, this evidence denotes the growing influence of China on the global financial market in general and the precious metals market in particular after the financial crisis of 2008.

With respect to the case of the U.S., the signs of the coefficients  $\theta$  and  $\gamma$  of the macro-finance factors of this country show the most significant change between the pre-crisis and  
335 crisis periods compared to other periods. In detail, several drivers of the U.S. turn from negative to positive (i.e., signs of  $\theta$  of the Export, Gold & Foreign Reserves growth or Stock on the long-term volatility of GoldF and PalladiumF and signs of  $\gamma$  of M1 on GoldF-SilverF, Exchange Rates on GoldF-PlatinumF and GoldF-PalladiumF, T-Bill 3M on GoldF-PlatinumF, Interest rate on PalladiumF-PlatinumF). This confirms the significant impact on the U.S.  
340 economy during the GFC of 2008.

Finally, the long-term volatility of Silver futures and long-term correlations of Silver and other metals are the least responsive to any changes of economic variables during the crisis period (i.e., only the Capacity Utilization and Exchange rate of the U.S. and Gold & Foreign Reserves growth of China influence the volatility of Silver futures 1 month and only M1 growth  
345 of the U.S. impact on the correlation of the Silver-Palladium futures pair) in comparison with non-crisis periods. Meanwhile, the volatility of Palladium futures is the most strongly influenced by the GFC. A similar tendency can be found in Platinum volatility under the impact of the economics drivers of China (in the case of M2, Inflation, Stock and Interest

rate), apart from Gold and Silver futures volatility.

#### 350 4.2.3. Extensive Estimation Results for other G7 and BRICS countries

In this section, we extend our analysis to other G7<sup>10</sup> and BRICS<sup>11</sup> countries, which are top-ranked in precious metals exchanges. Tables 8 to 12 in the Appendix present the estimates of statistically significant  $\theta$  and  $\gamma$  signs for each of the macroeconomic and financial variables of the 10 countries in the full sample from 1998 to 2018.

355 We first focus on the macroeconomic factors in other G7 and BRICS countries. Tables 8 and 9 indicate that neither the export nor the import growth of G7 and BRICS countries affect the correlations between metals to a large extent, despite acting as important drivers of the volatility of precious metals. Here, we find that the influence of the export growth of almost all G7 and BRICS nations on long-term volatility is negative or positive, respectively.  
360 More precious metals are affected by the export of BRICS than that of G7 countries. The export growth of Russia, is considered the strongest determinant of the long-term volatility of all precious metals in both spot and future returns, followed by the export growth of South Africa, the United Kingdom, and France. With respect to the impact of import growth on precious metals volatility, we find the strongest positive effect from India and South Africa.  
365 For G7 countries, we observe a varying impact of countries' import growth on volatility with mostly negative effects.

The Gold & Foreign Reserves Growth of G7 and BRICS appear to be important drivers for long-term volatility, but not applicable for long-term correlations. In particular, Table 8 illustrate that the Gold & Foreign Reserves Growth of BRICS have considerably more impact  
370 on the volatility of precious metal markets than G7's Gold & Foreign Reserves Growth. This finding is in accordance with the fact that approximately two-thirds of global Gold and foreign currency reserves are held by emerging and developing economies.<sup>12</sup> Additionally, the positive

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<sup>10</sup>United Kingdom, Canada, Japan, Germany, France and Italy

<sup>11</sup>Brazil, Russia, India and South Africa

<sup>12</sup>[https://www.ecb.europa.eu/pub/economic-bulletin/articles/2019/html/ecb.ebart201907\\_01~c2ae75e217.en.html](https://www.ecb.europa.eu/pub/economic-bulletin/articles/2019/html/ecb.ebart201907_01~c2ae75e217.en.html)

figures for most of the statistically significant coefficients of this variable reveal that the rise in Gold and foreign currency reserves of countries, especially BRICS, may contribute to the increase in the volatility of the global precious metals market.

Tables 8 and 9 also show that the impacts of the Composite Leading Indicator (CLI), Consumer Confidence (CC), and Industrial Production (IP) of both G7 and BRICS on volatility are negative, but CLI and CC increase correlation between precious metals. CLI represents the future expectation of the business cycle, therefore, the results mean that an increase in the future expectations of real economic activity leads to a decrease in volatility and an increase in correlation. Moreover, the CLI of the United Kingdom and India appears to be more important than the CLI of other countries. The results also suggest that the impacts of CC and the IP of G7 countries on both volatility and correlation are much stronger than that in BRICS countries. Apart from the positive impact of Russia and Brazil's CC on the long-term volatility of Gold, the negative signs of all  $\theta$  and  $\gamma$  coefficients of CC can be observed. This implies that the increase in consumer confidence along with the decrease in the volatility and correlation between precious metals returns may raise diversification benefits among them.

Regarding the variables of the monetary environment (i.e. M1, M2, INF), the results of Table 10 reveal that these variables have a stronger influence on the long-term correlation between precious metals than on their volatility. In addition, the empirical results illustrate that the impact of the monetary supply growth is much more influential on Gold volatility than on any other precious metals, which is reasonable since Gold is still regarded as surrogate money. Moreover, according to the money supply, the positive sign of  $\theta$  of M2 and the negative one of its  $\gamma$  in almost all cases indicate that precious metal prices are more volatile and more closely linked during the recession period (i.e., because an increase in M2 reflects the recession of the economy). Although Gold and Silver are known as a hedge for inflation (Ghosh et al., 2004), our results show that higher inflation rates in both G7 and BRICS countries explain the rise in the volatility of all four precious metals (except for Japan). Meanwhile, we find



400 that G7 (BRICS) inflation rates have a negative (positive) association with correlation.

