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 especially influence the precious metal markets, but in opposite directions. Besides, 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 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 United States 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. As a consequence of market shocks, investors prefer to keep safe assets and stay away from risky assets, a concept is known as the 'flight to quality' phenomenon in financial markets. Precious metals, which are considered as safe investment assets especially in times of high uncertainty, outperform than traditional assets, such as stocks or bonds (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 United States and China due to the fact that around 80% of the precious metals used by the United States were imported from China between 2014 and 2017.[1] The resilience of precious metals to financial crises has also been highlighted academically in recent years (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 shocks or 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 volatility and correlation dynamics are crucial characteristics of these markets. Investors and portfolio managers can make wiser investment decisions if they understand the true dynamics of the volatility as well as the correlation of the precious metals markets. Besides, many studies find that the dynamic volatility and correlation of commodities markets in general and precious metals markets in particular are not only related to supply and demand dynamics, but is also associated with changes in economic activities (Anson, 2008; Belousova and Dorfleitner, 2012). However, the related literature so far reports inconclusive results and

[1] https://www.reuters.com/article/us-usa-trade-china-rareearth-explainer-idUSKCN1TS3AQ

is generally limited to determining the economic drivers of the conditional volatility and correlation of precious metal markets. Macroeconomic and financial variables are well-known as the key potential drivers of dynamic movements in precious metal markets because these factors have certain statistical properties that can have significant impacts on policymakers, investors, manufacturers, consumers, researchers, and portfolio managers. Besides, another important economic variable linked to high volatility markets such as precious metal markets is Economic Policy Uncertainty (EPU) (Li and Lucey, 2017; Huynh, 2020) which has also attracted considerable attention.

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 GARCH-type models (Hammoudeh et al., 2011; Pan et al., 2017), popular classes of multiple-equation models including VAR (Andersen et al., 2003; Apergis et al., 2014), VECM-based approaches (Kucher and McCoskey, 2017), and different DCC models (Fernandez-Diaz and Morley, 2019), among others. However, these methods predominantly investigate only the separated effect of a single driver or focus solely on a small number of given macro-finance variables. 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 of precious metals are mainly based on high-frequency data. By applying an econometric model of mixed data sampling (MIDAS), hence, 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) can handle this problem. The main advantage of the GARCH-MIDAS and DCC-MIDAS models is that they slowly extract the long-term component from the short-term component of the volatility and correlation, respectively. Furthermore, from the standard GARCH-MIDAS and DCC-MIDAS models, there are many flexible modifications to cover various cases of the long-term variance and correlation. Specifically, Conrad et al. (2014) and Asgharian et al. (2015) introduce the GARCH-MIDAS-X model and the DCC-MIDAS-X model to allow for considering the impact

of exogenous variables (X) on the long-run volatility and correlation, respectively.

Our study's primary objective is to analyze the impact of the economic and financial drivers on the time-varying volatility and correlation of precious metals. Our results indicate that there are significantly different and relatively opposite in the economic drivers of the precious metals volatility between the highly developed (Group of Seven, G7) and emerging (Brazil, Russia, India, China, South Africa, BRICS) economies, most notably between the United States and China. Among the economic and financial factors proposed, changes in stock market yields, interest rates and consumer confidence act as the most helpful predictors for both volatility and correlation. In addition, the trade balance growth is the most important in driving dynamic volatility and money supply and inflation rate also are important determinants of long-term correlation between four precious metals. Finally, very much in line with previous works, the global financial crisis 2008 had has a significant impact on the economic and financial drivers of the dynamics of the precious metals markets as we find that many drivers changed the direction of their impact after the crisis.

Our study makes several contributions to the existing literature. Firstly, by employing mixed data sampling techniques, this study investigates various economic and financial variables that may influence the dynamic of the precious metal markets rather than examining a single driver or a small number of macroeconomic determinants. In particular, we use a total of 19 economic and financial variables at the country level to analyze their specific effects on the long-term volatility and correlation of precious metals markets. Secondly, to the best of our knowledge, our paper is the first work that analyses macroeconomic and financial drivers of the dynamic correlation among four precious metals, although many previous studies have investigated the determinants of dynamic correlations between precious metals and other assets, such as stocks (Mensi et al., 2013; Jain and Biswal, 2016), oil (Šimáková, 2011), or the exchange rate (Pal et al., 2014; Apergis, 2014). 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. Thirdly, in an attempt to answer the

question of whether the impact of the economic determinants on the dynamic volatility and inter-relationships change between tranquil and turbulent times, our sample is divided into three sub-samples: 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 to address any global financial crisis in the future. Fourthly, based on the economic data of G7 and BRICS countries, our study provides international evidence on the relationship between economic and financial variables and the dynamic movements of precious metal markets. Because 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 metals prices has been addressed in a range of studies, especially after the 2008 global financial crisis. Up to now, there is an extensive literature identifying factors which drive the price of precious metals (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, we cannot identify a single study of the determinants of pair-wise correlation between precious metals. 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 four 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 other precious metals.

In addition, with the aim of testing the relationship between macroeconomic variables and the commodity futures volatility of Chinese and Indian markets including agricultural commodity futures, precious metal futures and oil futures, 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, this study shows that the uncertainty in macroeconomic variables, except for the Consumer Confidence Index, causes an increase in the volatility of precious metal futures.

