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Macroeconomic factors and frequency domain causality between Gold and Silver returns in India

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ARTICLE INFO
Keywords:
Macroeconomic variables
Inflation rate
Causality
India

ABSTRACT
This paper examines the relationship between gold and silver returns in India, using monthly data for the period May 1991 to June 2018. To this end, we employ the recently developed frequency domain rolling-window analysis (which is able to show that transitory high frequency shocks are not equal to permanent low frequency shocks over time), as well as the conditional, partial conditional, difference conditional approaches, in addition to the Toda Yamamoto and frequency domain Granger Causalities methods. Further, the relationship is examined in conditional and unconditional frameworks. To condition the relationship, three macroeconomic variables, namely interest rate, BSE stock index and inflation rate are used as the control variables. The results uncover some interesting predictability patterns that vary along the spectrum. Specifically, by applying the rolling-window analysis, we find mixed results of the causality between the gold and silver markets based on the frequencies of different lengths. Our results provide policy inputs, assist investors and hedgers who wish to invest in these markets by constructing strategies and diversify their portfolios based on different frequencies.

1. Introduction

Over the past few decades, the major precious metals namely gold and silver have been treated as important financial assets. Scholars argue that the largely traded volumes of these precious assets have greatly increased their liquidity, which has helped promote their tradability (Frankel, 1986; Lutzenberger et al., 2017; Shammugam et al., 2019). Consequently, these assets can be treated at par with other traditional financial assets like stocks and bonds. However, others hold gold and silver as passive investments. Since these assets are unproductive, any growth in their values is entirely dependent on the belief that eventually other investors will be willing to pay more for having these precious metals. Despite the polarized opinions on the investment in gold and silver, pair trading remains a popular trading strategy. This is a market neutral strategy which empowers traders to make profit from essentially any market conditions: sideways, upturns and downturns. Herein, different positions on these two metals are taken simultaneously by hedge fund traders to hedge risk (Huang and Martin, 2017). In order to maximize profits, the traders adopt effective strategies using all the concomitant information about the price behaviour of these metals and all other information related to the macro-economy.

The volatility of all metal prices in general has been a constant source of motivation in examining the behaviour of these prices, particularly during tumultuous times. Therefore, the consequent threat to financial stability makes the macroeconomic management cumbersome. In such a situation, it is advisable to pursue a well-defined portfolio diversification strategy in order to mitigate the external economic threats associated with all volatile metal prices. Nevertheless, the portfolio diversification strategy is effective, if the related metals do not react in consonance with financial markets’ information (CPA Australia, 2012). Similarly, the high volatile prices of the precious metals namely gold and silver would enhance diversification opportunities, which will enable investors to have optimal hedged portfolios. For instance, Baur and Lucey (2010) examine the time-varying relationships between US, UK and German
stones and bonds returns, and gold returns. Those authors’ aim was to probe the existence of gold as a hedge and a safe haven. Their findings suggest that gold is a hedge against stocks but is not a safe haven for bonds in any market situations.

Silver also hold similar properties as that of gold because of its precious value (Ciner, 2001), being a symbol of virtues of fortune (Liu and Su, 2019), and is considered as a close substitute for gold (Lucey and Tully, 2006). Due to silver’s miniaturization stititutability and high similarities with gold, both precious metals pursue arbitrage and low risk spread trading properties. Therefore, a study of this kind is important for investors and policymakers because it helps understand the relationship between the most important precious metals and the macroeconomic environment which should help in financial planning and mitigating risk.