In terms of financial variables, the results from Table 11 show the influence of equity market returns on both precious metals volatility and correlation is larger than any other financial variables. Notably, the volatility of all the precious metals are negatively linked to the stock market returns of both G7 and BRICS countries, while the correlations among these  
405 metals respond positively to equity market returns.<sup>13</sup> In addition, a mainly positive impact from the government bond returns of the G7 and BRICS countries on volatility as well as on correlation among precious metal markets can be found. With respect to interest rates, we can see clearly that while there are varying effects across countries on volatility, the impact on long-term correlations is consistently negative. This could be an illustration of the decline  
410 in correlations between precious metals during periods of high interest rates. In regard to the impact of the exchange rate, our major finding is a significant but negative effect of the exchange rate of each country on precious metals volatility, while there is a minor impact on correlation.

Finally, Table 12 shows the influence of the EPU growth of each country in our sample  
415 on the long-term volatility and correlation of precious metals markets. Our analysis reveals that the EPU growth of G7 and BRICS cannot explain the dynamic correlations. In contrast, EPU growth is associated with the volatility of precious metals. Except for the negative impact of the EPU growth of Japan on the volatility of Gold, the EPUs of all other countries increase the volatility of precious metals. This result is in line with the findings of Fang et al.  
420 (2018b) and Nguyen and Walther (2020) who point out that EPU has a positive effect on the long-run volatility of precious metals. Notably, the EPU growth of G7 countries seem to have a stronger effect on volatility than the EPU growth of BRICS. This finding strongly confirms the leading role of the G7 group in shaping the stability of the global financial market in general and the precious metals market in particular.

425 In regard to the long-term correlations' reaction to the EPUs of two groups, we can observe

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<sup>13</sup>This finding is in line with Arouri et al. (2015) and Mishra et al. (2010).

that while the positive response of Gold-Platinum, Gold-Palladium, and Silver-Palladium to the change of the EPU of Russia can be seen, other pairs are all negatively related to EPUs with significant coefficients. This means an increase in EPU growth would lead to a decrease in the long-run correlations between precious metals markets. Hence, we find a decoupling of  
430 precious metal markets in times of higher economic uncertainty.

## 5. Conclusion

Our study contributes to the current literature by investigating the impact of macroeconomic and financial drivers on the long-term volatility and correlation of precious metals markets over the last 20 years. Using GARCH-MIDAS-X and DCC-MIDAS-X, we find that the  
435 stock market returns of G7 and BRICS countries play the most important role in determining both the long-term volatility and correlations among precious metals. In particular, stock market returns leave a negative impact on the long-term volatility of four precious metals while having a positive effect on the long-run correlation of these metals. Besides stock market returns, other variables including M1, M2, inflation rate, and the short-term interest rate of  
440 considered countries are also helpful predictors of both volatility and correlations, albeit with mixed effects.

Additionally, economic drivers cause a stronger effect on the volatility than on the correlation. To be more specific, the EPU growth of G7 countries has a significantly positive influence on the volatility of precious metals; however, no effect caused by this driver can be  
445 seen on the long-term correlations between precious metals to a similar extent. Therefore, in periods of policy instability, it is recommended that investors invest into these metals to reduce risks. Similarly, the volatility of precious metals is closely linked to the growth of import, export, Gold & foreign reserves, and exchange rates, but there is no such association in the case of correlations between precious metals.

We find considerable differences in the impact of drivers between G7 and BRICS, especially  
450 in terms of consumer confidence. In detail, consumer confidence in G7 countries makes the

volatility of precious metals follow a negative direction, but drives the pairwise correlation in a positive way. On the contrary, consumer confidence in BRICS countries has almost no effect on either volatility or correlation. As a result, the more consumer confidence is improved  
455 in G7 countries, the better the portfolio hedging benefits that precious metals would offer. Similarly, this trend can be investigated in the influence of industrial production on both volatility and correlation, bond return on volatility, or short-term interest rate on correlation.

Notably, our study also shows that the 2008 GFC plays a key role in the change of the impact of determinants on precious metals markets as the signs of many determinants are  
460 reversed over the course of this crisis. Palladium is the most strongly influenced by the GFC while Silver is the least responsive to this crisis.

Finally, we find that the return volatility of Gold markets and the correlation between Gold and Silver have the closest relationship to the changes in the economic drivers of both the G7 and BRICS countries.

465 With the above analysis, our findings may help both investors and portfolio managers to make optimal and timely choices based on forecasting the changes in financial markets as well as macroeconomic activity. In addition, predicting the future development of low-frequency real economic variables also helps policymakers to formulate appropriate and early policy responses to prevent possible recessions.

## 470 **Acknowledgement**

The first author acknowledges the financial support from the National Economics University, Hanoi, Vietnam.