Contrary to the two above-mentioned studies, Fang et al. (2018b) solely pay their attention to identify the economic drivers of the long-term volatility of the gold future market in the United States by employing the GARCH-MIDAS method, the results show that the macroeconomic variables have a significant impact on gold volatility during and after the economic turmoil. More specifically, Economic Policy Uncertainty, Employment Rate and Inflation Rate have a positive effect on the long-run volatility of the gold future 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 at both modeling and forecasting levels. They find that the long-term volatility of most commodity futures including gold, silver, platinum and other commodities is significantly affected by the level of Global Real Economic Activities as well as the 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, 2007), Inflation (Gorton and Rouwenhorst, 2006), Private Inventories (Radetzki, 1989), Capacity Utilisation and Unemployment Rates (Apergis et al., 2014).

Financial variables are well-known as the key drivers of asset prices. Hence, the second strand of literature pays attention to *the impact of financial variables on the dynamic movements of the volatility and correlation of precious metal markets*. Among 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).

In terms of the relationship between the Exchange rate and precious metals, Ghosh et al. (2004) and Akram (2009) show that many commodity prices, including precious metal prices, can be attributed to the influence of exchange rate changes, especially with respect to the U.S. dollar. Sari et al. (2010) study the relation 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 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 and the related literature provides inconclusive findings. Tully and Lucey (2007) 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 contrast, Boako et al. (2019) conclude that establishing a positive average dependence between equity returns and gold may still be somewhat correct.

With the purpose of investigating the effects of multiple economic and financial factors

on metals price movements, Liberda et al. (2017) uses 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 Rate, Exchange Rate, Stock Returns, and Crude Oil Returns* affect precious metal markets more than macroeconomic variables including 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.

The third strand of literature on *how the time-varying volatility and correlation of precious metals market react to Economic Uncertainty Policy* also receives considerable critical attention because precious metals that can act as a hedge or safe haven for stock investment (Baur and Lucey, 2010; Baur and McDermott, 2010), become increasingly crucial when the degree of policy uncertainty of world financial markets grows (Białkowski et al., 2015; Balcilar et al., 2016). In particular, based on the GARCH-MIDAS model, Fang et al. (2018a) and Nguyen and Walther (2020) test the impact of global economic policy uncertainty (GEPU) on the long-term component of the volatility of the precious metal future markets. Both studies find that GEPU positively affects the volatility of precious metals. More specifically, Nguyen and Walther (2020) show that the changes in GEPU positively affect the long-term volatility of gold and platinum, but not of silver.

Also based on the mixed data sampling technique, Zhou et al. (2018) use DCC-MIDAS combining the threshold VAR model in order to give international evidence on the impact of macroeconomic policy uncertainty on the correlation between gold and the dollar. This study concludes 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 various. The results also show that both gold and the dollar, in return, can influence the economic uncertainty of the United States,

Europe, Russia and China. To be more specific, Europe is the most sensitive towards the gold market and the exchange rate of dollar, and China is the least sensitive.

As a very limited literature that provides international evidence on the impact of extreme events such as the 9/11 terrorist attack, the Global Financial Crisis, the European Debt Crisis, and the Brexit vote on the inter-correlation among precious metals, the contributions of Klein (2017) are noteworthy. By applying a flexible modification of the widely-used DCC-GARCH, the study points out the significant differences in correlation structures between the first group of Gold and Silver and the latter of Palladium and 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

The component models of our study contain two sections. The first relates to the heteroscedasticity process of the return series with the GARCH-MIDAS model (Engle et al., 2013) and its extended models to assess 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 to analyze the effect of economic determinants on the dynamic correlations between precious metals themselves.

3.1. GARCH-MIDAS model with economic variables

Extended from Spline-GARCH which disentangles the volatility into short-term and long-term components, the main contribution of GARCH-MIDAS (Engle et al., 2013) is that it presents a possibility for modeling the long-term component part with exogenous variables.

First, 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:

$$r_{i,t} = \mu + \sqrt{\tau_t g_{i,t}}\varepsilon_{i,t} \quad \forall i = 1, \ldots, N_t \tag{1}$$

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 τ_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:

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

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 τ_t as a slowly varying function of an exogenous variable X_t:

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

which we denote as GARCH-MIDAS-X . Here, K is the number of lags and m is an intercept of long-term trend. The weighting scheme φ_k is determined by a beta lag polynomial (Ghysels et al., 2007) as follows

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

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 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 vector of returns r_t follows the process

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

where μ 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 Ω_t represents the conditional correlation matrix of returns on time $(t-1)$ information:

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

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

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 Section 3.1 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) of a matrix Q as follows

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

where $\overline{\rho}_{ij,t}$ 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 transforma-

tion:

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

where $z_{ij,t}$ is driven by an exogenous variable X_t:[2]

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

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

Finally, the conditional correlation matrix is given as

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

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.

4. Empirical Application

4.1. Data and variables

4.1.1. Precious metals data

Our data consist of daily spot and future (1 month) price series of gold, silver, platinum, and palladium, which are obtained from Thomson Reuters Datastream. Table 1 summarizes the descriptive statistics for the daily spot and future returns (Panel A and panel 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 future returns. We can see that the mean is small and positive for most

[2]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.

return series in both total sample and sub-samples, except for platinum and palladium cases in the crisis period. Interestingly, gold returns exhibit the highest mean but smallest volatility in the crisis time, reflecting the safe haven role of this metal which has been investigated by 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 leptokurtic distribution, which is also confirmed by a Jarque-Bera statistical test.

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 high dependence on the long horizon. 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.

Finally, Table 1 provides the results of the traditional unit roots tests including ADF, PP and KPSS, respectively. We find strong evidence against the null hypothesis of a unit root, reflecting that all the return series are stationary with a high level of significance.

4.1.2. Exogenous variables

We divide the exogenous variables into three categories: Macroeconomic variables, Financial variables, and Economics Policy Uncertainty (see Table 7 in the Appendix).