The underlying theory explaining the possible linkage between these two precious metals is not clear in the literature of resource economics (Escribano and Granger, 1998). One strand of the literature argues that both metals are different from one another and are distinctive based on their commercial uses. Therefore, the markets pertaining to these two precious metals should be separated as gold and silver are not close substitutes. Another strand of literature explains that gold and silver, most often act as close substitutes, since they are considered as alternatives and secure investments during financial turmoil and help in mitigating inflationary risks. The prices of the gold and silver are expected to follow unit root process as it is determined in speculative markets. Any evidence of cointegration between these markets, provide insights about the efficient markets.¹ The inclusion of several macro-economic factors which reflects public information in the current study is a value addition in understanding the various forms of the Efficient Market Hypothesis.²

The literature on the gold and silver markets emphasizes three aspects: (i) the responses of those precious metals prices under different economic conditions (Frankel and Hardouvelis, 1985; Cornell and French, 1986; Christie-David et al., 2000; Lucey and O’Connor, 2016); (ii) the predictability of the gold and silver prices (Miffre and Rallis, 2007; Auer, 2016); and (iii) the causal relationship between the gold and silver prices (Wahab et al., 1994; Hillier et al., 2006; Piederzioch et al., 2015; Zhu et al., 2016; Schweikert, 2018). There are a few other researchers that focus on the importance of precious metals such as examining the determinants of price of gold (Levin and Wright, 2006); gold as a safe haven for investments (Hood and Malik, 2013; Shahbaz et al., 2014; Walczak-Gaiko, 2016); investment in gold as a hedge against inflation (Ranson, 2005; Shahbaz et al., 2014) and investment of gold as a hedge against variations in exchange rates (Capie et al., 2004). Therefore, most of the literature focus on gold markets only and ignore other precious metals. In India the platinum and palladium markets are not important. Several past studies had provided evidence of the association between gold and silver prices (e.g., Liu and Su, 2019 for China; Kirithiga and Naresh, 2016 for India; Mishra et al., 2019 for India) in the emerging market economies. In the current study, we contribute to the third aspect by investigating the dynamic causality between gold and silver prices given the presence of major macroeconomic factors in India, by employing among others the recently developed frequency domain rolling window analysis.

From the past literature, we find that Frankel and Hardouvelis (1985), and Cornell and French (1986) underscore the impact of the announcements of money supply on the gold and silver prices. Similarly, Bampinas and Panagiotidis (2015) test the performance and the ability of the long-run hedging of gold and silver to hedge against changes in macroeconomic indicators such as the consumer price index. They find that gold can be completely hedged, while silver cannot. In another study, Hammoudel and Yuan (2008) employ several GARCH-based models to explore the properties of the conditional volatility for four precious metals (i.e., gold, silver, platinum and palladium) by controlling for the shocks of the three-month US Treasury bill interest rate and global oil prices (WTI). They find that the conditional volatility of gold and silver is more persistent but is less sensitive to the leverage effects than that of other precious metals (platinum and palladium) and copper. However, their results become more pervasive when both the federal funds rate and the exchange rate are included.

Among the few available works deciphering the nexus between gold and silver returns, Wahab et al. (1994) explore the relationship between the two series for those precious metals, using data on their daily prices over the period ranging from 1982 to 1992. Further, using monthly data during the period 1971 to 1990, Escribano and Granger (1998) investigate the long-run relationship between gold and silver prices and find cointegration between those two precious metal markets during the bubble and post-bubble periods. Similarly, Ciner (2001) probes the long-run relationship between gold and silver prices of the futures contracts traded on the Tokyo Commodity Exchange and shows a disappearance of the stable long run relationship between those prices during the 1990s (the disappearance is primarily due to the separation of markets). The daily closing data on gold and silver prices commences from 1992 through 1998.

Lucey and Tully (2006) examine the dynamic relationship between gold and silver prices using Fridays’ closing prices over the period 1978 through 2002. They find a strong and convincing relationship between gold and silver prices for the period under investigation. Nevertheless, they also find significant periods when this relationship is weakened. Batten et al. (2013) use daily observations of gold and silver prices over the period 1999 through 2005 to test the association between these two precious metals over different periods and find a dominance of the dependence of positive episodes over the dependence of negative episodes. Mishra et al. (2019), using monthly data during the period June 1991 to June 2018, examine the dynamic causal relationship between gold and silver returns in the Indian market and indicate a short-run causality between gold and silver prices in the full-sample period. Their study uses the rolling window bootstrap approach and confirms a unidirectional causality from gold to silver prices, and the results were in congruence with the findings of the non-linear Granger causality and wavelet-based causality tests. In recent works such as Qin et al. (2020) and Su et al. (2020) examined the Granger-causal relationship in rolling window framework highlighting the importance of capturing the parameter instability to in the gold and silver Granger-causality analysis.