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## Appendix

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<sup>15</sup><https://corporatefinanceinstitute.com/resources/knowledge/finance/what-is-corporation-overview/>

Table 6: Parameter estimation results of GARCH, GJR, GARCH-MIDAS-RV and GJR-MIDAS-RV

Asset	Model	$\mu$	$\alpha$	$\beta$	$m$	LL	BIC
Gold	GARCH	0.0158	0.0508***	0.9366***	0.1970	-6624.20	13282.13
	GJR	0.0249*	0.0678***	0.9392***	0.2277	-6612.13	13266.40
	GARCH-MIDAS-RV	0.0201	0.0288***	0.9664***	0.1212	<b>-5576.00</b>	<i>11209.67</i>
	GJR-MIDAS-RV	0.0280*	0.0405**	0.9604***	0.0376	-5909.39	11263.80
Silver	GARCH	0.0034	0.0408***	0.9531***	1.1818***	-8973.04	17979.80
	GJR	0.0130	0.0552***	0.9510***	1.2803***	-8966.31	17974.76
	GARCH-MIDAS-RV	0.3387***	0.0899***	0.9101***	-0.0440***	<b>-8565.24</b>	<i>17188.16</i>
	GJR-MIDAS-RV	0.0322	0.0864***	0.8613***	0.6445***	-8669.08	17208.46
Platinum	GARCH	0.0153	0.0718***	0.9101***	0.7567***	-7811.90	15657.51
	GJR	0.0221	0.0843***	0.9092***	0.7828***	-7809.45	15661.06
	GARCH-MIDAS-RV	0.0143	0.0946***	0.8457***	0.1896*	-6315.86	<i>12689.40</i>
	GJR-MIDAS-RV	0.0158	0.0982***	0.8500***	0.1981*	<b>-6315.69</b>	12697.29
Palladium	GARCH	0.0764***	0.0778***	0.9100***	1.6448***	-9565.36	19164.44
	GJR	0.0740***	0.0757***	0.9095***	1.6384***	-9565.23	19172.62
	GARCH-MIDAS-RV	0.0601***	0.0279***	0.9155***	1.2577***	<b>-8084.97</b>	<i>16227.63</i>
	GJR-MIDAS-RV	0.0465*	0.0703***	0.9183***	1.2206*	-8384.70	16822.96
GoldF	GARCH	0.0199	0.0456***	0.9407***	0.2060	-6720.80	13475.34
	GJR	0.0258*	0.0571***	0.9410***	0.2307	-6716.34	13474.83
	GARCH-MIDAS-RV	0.0260*	0.0406***	0.9459***	0.3078*	<b>-5664.93</b>	<i>11387.54</i>
	GJR-MIDAS-RV	0.0278*	0.0392***	0.9605***	0.3870*	6011.17	12072.15
SilverF	GARCH	0.0114	0.0385***	0.9540***	1.2137***	-9149.26	18332.24
	GJR	0.0198	0.0506***	0.9529***	1.2944***	-9143.54	18329.23
	GARCH-MIDAS-RV	0.0387*	0.0727***	0.8404***	0.7658***	<b>-7782.28</b>	<i>15622.23</i>
	GJR-MIDAS-RV	0.0375*	0.0802***	0.8713***	0.7274***	-8207.01	16487.18
PlatinumF	GARCH	0.0183	0.0589***	0.9262***	0.7318***	-7887.02	15807.76
	GJR	0.0225	0.0660***	0.9254***	0.7519***	-7883.11	15804.38
	GARCH-MIDAS-RV	0.0151	0.0569***	0.9237***	0.4255***	-6447.86	<i>12953.41</i>
	GJR-MIDAS-RV	0.0159	0.0585***	0.9237***	0.4310**	<b>-6447.82</b>	12961.56
PalladiumF	GARCH	0.0759***	0.0778***	0.9060***	1.6166***	-9634.40	19302.53
	GJR	0.0774***	0.0791***	0.9061***	1.6193***	-9634.36	19310.87
	GARCH-MIDAS-RV	0.0692**	0.0759***	0.8892***	0.9678***	<b>-7816.59</b>	<i>15690.86</i>
	GJR-MIDAS-RV	0.0788**	0.0798***	0.9070***	0.1064*	-8464.81	16918.54

Note: This table presents the estimates of GARCH(1,1), GJR(1,1,1), GARCH(1,1)-MIDAS-RV and GJR(1,1,1)-MIDAS-RV general coefficients, respectively for both spot returns and future 1 month returns of four precious metals. The full sample covers the period from 1998 to 2018. The symbols \*\*\*, \*\*, and \* denote statistical significance at the levels of 1%, 5% and 10%, respectively. LL is the Log-Likelihood and BIC is the Bayesian Information Criterion. Numbers in italic and bold show the model with the best goodness-of-fit (i.e. lowest BIC) and best statistical fit (i.e. highest LL), respectively.