The monthly data of macroeconomic and financial variables are retrieved for 12 countries (G7 and BRICS) from March 1998 to August 2018 from Thomson Reuters Datastream, FRED database at the Federal Reserve Bank of St. Louis, OECD database, and World Bank database. Additionally, monthly data of economic policy uncertainty index is collected from https://www.policyuncertainty.com. In order to ensure consistency between countries and 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.

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

	Mean	Stdev	Skewness	Kurtosis	J.B.	Q(15)	$Q^2(15)$	ARCH(15)	ADF	PP	KPSS
Panel A: Spot return											
Full sample											
Gold	0.032	1.073	0.085	6.226	0.000	0.010	0.000	0.000	−17.884	−73.965	0.224
Silver	0.032	1.803	−0.523	6.573	0.000	0.012	0.000	0.000	−17.573	−73.333	0.174
Platinum	0.023	1.406	−0.296	4.950	0.000	0.035	0.000	0.000	−16.171	−72.204	0.422
Palladium	0.049	2.092	0.016	5.091	0.000	0.000	0.000	0.000	−16.109	−68.819	0.067
Pre-crisis											
Gold	0.038	0.985	0.183	7.786	0.000	0.009	0.000	0.000	−14.130	−51.302	0.246
Silver	0.038	1.568	−0.907	6.443	0.000	0.041	0.000	0.000	−14.326	−50.605	0.363
Platinum	0.058	1.379	−0.004	6.009	0.000	0.010	0.000	0.000	−14.331	−52.714	0.043
Palladium	0.040	2.264	0.295	5.934	0.000	0.001	0.000	0.000	−13.514	−46.618	0.196
Crisis											
Gold	0.091	1.793	0.300	2.099	0.000	0.129	0.000	0.000	−7.091	−17.828	0.157
Silver	0.028	2.839	−0.147	3.878	0.000	0.441	0.005	0.000	−7.132	−18.943	0.233
Platinum	−0.057	2.316	−0.795	2.347	0.000	0.209	0.000	0.000	−6.874	−16.630	0.650
Palladium	−0.120	2.641	−0.532	3.004	0.000	0.319	0.022	0.000	−5.856	−16.055	0.406
Post-crisis											
Gold	0.018	1.023	−0.227	4.872	0.000	0.006	0.000	0.000	−14.090	−51.271	0.363
Silver	0.026	1.835	−0.416	5.523	0.000	0.030	0.000	0.000	−13.461	−49.727	0.417
Platinum	0.001	1.257	−0.138	1.810	0.000	0.058	0.000	0.000	−13.661	−48.364	0.450
Palladium	0.081	1.809	−0.235	2.252	0.000	0.057	0.000	0.000	−14.142	−48.913	0.364
Panel B: Futures one month return											
Full sample											
F_Gold	0.032	1.088	0.049	6.815	0.000	0.004	0.000	0.000	−17.832	−73.251	0.218
F_Silver	0.033	1.867	−0.628	6.919	0.000	0.235	0.000	0.000	−17.590	−74.901	0.172
F_Platinum	0.024	1.458	−0.957	7.542	0.000	0.004	0.000	0.000	−16.376	−71.559	0.414
F_Palladium	0.049	2.085	−0.014	5.383	0.000	0.000	0.000	0.000	−16.255	−67.966	0.069
Pre-crisis											
F_Gold	0.038	0.999	0.336	7.839	0.000	0.040	0.000	0.000	−14.299	−50.525	0.252
F_Silver	0.039	1.625	−0.882	7.711	0.000	0.058	0.000	0.000	−14.453	−51.479	0.357
F_Platinum	0.059	1.441	−1.665	5.283	0.000	0.000	0.000	0.000	−14.731	−50.307	0.040
F_Palladium	0.040	2.232	0.185	6.607	0.000	0.001	0.000	0.000	−13.397	−45.804	0.203
Crisis											
F_Gold	0.090	1.733	0.297	2.631	0.000	0.049	0.000	0.002	−7.249	−16.635	0.151
F_Silver	0.027	2.863	−0.311	3.432	0.000	0.239	0.000	0.000	−7.304	−18.440	0.228
F_Platinum	−0.058	2.363	−0.591	1.964	0.000	0.294	0.000	0.000	−7.075	−16.589	0.642
F_Palladium	−0.122	2.635	−0.339	3.347	0.000	0.204	0.000	0.000	−6.123	−15.955	0.410
Post-crisis											
F_Gold	0.018	1.056	−0.385	6.198	0.000	0.015	0.000	0.000	−14.143	−52.012	0.346
F_Silver	0.028	1.914	−0.558	6.095	0.000	0.077	0.000	0.000	−13.542	−51.692	0.421
F_Platinum	0.001	1.301	−0.100	1.669	0.000	0.013	0.000	0.000	−13.567	−49.915	0.447
F_Palladium	0.082	1.835	−0.183	2.211	0.000	0.217	0.000	0.000	−14.144	−48.586	0.360

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 Q2(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. Finally, the ADF, PP and KPSS represent the Augmented Dickey and Fuller (1981), Phillips and Perron (1988) and Kwiatkowski et al. (1992) unit root tests. With the critical values at significance level 10%, 5% and 1% are −1.62, −1.95 and −2.58, respectively, all three tests show that all series are stationary.