The prime motive of choosing a study examining the linkage between the gold and silver markets in India is due to multiple reasons. First, India hosts the oldest and most extensive physical gold market in the world and Indian gold consumption is often estimated at 1000 tonnes per year. India is also one of the largest silver markets in the world. Most of the gold and silver supplies are imported. Second, India is a country with rich cultural heritage and customs. The precious metals such as gold and silver are highly demanded and hold cultural and traditional significance in India. In particular, the gold and silver ornaments and jewelleries are preferred over other metals during Indian weddings and are considered to be auspicious for new beginnings. The Indian Hindu calendar also mentions the importance of buying these precious metals on auspicious days namely Akshaya Tritiya, Dhanteras, Durga Puja,

¹ Certain attributes namely, prices of assets being sensitive to any new information and the random movement of the asset prices are considered as the basis of the Efficient Market hypothesis (EMH) assessments. If the price adjusts more or less than the normal and the asset prices are non-random, then this leads to a violation of EMH. Granger (1986) mentions that the determination of asset prices in efficient markets cannot be cointegrated.

² The three forms of market efficiency are strong, semi-strong and weak i.e. (1) Strong-it asserts that all information of every kind is reflected in the price of an asset; (2) Semi-strong- this form of EMH asserts that current prices reflect not only historical price information but all publicly available information relevant to an individual asset; and (3) Weak form-asserts that prices fully reflect the information contained in the historical sequence of prices.
Pongal and Onam. Gold is offered to Indian deities and also gifted to people during various occasions. Silver, on the other hand, is least costly and hence preferred over other precious metals by the people for gifting purposes. Moreover, silver jewelleries have become more popular among youngsters because the jewelleries and ornaments made out of it is much more apt and elegant as compared to gold and platinum.

Third, the demand for gold and silver in India is underpinned by the unusually strong demand for jewellery and fast growth in the Indian economy. Fourth, gold and silver prices are affected by the government’s trade policies which affect supply by regulating the material flows. Fifth, prices of these metals are also affected by the volatile behaviour of the Indian rupee. Finally, Indian investors also consider gold and silver as safe havens, and they have moved to those safe havens in a risk-off environment after the increase in coronavirus cases in India.

We contribute to the growing literature on commodity markets, and particularly those of gold and silver, in a multiple of ways.

(i) The present study is focussed on India which is the second largest emerging market after China and has the sixth largest global economy. However, since India’s high gross domestic product (GDP) growth, which affects precious metals prices, dipped to 5.8% in the most recent quarter (that is, the first quarter of the three months going through March of 2019), this slowdown had placed India’s growth behind that of China, thereby making the latter again the world’s fastest-growing large economy (Bellman, 2019). This may have a repercussion on gold and silver markets in India.

(ii) The relatively high demand for gold and silver in India proves the Indian economy to be an ideal candidate for the current study. The literature on platinum and palladium in India is not significant because those precious metals do not play a major role in the Indian context, which justifies conducting this current study on gold and silver markets for India.

(iii) Our contribution to the literature regarding the gold and silver metal markets is particularly in terms of the innovative methodology applied to a very populous country where those precious metals figure highly. Previous studies employ the Johansen cointegration, VECM and linear Granger causality to probe the relationship between Indian futures and spot markets of Gold and Silver (Kirithiga and Naresh, 2016); the rolling-window bootstrap approach to investigate the time-varying causalities between gold and silver prices (Liu and Su, 2019); rolling window bootstrap approach, the wavelet based time-varying Granger-causality test and the non-linear Granger-causality test to provide different insights to the gold and silver returns relationship (Mishra et al., 2019). In particular, the current study employs the frequency domain rolling-window analysis to unfold the causal link between these precious metals. Gold & Silver prices are linked with financial and macro-economic variables as established by Priedziok et al. (2014a,b), Qian et al. (2019) considered the dollar index, the federal funds rate, CPI, exchange rate, oil price and S&P500 in explaining the gold price as drivers of the link. Christie-David et al. (2000) recognize that macroeconomic factors as reflected by financial news that affect metal prices. Therefore, we include some macroeconomic variables, namely the stock market index (BSE), interest rate and rate of inflation, which are used as control variables to examine the causality between gold and silver returns in a conditional economic and financial framework. These variables would reflect the various macro-economic policies undertaken by the government that comes in the form of financial news. This kind of set-up has not been explored in the past literature, and therefore makes this study unique in experiment with regard to the Indian gold and silver markets.