Table 7: List of macro-finance variables

Variable name	Acronym	Description	Data sources
<b>Macroeconomic variables</b>			
Export Growth	EX	The % annual growth rate of exports of goods and services, is used to assess the progress of an economy because exports boost economic output	Thomson Reuters Datastream
Import Growth	IM	The % annual growth rate of imports of goods and services. Imports make a country dependent on other countries' political and economic power	Thomson Reuters Datastream
Capacity Utilisation	CU	Measure the manufacturing and production capabilities that are being utilized by a nation at any given time. It is a useful indicator of the strength of demand <sup>14</sup>	Thomson Reuters Datastream
Gold&Foreign Reserves	GFR	The % annual growth rate of total reserve of Gold and U.S dollars.	Thomson Reuters Datastream
Consumer Confidence	CC	Measure the degree of optimism that consumers fell about the state of the economy. Its increase may signal a strong consumer demand and, thus, a growing economy	OECD
Industrial Production	IP	Measure the real output of the industrial sector. It covers~manufacturing, mining, electric and gas industries, relative to a base year	OECD
Composite Leading Indicator	CLI	Provide early signals of turning points in business cycles	OECD
M1 Growth	M1	The % annual growth rate of the narrow measure of the money supply that includes physical currency, demand deposits, traveler's checks, and other checkable deposits.	Thomson Reuters Datastream
M2 Growth	M2	The % annual growth rate of a broader measure of the money supply than M1 (includes cash and checking deposits). This variable reflects future inflation.	Thomson Reuters Datastream
Inflation Rate	INF	Computed as the percentage change of consumer price index for all urban consumers of all items. This price variable is related to consumers consumption decisions and their real wealth.	Thomson Reuters Datastream
Unemployment Rate	UNP	Calculated as the ratio of the employed to the working age population. Employment rates are sensitive to the economic cycle.	Thomson Reuters Datastream
<b>Financial variables</b>			
Stock Market Return	Stock	Calculated from national stock market indices including S&P500 of US, FTSE 100 of UK, S&P/TSX Composite Index of Canada, NIKKEI 225 of Japan, CAC 40 of France, DAX of Germany and FTSE MIB of Italy.	Thomson Reuters Datastream
Bond Market Return	Bond	Calculated from 10-year government bond indices of each country in sample	Thomson Reuters Datastream
Short-term Interest Rate	IR	Interest rate charged on a short-term borrowings which are effected between financial institutions or the rate at which short-term government paper is issued or traded in the market. Short-term interest rates are generally averages of daily rates, measured as a percentage	Thomson Reuters Datastream
Real Effective Exchange Rate	ExR	The weighted average of a country's currency in relation to an index or basket of other major currencies. The weights are determined by comparing the relative trade balance of a country's currency against each country within the index <sup>15</sup>	Thomson Reuters Datastream
<b>Economic Policy Uncertainty</b>	EPU	Measure the contribution of government policy makers to the uncertainty regarding fiscal, regulatory, or monetary policy	<a href="https://www.policyuncertainty.com">https://www.policyuncertainty.com</a>

Table 8: Impact of macroeconomic variables of G7 and BRICS countries on the long-term volatility of precious metals

	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
<b>Export Growth</b>												
Gold	0.4668*		-0.0238**			-0.1464**			0.0988*	0.2046**	0.2379***	0.1153*
GoldF	-0.0548*					-0.1686**		-0.0619*	0.0967*	0.2211**	0.2070***	0.0088*
Silver		0.2218**		0.6540*		-0.1875***	0.7427*	0.4429*	0.4318**		0.4766*	
SilverF		0.7227**		0.6710*		-0.1915***		0.4986*	0.3138***	0.2350**	0.5682*	-0.4694*
Platinum		0.0512**	0.1530***	-0.2883***	-0.0148**		0.1569***		-0.1215**	0.0503*	0.0495**	0.1942***
PlatinumF	-0.0855***		0.1375***				0.1181**		-0.4809***	0.0394**		0.1394*
Palladium	-0.1011**	0.2425*	-0.0267***	-0.0249*		-0.0353***	-0.0951**		0.0966*			
PalladiumF		0.1723*									0.0199***	
<b>Import Growth</b>												
Gold	0.4283*			-0.0451**		0.2374**	0.1628*	0.2263**		0.2487***		0.2317**
GoldF			-0.0155*	-0.1244**						0.2509***		0.2108***
Silver	0.7013*	0.3077*	-0.0885*	-0.1210**					0.2860*		0.6376***	
SilverF	0.8101*								0.4051**	0.2858***	0.6859***	0.1119**
Platinum	-0.2011**		0.1440***	-0.2539***	-0.0129**	-0.3025**	0.0057*	0.0746*				
PlatinumF			0.1246***			0.1181**		-0.0738**		0.0969*		0.1848**
Palladium		0.2907***	-0.0280***	-0.2991**		-0.0951*						
PalladiumF		-0.0290*					-0.0266**	-0.0385***	0.0207***	0.2154*		-0.1538**
<b>Gold &amp; Foreign Reserves</b>												
Gold	0.1813*	-0.0386***	0.5165**		-0.0597***		-0.0474***	0.0517**	0.3566*	0.0650*	0.1892*	0.2964***
GoldF	0.1813**		0.5073**		-0.0517***	0.0459***	-0.0432***	0.2797***		0.0616*	0.0638**	0.1077*
Silver	0.4138**		-0.1015**					0.3342***		0.1094***		0.0583*
SilverF	0.5142**					0.2188**	-0.0490***	0.2017**		0.0897***	0.0897***	0.1913***
Platinum			0.3667**	0.0884**	0.1279*		0.2039***	0.2061**		0.0345*	0.9346*	0.0870*
PlatinumF				-0.1378***	0.1051*		0.1912*		0.0358**			-0.2977**
Palladium	0.3077**			0.1588*	0.3145***		0.3316***	0.1375*		-0.0714**	-0.0714**	0.0471***
PalladiumF	0.2495**						0.3517***	0.1873**				
<b>Consumer Confidence</b>												
Gold	-0.2731***	-0.2215**	-0.0484**	-0.2031**	-0.1289*		-0.2100**	0.2109**	0.1350***	-0.1373**		
GoldF		-0.2358***	-0.0391**	-0.1949*		-0.3923**		0.2128**	0.1256***	-0.1310**		
Silver	-0.2762***	-0.2919***	-0.0949**		-0.3519**							
SilverF	-0.3054***		-0.0774*	-0.2493**	-0.4052**		-0.3284**			-0.2869***		
Platinum	-0.1691**	-0.1905**	-0.0578***	-0.2653***					-0.0820**	-0.2292***		
PlatinumF	-0.1754**	-0.1819**		-0.1911**								
Palladium		-0.1856**	-0.0574***	-0.4122***	-0.2452***	-0.2733**		-0.1007*				
PalladiumF	-0.2157***	-0.1736**	-0.0481***		-0.2209***							
<b>Composite Leading Indicator</b>												
Gold		-0.1425**						0.2373*				-0.1848*
GoldF		-0.1974**										-0.2100*
Silver		-0.1376*		-0.3088*					-0.1095*	-0.3397**	-0.1976***	
SilverF		-0.1466*	-0.2366*	-0.3250*	-0.2202**			-0.0348**		-0.3629**	-0.2054***	
Platinum		-0.2342***		-0.2762**		0.2393*					-0.1848**	
PlatinumF		-0.2243***								-0.2004***	-0.1635*	
Palladium	-0.1611*	-0.2623***	-0.2776**							0.2145*	-0.2376***	-0.2464***
PalladiumF		-0.2431***	-0.2474***		-0.1448*					0.2485*	-0.1906***	
<b>Industrial Production</b>												
Gold	-0.0494**		-0.0595**		-0.0326***		0.0187*					-0.0336*
GoldF	-0.0411**		-0.0607**		0.0262*							-0.0277**
Silver		-0.1975***	-0.0918**	-0.0579**			-0.0969***	-0.0635*				
SilverF	-0.1195**	-0.2074***	-0.1004*	-0.0652**			-0.1011***	-0.0709***				
Platinum												
PlatinumF				0.0626*								
Palladium	-0.0728***		-0.0478*		-0.0352**		0.0184***					
PalladiumF	-0.0645***		-0.0365**									