4.2. Results and discussions

We begin our analysis by testing the impact of various macroeconomic and financial drivers on the conditional volatility of each precious metal and six pairs of correlations of four major precious metals[3] in our sample by employing the GARCH-MIDAS-X model and DCC-MIDAS-X. In the results reported in Table 2, we first estimate standard and asymmetric GARCH and GARCH-MIDAS variants in order to check whether a decomposition in short- and long-term volatility components 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 BIC. In addition, we determine that $K = 36$, i.e. three years of monthly observations, is the optimal lag-length for the MIDAS component with regards to the BIC. Contrary to previous studies, we are not only limiting the exogenous variables on the U.S. market, but analyse the effect of macroeconomic and financial drivers in other countries.

We only focus on the statistical significance of coefficients θ in Equation (3) and γ 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. Following this, the signs of θ and γ 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.

4.2.1. Macro-finance determinants of precious metals volatility and correlation - opposite evidence between the United States and China

Due to the escalating tension between the United States and China after 2018 leading to a more persistent headwind for all financial markets, the results of researching in these two countries therefore deserve to be explained first.

In general, the results in Table 3 and 4 show that Chinese economic drivers have less impact on dynamic volatility as well as the correlation among precious metals pairs while the

[3]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 2: Comparable parameters estimation results of GARCH, GJR-GARCH, GARCH-MIDAS-RV and GJR-GARCH-MIDAS-RV

Asset	Model	μ	α	β	m	LL	BIC
Gold	GARCH	0.0158	0.0508***	0.9366***	0.1970	-6624.20	13282.13
	GJR-GARCH	0.0249*	0.0678***	0.9392***	0.2277	-6612.13	13266.40
	GARCH-MIDAS-RV	0.0201	0.0288***	0.9664***	0.1212	**-5576.00**	*11209.67*
	GJR-GARCH-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-GARCH	0.0130	0.0552***	0.9510***	1.2803***	-8966.31	17974.76
	GARCH-MIDAS-RV	0.3387***	0.0899***	0.9101***	−0.0440***	**-8565.24**	*17188.16*
	GJR-GARCH-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-GARCH	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**	*12689.40*
	GJR-GARCH-MIDAS-RV	0.0158	0.0982***	0.8500***	0.1981*	-6315.69	12697.29
Palladium	GARCH	0.0764***	0.0778***	0.9100***	1.6448***	-9565.36	19164.44
	GJR-GARCH	0.0740***	0.0757***	0.9095***	1.6384***	-9565.23	19172.62
	GARCH-MIDAS-RV	0.0601***	0.0279***	0.9155***	1.2577***	**-8084.97**	*16227.63*
	GJR-GARCH-MIDAS-RV	0.0465*	0.0703***	0.9183***	1.2206*	-8384.70	16822.96
F_Gold	GARCH	0.0199	0.0456***	0.9407***	0.2060	-6720.80	13475.34
	GJR-GARCH	0.0258*	0.0571***	0.9410***	0.2307	-6716.34	13474.83
	GARCH-MIDAS-RV	0.0260*	0.0406***	0.9459***	0.3078*	**-5664.93**	*11387.54*
	GJR-GARCH-MIDAS-RV	0.0278*	0.0392***	0.9605***	0.3870*	6011.17	12072.15
F_Silver	GARCH	0.0114	0.0385***	0.9540***	1.2137***	-9149.26	18332.24
	GJR-GARCH	0.0198	0.0506***	0.9529***	1.2944***	-9143.54	18329.23
	GARCH-MIDAS-RV	0.0387*	0.0727***	0.8404***	0.7658***	**-7782.28**	*15622.23*
	GJR-GARCH-MIDAS-RV	0.0375*	0.0802***	0.8713***	0.7274***	-8207.01	16487.18
F_Platinum	GARCH	0.0183	0.0589***	0.9262***	0.7318***	-7887.02	15807.76
	GJR-GARCH	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**	*12953.41*
	GJR-GARCH-MIDAS-RV	0.0159	0.0585***	0.9237***	0.4310**	-6447.82	12961.56
F_Palladium	GARCH	0.0759***	0.0778***	0.9060***	1.6166***	-9634.40	19302.53
	GJR-GARCH	0.0774***	0.0791***	0.9061***	1.6193***	-9634.36	19310.87
	GARCH-MIDAS-RV	0.0692**	0.0759***	0.8892***	0.9678***	**-7816.59**	*15690.86*
	GJR-GARCH-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-GARCH(1,1,1), GARCH(1,1)-MIDAS(36)-RV and GJR-GARCH(1,1,1)-MIDAS(36)-RV general coefficients, respectively for both spot returns and future 1 month returns of four precious metals. The total 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.

figure in the United States shows a clearer influence. In addition, the long-term volatility of gold and long-term correlations of the Gold-Silver pair and Platinum-Palladium pair are affected by more economic variables of both the United States and China than the others. This is consistent with the finding 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 estimated results reveal that, with the exception of a few economic variables of both countries having similar effects on the long-run volatility (i.e. EPU growth (positive impact), Exchange rate (negative impact), and Gold & Foreign Reserves growth (positive impact) and on the long-run correlation (i.e. import growth), there is a totally opposite scenario between the United States and China in the impact of almost macro and financial drivers on the precious metals return volatility and their pair-correlations.

In particular, the effect of Consumer Confidence on the both volatility and correlation can be observed more clearly. This indicator of the United States 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 be 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 have been significantly affected by the foreign trade of both countries. However, the Chinese export growth has more influence on volatility than that of the United States whereas the import growth of China has less impact on the volatility than that of the United States.