(iv) We consider a relatively large sample using monthly gold and silver returns during the period from May 1991 to June 2018 which also has not been explored earlier. In the year 1991, the government of India adopted a new economic policy to immune the economy from the balance of payment (BOP) crisis. To meet the unsustainable deficit of the BOP, the Reserve Bank of India, in consultation with the government of India, decided to confiscate the gold reserves held by them in order to raise the foreign exchange resources. The government also stopped the import of gold with an immediate effect from October 1, 1990 and allowed the State bank of India to the use of gold lying in the government mint to meet the requirements of the jewellery exporters when gold saved the day for India (i.e., September 4, 2013) (Business Standard, 2013). It is for the first time the gold reserves of the country were depleted drastically. The rationale of the choice of this sample period is due to these notable historic events.

(v) Additionally, the time period considered for the present analysis includes several episodes of crises that occurred in the past namely the East Asian crisis of 1997–1998, the Dot com bubble burst of 2000, the Global financial crisis of 2007–2009 and the European sovereign debt crisis of 2010–2012. We expect that the consequences of the crises would have a considerable impact on the prices and returns of these precious metals, given the macroeconomic factors. The past literature did not consider a dataset of this length. For instance, Ciner (2001) uses the daily closing prices of gold and silver future contracts covering a period from 1992 through 1998 and explores the long-run relationship. Lucex and Tully (2006) consider the Friday closing prices covering a period from 1978 to 2002 and find a weak relationship between gold and silver prices in a few sub-periods and a long-run stable cointegration relationship between these precious metals. Using 15-intraday data ranging from 27 December 1993 through 30 December 1995, Adrangi et al. (2000) probe the price discovery process in the gold and silver price futures contracts. Batten et al. (2013) consider the daily prices of gold and silver from a period 1999 through 2005 to test the bivariate relationship between gold and silver prices. By departing from those earlier studies, an extensive time series data of more than 27 years should be able to provide insights into the various nuances of the markets of these precious metals.

(vi) Finally, the outcome of this study is expected to provide policy inputs to various market participants regarding the bonding relation between those two precious metals in India, using the employed novel and other techniques. Most importantly, a country-level study of this kind is crucial given the uniqueness and heterogeneity of the Indian commodity markets, compared to other emerging market peers. Using four variants of the Granger Causality test and the recently developed frequency domain rolling-window analysis, the study finds a significant bi-directional causality between gold and silver markets in both high and low frequencies, suggesting a strong bonding of the two markets in India.

The remainder of the paper is arranged as follows. In Section 2, we provide a brief description of the methodology and the data used in this research. In Section 3, we discuss the empirical results and policy intricacies. In Section 4 the study concludes.

2. Methodology

To achieve our objectives, we use four variants of the Granger causality: the Conditional Granger Causality (GC), the Partial Conditional Granger Causality, the Difference Conditional Granger Causality and the Toda-Yamamoto Causality as well as the more recent frequency domain rolling-window causality analysis. The conditional GC computes the causality between two variables conditional on another variable (zero or more). It is used to remove the impact of other variables in the causality setting which is not possible using the standard granger causality methods. The partial GC controls the latent and/or exogenous influence.
in the model, in a better way than the conditional Granger Causality. The difference GC is better than the conditional GC in controlling the loss of information that may arise from the low-pass filtering introduced by the hemodynamic response function. The Toda Yamamoto test is a modified version of the Granger causality test which takes one extra lag and can be used for causality testing of the variables, irrespective of the stationary properties. In our case we had applied the Toda and Yamamoto approach to log level series while for other causality tests stationary series were used for analysis. The rolling window method is used to obtain the time-varying relationship, while the frequency domain GC is used to understand the behaviour of traders in the short and long run. The mechanism of the various methods used in the analyses is explained as follows.\(^3\)