Note: Estimation results  $\theta$  of Trade Balance Growth, Gold and Foreign Reserves Rate, Consumer Confidence, Composite Leading Indicator and Industrial Production of other G7 and BRICS nations from GARCH(1,1)-MIDAS-X. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise, the field is left blank. The results of the U.S. and China in gray format are for reference.

Table 9: Impact of macroeconomic variables of G7 and BRICS countries on the long-term correlations between precious metals

Countries	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
<b>Export Growth</b>												
Gold-Silver	-0.1739*	-0.1351*		-0.1694*				-0.1004**		-1.3839*		-0.1201*
Gold-Platinum		-0.0208**						1.5306***				-0.3845***
Gold-Palladium	0.1772***											
Silver-Platinum								0.7893***			-0.1161**	-0.3358***
Silver-Palladium	0.1812**											
Platinum-Palladium											1.0045***	
GoldF-SilverF	-0.1923*			-0.1654*		-0.2870*	-0.2735*	-0.1136**				-0.0940*
PlatinumF-PalladiumF			-1.5145***			0.3484*	-0.8478*					
<b>Import Growth</b>												
Gold-Silver	-0.1969**		1.0339***	-0.1149**				-0.2362***			-1.0317***	0.6697***
Gold-Platinum								-0.2562***				-0.2654***
Gold-Palladium										-1.4910***		
Silver-Platinum								-0.2661***		-1.4740***		-0.2202***
Silver-Palladium								-0.2105*		-0.0190***		
Platinum-Palladium												
GoldF-SilverF	-0.2198**					-0.2735*			1.5273***		-0.1927**	
PlatinumF-PalladiumF						-0.8478*						
<b>Gold &amp; Foreign Reserves</b>												
Gold-Silver					-1.4564*	-0.0554***			-0.0783***	-0.1214**	-0.0254**	
Gold-Platinum			-0.1751**	-0.2371***						-0.5718***	-0.2788***	-1.0827***
Gold-Palladium								0.3947***				
Silver-Platinum				-0.4336**								
Silver-Palladium				1.6086***				1.9438***				
Platinum-Palladium	0.1599*		1.0297*							1.0314***	0.5301***	
GoldF-SilverF				-0.1952***		-0.0545***		0.8992***		0.9938***	0.2998***	-0.0574***
PlatinumF-PalladiumF								1.0287***		-0.6687***	-0.2644***	
<b>Consumer Confidence</b>												
Gold-Silver	1.5113**			0.9181*								
Gold-Platinum	1.9844***			1.3277**								
Gold-Palladium	1.7165**				1.2177*							
Silver-Platinum	1.4700*				0.8710*							
Silver-Palladium	1.7635*											
Platinum-Palladium	2.7214**		0.2822**		1.7999***							
GoldF-SilverF	1.6091***			0.9118*		2.1157***	1.0325**				0.3571**	
PlatinumF-PalladiumF			0.5039*									
<b>Composite Leading Indicator</b>												
Gold-Silver		-1.7928*			-1.0897*		-1.6025*					
Gold-Platinum	1.5281*	1.9337*	0.6183**								1.7337*	1.2760*
Gold-Palladium												
Silver-Platinum												
Silver-Palladium												
Platinum-Palladium		1.2289**		1.4314*	1.0245*				0.5204*		1.2851*	
GoldF-SilverF			-1.1972***					0.6066***				
PlatinumF-PalladiumF												
<b>Industrial Production</b>												
Gold-Silver		-0.3194*		-0.1963**	-0.2301	-0.3334*	-0.2532					
Gold-Platinum	0.3386**											
Gold-Palladium				0.4761*						-1.0032***		
Silver-Platinum												
Silver-Palladium												
Platinum-Palladium		-1.3522***				-1.7507**						
GoldF-SilverF		-0.3170		-0.1946*		-0.2302*	-0.2680*					
PlatinumF-PalladiumF							-1.4254***					