Notably, all four main precious metals including both their futures and spots react significantly and negatively to the U.S. stock returns while only the long-term volatility of spot precious metal returns has a significantly positive response to the stock returns in China. This reveals that upward growth in the U.S. stock market would help to stabilize precious metal markets in the long-term while it might be inefficient with Chinese stock. With

respect to the correlation, Table 4 reveals that the U.S. stock variable is positively associated with almost all DCC pairs between precious metals spot returns. Meanwhile, the Chinese counterparts do not appear to affect any conditional correlation. Several other factors also show opposite impacts between the United States and China on the dynamic correlation levels among precious metal returns (e.g. M1, M2, INF).

Table 3: Estimation results for parameters θ of macroeconomic and financial variables of the United States and China

Assets	Gold	Gold_F	Silver	Silver_F	Platinum	Platinum_F	Palladium	Palladium_F
Panel A: United States								
Macroeconomic variables								
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**
Financial variables								
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***	
EPU					0.2242***			
Panel B: China								
Macroeconomic variables								
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**	
Financial variables								
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***					
EPU					0.0489***			

Note: The table reports estimated results for parameters θ of macroeconomic and financial variables of the United States and China from GARCH(1,1)-MIDAS(36)-X model. The symbols ***, **, and * denote statistical significance at the levels of 1%, 5% and 10%, respectively. Otherwise the field is left blank.

Table 4: The estimators γ of the U.S. and Chinese economic drivers of conditional correlation between precious metals

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
Macroeconomic variables												
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***
Financial variables												
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**
EPU	−0.0138***											

Note: The table shows estimation results γ of macro-finance drivers of the United States and China from DCC-MIDAS(36)-X model. The asterisks ***, **, and * denote significance at 1%, 5%, and 10%, respectively. Otherwise the field is left blank.

4.2.2. Global financial crisis 2008 and macro-finance drivers of dynamic volatility and correlation between precious metals

The safe-haven ability of precious metals against market shocks such as the global financial crisis 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 sub-period analysis, still focusing on the United States and China, to investigate any change in the role of economic drivers of precious metals across the various phases of the global financial crisis 2008. Table 5 and 6 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 United States and China have played an important role in the global derivatives trading for metals (Klein and Todorova, 2021).

Generally, the period after the 2008 global financial crisis has witnessed a greater number

Table 5: Estimation results for parameters θ of macroeconomic and financial variables of United States and China over three sub-periods of global financial crisis

Assets		Gold_F			Silver_F			Platinum_F			Palladium_F	
Periods	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.
Panel A: United States												
Macroeconomic variables												
M1 Growth	0.6574*	0.5116***				−0.5661**		−0.9755***		2.000*	−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***
Financial variables												
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***	
EPU		−0.1069***		−0.0382**			0.0095***	−0.0969***		0.0116***	−0.1009***	
Panel B: China												
Macroeconomic variables												
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***
Financial variables												
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***	
EPU	−0.0070**	−0.0979***	−0.0015**				0.0106***	−0.0979*	−0.0050***	−0.0113**		

Note: The table reports estimated results for parameters θ of macroeconomic and financial variables of the United States and China over three sub-periods of global financial crisis from GARCH(1,1)-MIDAS(36)-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 6: The estimators γ of the U.S. and Chinese economic drivers of conditional correlations between precious metals futures one-month across various sub-periods related to global financial crisis 2008

Pairs of Assets	Gold_F−Silver_F			Gold_F−Palladium_F			Gold_F−Platinum_F			Silver_F−Palladium_F			Silver_F−Platinum_F			Palladium_F−Platinum_F		
Periods	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.	Pre.	Crisis	Post.
Panel A: U.S.																		
Macroeconomic variables																		
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	0.7872
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		
Financial variables																		
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		
EPU	−0.6191		0.0912	−0.2343							0.6190	−0.0055			−0.0063	−0.1557	−0.9037	−0.1054
Panel B: China																		
Macroeconomic variables																		
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				
Financial variables												−0.0258						
Stock market		1.2630					−0.5088	0.8928	0.0376							0.0329	1.0091	−0.1691
Bond market										0.9922								
Interest Rates					0.3312		0.9830									−1.1517		0.9544
Interbank 3M Rates																		
T-bill 3M Rates																		
Exchange Rates			−0.2724	−0.3934	1.4551		−0.0223			−0.2085			−1.5215					
EPU	−0.0642	−0.8463							−0.0358				−0.1518	−0.1042			−1.8683	−0.0614

Note: The table reports estimated results for parameters γ of macroeconomic and financial variables of the United States and China over three sub-periods of global financial crisis from DCC-MIDAS(36)-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 γ is statistically significant, i.e. the critical values at significance level is 10%. Otherwise the field is left blank.

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 of θ and γ). In addition, an opposite trend can be seen between the signs of significant coefficients θ and γ 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 negative (e.g. M1 on the GoldF-PlatinumF and GoldF-PlatinumF) or the reverse (e.g. M2 on PlatinumF-PalladiumF, Gold & Foreign Reserves growth on GoldF-SilverF). 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 in the U.S. financial market shocks. This result from the increased demand for these metals from emerging countries like China who have not been strongly affected by crisis 2008 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 United States, the signs of the coefficients θ and γ of the macro-finance factors of this country show the most significant change between the pre-crisis and crisis periods compared to other periods. In detail, several drivers of the U.S. turn from negative to positive (i.e. signs of θ of the Export, Gold & Foreign Reserves growth or Stock on the long-term volatility of GoldF and PalladiumF and signs of γ of M1 on DCC of GoldF-SilverF; RER on DCC of GoldF-PlatinumF and GoldF-PalladiumF; T-Bill 3M on DCC of GoldF-PlatinumF, Interest rate on PlatinumF-PalladiumF). This confirms the forecasting impact of the U.S. economy that led to the global financial crisis 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 Capacity Utilization and Exchange rate of the United States and Gold & Foreign Reserves growth of China influence the volatility of silver future 1 month and only M1 growth of the U.S. impact on the DCC of the silver future-palladium future pair) in comparison with non-crisis periods. Meanwhile, the volatility of palladium futures is the most

strongly influenced by the global financial crisis. 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.