Note: Estimation results  $\gamma$  of Export Growth, Import Growth, Gold and Foreign Reserves, Consumer Confidence, Composite Leading Indicator and Industrial Production of other G7 and BRICS nations from DCC-MIDAS-X. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise, the field is left blank. The results of the U.S. and China in gray format are for reference.

Table 10: Impact of macroeconomic variables of G7 and BRICS countries on the long-term volatility and correlations of precious metals

	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
<b>Panel A: Long-term volatility</b>												
<b>M1 Growth</b>												
Gold				-0.1222***		-0.5119***	-0.6396**	-0.0350*	0.1423**	0.6701**		0.8812*
GoldF	-0.1345**		-0.4013*	-0.1188*	0.0886***	-0.4449*	-0.7019***				0.3164*	
Silver	-0.9366**			-1.2088***	-0.4155**	-0.2401*			-0.0938**	1.1034***		0.3100*
SilverF	-0.8870**									0.8483***	-0.0730**	0.4788**
Platinum		-0.5808*	0.7389*	0.2325*				0.2790**				0.4741**
PlatinumF	0.1692*	0.1934***	0.2451***	-0.2535*				0.2606*			0.3275***	0.3843*
Palladium		0.1849**	-0.1676**	-0.0616**			0.1092***		0.0842*	0.3241*		0.2911**
PalladiumF										0.3883*	0.1788***	0.3065*
<b>M2 Growth</b>												
Gold	0.4923**	1.4255*		-1.4092***		-1.3128**	0.4357*	0.2004***				0.7124**
GoldF	0.6750*	1.1178*	1.0012**	-3.7169**	0.6718**	-1.1919*		0.2066***			0.6364**	0.5385**
Silver	0.2682**		0.7192***		1.7430*	-1.1935**	-0.1394*	0.8198**		1.0820***		
SilverF	0.3155**		0.4262*	0.2505*				0.3845***			0.7887**	
Platinum	1.2215***		1.1187***	1.5943**	1.5663***	1.5550**	-0.4514**					
PlatinumF					1.5598***	1.5424**		0.5624***				
Palladium	0.2331*	-0.5053***	0.9162*			-0.1733**		0.5905**	-0.0490**	0.3156*	3.7941***	0.0554*
PalladiumF		0.9777**	1.0379**					0.6782***		0.3685*		-0.3157*
<b>Unemployment Rate</b>												
Gold	0.0974*	0.1633***		0.2210**	0.1659***	-0.2351**	-0.1442***		0.1460**		1.2893**	
GoldF	0.0858**	0.1811***	-0.1309**		0.1482**	-0.2085**	-0.1356***		0.1288*		1.6245***	-0.1830**
Silver				-1.2091**	-0.6962***	-0.8011*	-0.4145*	-0.3236**	-0.6840*	-2.1264**	2.1366***	
SilverF				-1.2157***	-0.6186***		-0.5021**	-0.3374***			2.1216**	-0.2324**
Platinum						0.2941**				-0.5543**		-0.1378**
PlatinumF						-0.2940*			0.1145*	-1.0268*		-0.1085*
Palladium	0.1374*			0.3907**				0.0794*	0.1238*		2.5641***	0.1327*
PalladiumF	-0.1251*			0.2704*		-0.3595***			0.2653***		2.2086**	
<b>Inflation Rate</b>												
Gold	0.4079*	0.2742**	0.1817**	-0.1739**		0.2342*	0.2128*	0.0629**	0.0518***	0.0744***	0.1505***	
GoldF	0.2641*	0.2641*						0.0581**	0.0465**	0.0813***		-0.0870*
Silver		0.1861***			0.4219**			-0.1352***	-0.0366***		0.2840**	-0.0975**
SilverF									-0.1172**	0.1378*	0.1989**	
Platinum			0.3644***			-0.2551**			-0.0716**			0.1122***
PlatinumF									-0.0341**			
Palladium	0.0989*					0.2626*	0.2062**	0.1277***	0.0709**			0.0727**
PalladiumF	0.1749*		0.5444*	-0.1426***		0.2600*			0.0669**			
<b>Panel B: Long-term correlations</b>												
<b>M1 Growth</b>												
Gold-Silver	0.3568**				0.2647***		-0.3399*		-0.1640***			
Gold-Platinum	0.6277***	-0.6311**			1.0452***			-0.4540***	-0.2377***		-1.0963**	-0.6187*
Gold-Palladium				-0.3368***								
Silver-Platinum	0.5191***	-0.5603**			0.8958***	1.4759**		-0.3759**	-0.2134***			-2.2312**
Silver-Palladium										0.8599***		
Platinum-Palladium	0.4717**		1.1272**	-0.4952***	0.7579***		-0.5357*					
GoldF-SilverF	0.6579**	-0.4341*							0.9985***			
PlatinumF-PalladiumF					1.3945**					0.9528*	-1.7688***	
<b>M2 Growth</b>												
Gold-Silver	0.9507*	-1.0383***	0.5668*		1.0401***				-0.1565***		-1.1396***	
Gold-Platinum		-1.1931***	0.3490*	1.1883**			-0.6773**		-0.2290***		-1.1596***	1.0262***
Gold-Palladium	-1.1347*							0.3156*				
Silver-Platinum		-1.0857***		1.9932*	0.9188*	-0.7040*			-0.2116***		-0.1537***	-0.4269***
Silver-Palladium												
Platinum-Palladium	-0.6549***	-0.9149**	1.1455**	1.7706*		-0.6501*		-1.2196**				
GoldF-SilverF	1.9460*	-0.9547***	0.5307*		0.7638***						-1.3834***	
PlatinumF-PalladiumF	-2.0365***							0.5200**				
<b>Unemployment Rate</b>												
Gold-Silver						0.9212***		0.9011***				
Gold-Platinum		-0.7587***		1.2883***	0.9923***	0.9998***			-0.1398***			
Gold-Palladium				1.2967***								
Silver-Platinum								0.9980***		1.0033***	0.8990***	
Silver-Palladium	0.9423***											
Platinum-Palladium										1.2633***		
GoldF-SilverF			0.9970***			0.1299***	0.8321***			-0.4168*		
PlatinumF-PalladiumF												
<b>Inflation Rate</b>												
Gold-Silver	-0.1382**		-0.2470***					0.8183***		0.8990***	0.1387***	
Gold-Platinum	-1.2895***	-0.2777***		-1.3283*		-0.1957*	-0.1831**		0.9969***			
Gold-Palladium			1.5626***				0.6755***			0.0365*		
Silver-Platinum	-0.2543**	-0.2355**									0.1238**	
Silver-Palladium										0.7981***	0.1377***	
Platinum-Palladium												
GoldF-SilverF	-0.2769**		-0.2423***				-0.1305*	0.7169***		0.8990***		
PlatinumF-PalladiumF		0.6665***										