4.2.3. Extensive Estimation Results for other G7 and BRICS countries

In this section, we extend our analysis to other G7[4] and BRICS[5] countries, which are top-ranked in precious metals exchanges. Table 8 to 12 in the Appendix present the estimates of statistically significant θ and γ signs for each of the macro - finance variables of all ten countries with the full sample from 1998 to 2018. Here, we also divide our analysis into three parts according to three groups of variables.

We first focus on the macroeconomic factors in other G7 and BRICS countries. In general, we can see that these variables have various influences on precious metal volatility and correlation. Table 8 and 9 indicate that despite acting as important drivers of the volatility of precious metals, neither export nor import growth of G7 and BRICS countries much affect the long-term correlations between these metals. Therefore, here, we focus on the impact of trade deficit on the long-term volatility of precious metals. More specifically, it is obvious that the influence of the export growth of almost G7 nations and BRICS nations on long-term volatility are negative and positive, respectively. More precious metals are affected by the export of BRICS than that of G7 countries. The export growth of Russia, one of the world's largest exporters of metals[6], is considered the strongest determinant of 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, respectively. With respect to the impact of import growth on precious metals volatility, we find the strongest positive effect from the import growth of India[7] and South Africa. In the case of G7 countries, the relatively different impacts

[4]United Kingdom, Canada, Japan, Germany, France and Italy
[5]Brazil, Russia, India and South Africa
[6]https://investinrussia.com/data/files/sectors/Metals-and-Mining-in-Russia.pdf
[7]India imported the highest dollar value worth of gold during 2019 http://www.worldstopexports.com/international-markets-for-imported-gold-by-country/

of G7 countries' import growth on the long-run volatility can be observed. In particular, negative effects dominate positive ones, typically in the case of Japan.

Aside from trade balance, the Gold&Foreign Reserves Growth (GFR) of both other G7 and BRICS countries are also important drivers of the long-term volatility of precious metals markets, but not applicable to long-term correlations. In particular, Table 8 illustrate that the GFR of BRICS nations, especially in the cases of Brazil, South Africa, and China, have considerably more impact on the volatility of precious metal markets than G7 countries' GRF. 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.[8] Additionally, the positive 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.

Table 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 precious metals volatility are negative, while the CLI and CC of these two groups mainly positively affect long-term correlation between precious metals pairs. CLI represents the future expectation of the business cycle, therefore, the results mean that a rise in the future expectations of the business cycle leads to a decreasing volatility of precious metals and an increasing correlation between these metals. Moreover, in the United Kingdom and India, the CLI of these countries appear to be more important drivers than that of other countries. The results also suggest that the impacts of CC and 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 θ and γ 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

[8] https://www.ecb.europa.eu/pub/economic-bulletin/articles/2019/html/ecb.ebart201907_01~c2ae75e217.en.html

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 their volatility. Plus, 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, due to an increase in M2, reflecting the economic weaknesses, the positive sign of θ and the negative one of γ of in almost all cases indicate that the precious metals prices are more volatile and more closely linked during the recession period. Although gold and silver are known as a hedge for inflation (Ghosh et al., 2004), our results show that higher inflation rates of both G7 and BRICS explain the rise in the volatility of all four precious metals (except for Japan). Meanwhile, we find that G7 (BRICS) inflation rates have a negative (positive) association with the DCCs between precious metals returns.

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 stock market returns of both G7 and BRICS countries, while the correlations among these metals respond positively to this driver. This indicates that an increase in stock returns of both groups, specially G7 countries, leads to a decrease in the volatility of precious metals and an increase in the long-term correlation among them which reduces the diversification benefits between precious metals together.[9] In addition, a mainly positive impact of the government bond returns of the G7 and BRICS countries on the conditional volatility as well as correlation among precious metal markets can be found.

In respect to the impact of interest rates, we can see clearly that while there are varying and heterogeneous effects of this variable across countries on long-term volatility, its impact

[9]This finding is in line with Arouri et al. (2015) and Mishra et al. (2010).

on long-term correlations is consistently negative. This could be an illustration of the decline 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 the conditional correlation.

Finally, Table 12 shows the influence of EPU growth of each country in our sample on the long-term volatility and correlation of precious metals markets. Our econometric analysis reveals that the EPU growth of other G7 and BRICS countries have no contribution to explaining the behavior of the dynamic correlations in contrast to the dynamic volatility of precious metals. Except for the negative impact of the EPU growth of Japan on the volatility of gold spots and gold futures, all EPUs of other countries exert a positive effect on the precious metals' volatility. This means that the significant growth of EPU results in higher volatility in precious metals markets. This result is in line with the findings of Fang et al. (2018b) and Nguyen and Walther (2020) who point out that EPU has a positive effect on the long-run volatility of precious metals.

We also find that EPU growths of G7 nations provide a clearer explanation to the volatility of precious metals than those of BRICS. On the other hand, EPUs of countries cause more apparent effects on platinum and palladium than on gold and silver. 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.

In regard to the long-term correlations' reaction to the EPUs of two groups, we can observe that while the positive response of Gold-Platinum, Gold-Palladium, and Silver-Palladium with the change of the EPU of Russia can be seen, other pairs are all negative 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 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 twenty years. Using GARCH-MIDAS-X and DCC-MIDAS-X, we find that the 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 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 seen on the long-term correlations between precious metals to a similar extent. Therefore, in periods of policy instability, investors are recommended to 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 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 in G7 countries, the portfolio hedging benefits 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-interest rate on correlation.

Notably, our study also shows that the global financial crisis 2008 plays a key role in the change of the impact of determinants on precious metals markets as the signs of many determinants are reversed over the course of this crisis. Palladium is the most strongly influenced by the global financial crisis 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 with the changes in the economic drivers of both the G7 and BRICS countries.

With the above analysis, our findings may help both investors and portfolio managers to make optimal and timely choices based on forecasting the changes of 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.

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Appendix

Table 7: List of macro-finance variables

Variable name	Acronym	Description	Data sources
Macroeconomic variables			
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[10]	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
Financial variables			
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[11]	Thomson Reuters Datastream
Economic Policy Uncertainty	EPU	Measure the contribution of government policy makers to the uncertainty regarding fiscal, regulatory, or monetary policy	https://www.policyuncertainty.com

[11] https://corporatefinanceinstitute.com/resources/knowledge/finance/what-is-corporation-overview/

Table 8: Impact of macroeconomic variables of other 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
Export Growth												
Gold	0.4668*		−0.0238**			−0.1464**			0.0988*	0.2046**	0.2379***	0.1153*
Gold_F	−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*	
Silver_F		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***
Platinum_F	−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*			
Palladium_F		0.1723*									0.0199***	
Import Growth												
Gold	0.4283*			−0.0451**		0.2374**	0.1628*	0.2263**		0.2487***		0.2317**
Gold_F			−0.0155*	−0.1244**						0.2509***		0.2108***
Silver	0.7013*	0.3077*	−0.0885*	−0.1210**					0.2860*		0.6376***	
Silver_F	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*				
Platinum_F			0.1246***			0.1181**		−0.0738**		0.0969*		0.1848**
Palladium		0.2907***	−0.0280***	−0.2991**		−0.0951*						
Palladium_F		−0.0290*					−0.0266**	−0.0385***	0.0207***	0.2154*		−0.1538**
Gold&Foreign Reserves												
Gold	0.1813*	−0.0386***	0.5165**		−0.0597***		−0.0474***	0.0517**	0.3566*	0.0650*	0.1892*	0.2964***
Gold_F	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*
Silver_F	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*
Platinum_F				−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***
Palladium_F	0.2495**						0.3517***	0.1873**				
Consumer Confidence												
Gold	−0.2731***	−0.2215**	−0.0484**	−0.2031**	−0.1289*		−0.2100**	0.2109**	0.1350***	−0.1373**		
Gold_F		−0.2358***	−0.0391**	−0.1949*		−0.3923**		0.2128**	0.1256***	−0.1310**		
Silver	−0.2762***	−0.2919***	−0.0949**		−0.3519**							
Silver_F	−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***		
Platinum_F	−0.1754**	−0.1819**		−0.1911**								
Palladium		−0.1856**	−0.0574***	−0.4122***	−0.2452***	−0.2733**		−0.1007*				
Palladium_F	−0.2157***	−0.1736**	−0.0481***		−0.2209***							
Composite Leading Indicator												
Gold		−0.1425**						0.2373*				−0.1848*
Gold_F		−0.1974**										−0.2100*
Silver		−0.1376*		−0.3088*					−0.1095*	−0.3397**	−0.1976***	
Silver_F		−0.1466*	−0.2366*	−0.3250*	−0.2202**			−0.0348**		−0.3629**	−0.2054***	
Platinum		−0.2342***		−0.2762**		0.2393*					−0.1848**	
Platinum_F		−0.2243***								−0.2004***	−0.1635*	
Palladium	−0.1611*	−0.2623***	−0.2776**							0.2145*	−0.2376***	−0.2464***
Palladium_F		−0.2431***	−0.2474***		−0.1448*					0.2485*	−0.1906***	
Industrial Production												
Gold	−0.0494**		−0.0595**		−0.0326***		0.0187*					−0.0336*
Gold_F	−0.0411**		−0.0607**		0.0262*							−0.0277**
Silver		−0.1975***	−0.0918**	−0.0579**			−0.0969***	−0.0635*				
Silver_F	−0.1195**	−0.2074***	−0.1004*	−0.0652**			−0.1011***	−0.0709***				
Platinum												
Platinum_F				0.0626*								
Palladium	−0.0728***		−0.0478*		−0.0352**		0.0184***					
Palladium_F	−0.0645***		−0.0365**									

Note: Estimation results θ 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(36)-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 other 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
Export Growth												
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*					
Import Growth												
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*						
Gold&Foreign Reserves												
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***	
Consumer Confidence												
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*									
Composite Leading Indicator												
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												
Industrial Production												
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 γ 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(36)-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 other G7 and BRICS countries on the long-term volatility and correlations of precious metals (continued)