Note: Estimation results  $\theta$  and  $\gamma$  of Money Supply (M1, M2 Growth), Unemployment Rate, Inflation Rate of other G7 and BRICS nations from GARCH-MIDAS-X and DCC-MIDAS-X, respectively. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise the field is left blank. The results of the U.S. and China in gray format are for reference.

Table 11: Impact of financial variables of G7 and BRICS countries on long-term volatility and correlations of precious metals

	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
<b>Panel A: Long-term volatility</b>												
<b>Stock Market Returns</b>												
Gold	-0.0775**	0.0438***	-0.1332**		-0.0713***		-0.1213***	-0.0473*	-0.0691**	-0.0590*	-0.0230*	0.3294***
GoldF	-0.0652***	-0.1026***	-0.1294***		-0.0594***					0.0903**		0.2845**
Silver		-0.1070***	0.0979*		-0.0533**		-0.1016**	-0.0562***	-0.0347***	-0.0360***	0.2049*	
SilverF	-0.0569**	-0.1014***	-0.0945***		-0.0479**			-0.0569***	-0.0308***			
Platinum	-0.3542***	-0.0886***	-0.3749***	-0.2118***	-0.2170***	-0.2785***	-0.2678***			0.0260*	0.1382***	0.1283*
PlatinumF	-0.2593**		-0.3002***		-0.3504*						0.1567***	-0.2657***
Palladium	-0.6221***	-0.6200***		-0.2973***	-0.0333***	-0.4602***	-0.4310***	0.0322**	0.0286***	-0.0289*	-0.0953**	-0.1793**
PalladiumF	-0.5079***						-0.1129**		0.0923*			
<b>Bond Markets Returns</b>												
Gold		0.3220***	0.1562**	0.7560***	0.1720**	0.1914***	0.2654***					
GoldF		0.1593*			0.1375**	0.1456***	0.1517**					
Silver		0.2791***		0.5234**						0.2479**		-0.2818**
SilverF		-0.1737	-0.5924***									-0.5378*
Platinum				0.4937*							0.1692***	
PlatinumF											0.1469**	
Palladium		0.2585**			0.1531*						-0.3194***	0.3017***
PalladiumF	0.2028**		0.1747**		0.1591**	-0.4547**					-0.2726***	
<b>Interest Rate</b>												
Gold		0.0864**	0.1996**		0.2351***	0.1244**	0.2351***			0.1837**	0.5162***	
GoldF	0.1978*	0.0940*	0.1703*			0.1849**				0.1849**		
Silver				-2.5648**								
SilverF		-0.5317***		1.3974*			-0.6129***	1.3216**	1.1509***		-4.0609**	-0.3187**
Platinum				1.9709***							0.2120*	0.0952*
PlatinumF												0.0955***
Palladium	0.1691**		0.4122***	-1.6181**	0.2074***	0.2074**	0.2074**	0.7550*			-0.1630***	0.0850***
PalladiumF		0.0963*	0.3380***		0.1823***	0.1823**	0.1823***					
<b>Exchange Rate</b>												
Gold	-0.0313**	-0.0908***	0.0355***	0.0150***			0.0357**				-0.0252***	0.0332***
GoldF	-0.0304**	-0.0963***	0.0353***			0.0454***				-0.0462***	-0.0219***	0.0285***
Silver	-0.0492***	-0.1074***	-0.0291*	-0.0811***		-0.0536***	-0.0534***				-0.0201***	-0.0332**
SilverF	-0.0527***		-0.0383*	-0.0784***	-0.0696**	-0.0685***	-0.0685***		-0.0310**			0.0342***
Platinum								-0.0048*	-0.0322*			
PlatinumF				-0.0148*								
Palladium					0.0265*							-0.0197**
PalladiumF					0.0407**		0.0407**		-0.0256**			0.0302**
<b>Panel B: Long-term correlations</b>												
<b>Stock Market Returns</b>												
Gold-Silver	0.1486*			0.0508***	0.0440***	-1.9030***			-0.1074***			
Gold-Platinum	0.1774**	0.0906***				0.0539*	0.0648*		0.1270***	0.0371**		0.8430***
Gold-Palladium	0.0996***	0.1065***	0.1703*	0.6992*	0.0921***	0.0848***		0.0716***		0.0368***		
Silver-Palladium	0.0854**	0.0936**	0.0864***		0.0708*	0.0702**				0.0346***		
Silver-Platinum												
Platinum-Palladium	0.1019***		0.0831***		1.5640***				0.0012***		1.1359***	