	US	UK	Canada	Japan	Germany	France	Italy	Brazil	Russia	India	China	South Africa
Panel A: Long-term volatility												
M1 Growth												
Gold				−0.1222***		−0.5119***	−0.6396**	−0.0350*	0.1423**	0.6701**		0.8812*
Gold_F	−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*
Silver_F	−0.8870**									0.8483***	−0.0730**	0.4788**
Platinum		−0.5808*	0.7389*	0.2325*				0.2790**				0.4741**
Platinum_F	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**
Palladium_F										0.3883*	0.1788***	0.3065*
M2 Growth												
Gold	0.4923**	1.4255*		−1.4092***		−1.3128**	0.4357*	0.2004***				0.7124**
Gold_F	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***		
Silver_F	0.3155**		0.4262*	0.2505*		−1.1816**		0.3845***		0.7887**		
Platinum	1.2215***		1.1187***	1.5943**	1.5663***	1.5550**	−0.4514**					
Platinum_F					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*
Palladium_F		0.9777**	1.0379**					0.6782***		0.3685*		−0.3157*
Unemployment Rate												
Gold	0.0974*	0.1633***		0.2210**	0.1659***	−0.2351**	−0.1442***		0.1460**		1.2893**	
Gold_F	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***	
Silver_F				−1.2157***	−0.6186***		−0.5021**	−0.3374***			2.1216***	−0.2324**
Platinum						0.2941**				−0.5543**		−0.1378**
Platinum_F						−0.2940*			0.1145*	−1.0268*		−0.1085*
Palladium	0.1374*			0.3907**				0.0794*	0.1238*		2.5641***	0.1327*
Palladium_F	−0.1251*			0.2704*		−0.3595***			0.2653***		2.2086**	
Inflation Rate												
Gold	0.4079*	0.2742**	0.1817**	−0.1739***		0.2342*	0.2128*	0.0629**	0.0518***	0.0744***	0.1505***	
Gold_F	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**
Silver_F									−0.1172**	0.1378*	0.1989**	
Platinum			0.3644***			−0.2551**			−0.0716**			0.1122***
Platinum_F	0.0989*								−0.0341**			
Palladium			0.5363*	−0.1426***		0.2626*	0.2062**	0.1277***	0.0709**			0.0727**
Palladium_F	0.1749*		0.5444*			0.2600*			0.0669**			
Panel B: Long-term correlations												
M1 Growth												
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***	
M2 Growth												
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**				
Unemployment Rate												
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												
Inflation Rate												
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 θ and γ of Money Supply (M1, M2 Growth), Unemployment Rate, Inflation Rate of other G7 and BRICS nations from GARCH-MIDAS(36)-X and DCC-MIDAS(36)-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 other 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
Panel A: Long-term volatility												
Stock Market Returns												
Gold	−0.0775**	0.0438***	−0.1332***		−0.0713***		−0.1213***	−0.0473*	−0.0691**	−0.0590*	−0.0230*	0.3294***
Gold_F	−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*	
Silver_F	−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*
Platinum_F	−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**
Palladium_F	−0.5079***						−0.1129**			0.0923*		
Bond Markets Returns												
Gold		0.3220***	0.1562**	0.7560***	0.1720**	0.1914***	0.2654***					
Gold_F		0.1593*			0.1375**	0.1456***	0.1517**			0.2479**		−0.2818**
Silver		0.2791***		0.5234**								−0.5378*
Silver_F		−0.1737	−0.5924***									−0.7090***
Platinum				0.4937*						0.1692***		
Platinum_F										0.1469**		
Palladium		0.2585**			0.1531*					−0.3194***		0.3017***
Palladium_F	0.2028**		0.1747**		0.1591**	−0.4547**				−0.2726***		
Interest Rate												
Gold		0.0864**	0.1996**		0.2351***	0.1244**	0.2351***			0.1837**	0.5162***	
Gold_F	0.1978*	0.0940*	0.1703*			0.1849**	0.1849**			0.1971**		
Silver				−2.5648**			−0.6129***	1.3216**	1.1509***		−4.0609**	−0.3187**
Silver_F		−0.5317***		1.3974*						−0.1983***		−0.2284**
Platinum				1.9709***							0.2120*	0.0952*
Platinum_F												0.0955***
Palladium	0.1691**		0.4122***	−1.6181**	0.2074***	0.2074**	0.2074**	0.7550*		−0.1630***		0.0850***
Palladium_F		0.0963*	0.3380***		0.1823***	0.1823**	0.1823***					
Exchange Rate												
Gold	−0.0313**	−0.0908***	0.0355***	0.0150***			0.0357**				−0.0252***	0.0332***
Gold_F	−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**
Silver_F	−0.0527***		−0.0383*	−0.0784***	−0.0696**	−0.0685***	−0.0685**		−0.0310**			0.0342***
Platinum							−0.0048*	−0.0322*				
Platinum_F				−0.0148*								
Palladium					0.0265*							−0.0197**
Palladium_F					0.0407**		0.0407**		−0.0256**			0.0302***
Panel B: Long-term correlations												
Stock Market Returns												
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***
Bond Market Returns												
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***											
Interest Rate												
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***											
Exchange Rate												
Gold-Silver		−1.0225***								−0.3862**		
Gold-Platinum					−0.2714*	−0.2714*	−0.2714*					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 θ and γ of Stock Market Returns, Bond Market Returns, Interest Rate and Exchange Rate of G7 and BRICS nations from GARCH-MIDAS(36)-X and DCC-MIDAS(36)-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 other 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
Panel A: Long-term volatility												
Gold				−0.0939**		0.0297**						
Gold_F				−0.0868**		0.0232**						
Silver			0.1668**									
Silver_F							0.0295*	0.0505**				
Platinum	0.2242***	0.1154***		0.2585***	0.2035***		0.0886*				0.0489***	
Platinum_F			0.1783***	0.2575***	0.2146***				0.0622*			
Palladium					0.1341**		0.2026***					
Palladium_F	0.1415**	0.0912**	0.1702**	0.1458*	0.1361***		0.1656**					
Panel B: Long-term correlations												
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 θ and γ of EPUs of G7 and BRICS nations from GARCH-MIDAS(36)-X and DCC-MIDAS(36)-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.