GoldF-SilverF	0.0585***			0.0445***	0.0457***				-0.0898***	0.1215***		0.0726***
PlatinumF-PalladiumF	0.1584**	0.1786**			0.1261***	0.1240**				1.0985***	0.0833*	0.6562***
<b>Bond Market Returns</b>												
Gold-Silver			-0.1452***			-0.1249**	0.8990***					
Gold-Platinum	0.9956*			-0.3998*							0.9949***	0.9993***
Gold-Palladium												
Silver-Platinum		1.5151***	-0.1653***									
Silver-Palladium		1.4057***	0.7895***	-1.8601***								
Platinum-Palladium												
GoldF-SilverF			1.2006***	0.2446*						0.9981***		0.9998***
PlatinumF-PalladiumF	0.4587***											
<b>Interest Rate</b>												
Gold-Silver	-0.0745**		-0.0995**	-0.2773*	-0.7846***	-0.1119***	-0.1154***					0.8868***
Gold-Platinum	-0.1362***		0.8990***	-0.6451**			-0.1707***	-0.6857***				
Gold-Palladium	-0.1007*	0.5390***			-0.1357*							
Silver-Platinum	-0.5612***		-0.1472***			-0.1393***	-0.3212***					
Silver-Palladium	-0.1059**		0.3590***		-0.1417*		-0.5487*					
Platinum-Palladium	-0.2331***			-0.4514*								
GoldF-SilverF	-0.0612**		1.8169***	-0.2444*	-0.3406***	0.0237***	-0.0710***	-0.5578***				
PlatinumF-PalladiumF	0.2012***											
<b>Exchange Rate</b>												
Gold-Silver		-1.0225***			-0.2714*	-0.2714*	-0.2714*				-0.3862**	
Gold-Platinum												0.2615**
Gold-Palladium				0.1688*				0.2436***	0.3130*			
Silver-Platinum				0.1693*				0.2696**				
Silver-Palladium				0.1996**				0.2595**	-0.3870*			
Platinum-Palladium								0.1268**		0.4757*		
GoldF-SilverF	0.2544*	0.3824***								-0.3050**	0.3204*	
PlatinumF-PalladiumF												

Note: Estimation results  $\theta$  and  $\gamma$  of Stock Market Returns, Bond Market Returns, Interest Rate and Exchange Rate of G7 and BRICS nations from GARCH-MIDAS-X and DCC-MIDAS-X, respectively. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise, the field is left blank. The results of the U.S. and China in gray format are for reference.

Table 12: Impact of EPU growth of G7 and BRICS countries on the long-term volatility and correlations of precious metals

	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
<b>Panel A: Long-term volatility</b>												
Gold				-0.0939**		0.0297**						
GoldF				-0.0868**		0.0232**						
Silver			0.1668**									
SilverF												
Platinum	0.2242***	0.1154***		0.2585***	0.2035***		0.0295*	0.0505**			0.0489***	
PlatinumF			0.1783***	0.2575***	0.2146***				0.0622*			
Palladium					0.1341**		0.2026***					
PalladiumF	0.1415**	0.0912**	0.1702**	0.1458*	0.1361***		0.1656**					
<b>Panel B: Long-term correlations</b>												
Gold-Silver	-0.0138***		-0.0286**	-0.0344***	-0.0229*	-0.0230***						
Gold-Platinum								0.6119**				
Gold-Palladium					-0.0279**	0.7576***		0.9982**				
Silver-Platinum									-0.3046***			
Silver-Palladium				-0.0552**			0.0912**	0.9982***				
Platinum-Palladium					0.7598***	0.9618*						
GoldF-SilverF	-0.0112***		-0.0311**	-0.0328***	0.0358*	-0.0200***						
PlatinumF-PalladiumF		-0.9983***	-0.1782*	-0.1379**	-0.1997**	-0.4019***						

Note: Estimation results  $\theta$  and  $\gamma$  of EPU of G7 and BRICS nations from GARCH-MIDAS-X and DCC-MIDAS-X, respectively. The asterisks \*\*\*, \*\*, and \* denote significance at 1%, 5%, and 10%, respectively. Otherwise the field is left blank. The results of the U.S. and China in gray format are for reference.