2.1. Granger causality

Wiener (1956) advocated a way to measure the causal influence of one time series on another by intuiting that the prediction of one time series could be improved by capturing the knowledge about the other. This idea is formalized by Granger (1969) who contextualised the linear vector auto-regression (VAR) modelling of stochastic processes. The Granger Causality (GC) is sometimes called the Wiener-Granger causality.

Suppose X, Y, and Z are univariate time series of length T. The joint autoregressive representation of Y and Z can be written in the form of Eq. (1) as:

\[
Y_t = \sum_{i=1}^k a_i Y_{t-i} + \sum_{j=1}^k b_j Z_{t-j} + \epsilon_t
\]

(1)

To check whether X Granger causes Y given Z, the model can be extended in the form of Eq. (2) via,

\[
Y_t = \sum_{i=1}^k a_i Y_{t-i} + \sum_{j=1}^k d_j Y_{t-j} + \sum_{i=1}^k e_i Z_{t-i} + \epsilon_t
\]

(2)

where, \(a_i, b_j, d_j, e_i\) are coefficients of the variables, and \(\epsilon_t\) are error terms. The Granger causality statistic from X to Y conditioned on Z may be expressed as Eq. (3):

\[
F_2 = \ln \left( \frac{\text{VAR}(\epsilon_t | Z)}{\text{VAR}(\epsilon_t)} \right)
\]

(3)

This estimated value is a type of the F-statistics. If the information in the previous time points to X helping in predicting the current time point in Y, then the \(F_2\) value would be larger than zero. On the other hand, the \(F_2\) value shown in Eq. (3) would be around zero when X will not help in the prediction of Y.

This GC measure can be defined for multivariate time series. If the dependent variable Y is no longer univariate, but a vector of observed responses measured at time t (that is, \(Y_t = Y_{1t}, Y_{2t}, \ldots, Y_{kt}\) then Eqn. (3) is no longer useful. This formula is then extended to the multivariate case by two approaches. The first was advocated by Ladroue et al. (2009) who used the multivariate mean squared error or the trace of the error covariance matrix, \(\text{tr}[(\epsilon_t | \sum (\epsilon_t))\), that leads to Eq. (4) as follows.

\[
F_2 = \ln \left( \frac{\text{tr}[(\epsilon_t | \sum (\epsilon_t))]}{\text{tr}[(\epsilon_t)]} \right)
\]

(4)

The second approach is Geweke (1982) which uses the generalized variance or the determinant of the error covariance matrix, \(\text{det}[(\epsilon_t)]\) leading to Eq. (5) as follows.

\[
F_2 = \ln \left( \frac{\sum (\epsilon_t)}{\sum (\epsilon_t)} \right)
\]

(5)

The superiority of Eqn. (5) over Eqn. (4) is that it asymptotically approximates the \(\chi^2\) distribution for large samples (Barrett et al., 2010). But, for small samples, the distribution is unidentified and the resampling techniques are more appropriate to construct the null distribution. Based on Eqn. (5), the conditional multivariate GC (CMGC) can be computed. Further, the partial multivariate GC (PMGC) could be computed as introduced by Guo et al. (2008). PMGC is different from CMGC in the inclusion of the present conditioning variables Z in the joint autoregressive representation of Y and Z as reflected in Eq. (6)

\[
Y_t = a_i Y_{t-i} + b_j Z_{t-j} + \epsilon_t
\]

(6)

Now we can check whether X partial Granger causes Y given Z with Eq. (7).

\[
Y_t = c_i Y_{t-i} + d_j X_{t-j} + e_i Z_{t-i} + \epsilon_t
\]

(7)

where, \(a_i, b_i, c_i, d_i, e_i\) are coefficients of the variables, and \(\epsilon_t\) are error terms. The partial Granger causality from X to Y conditioned on Z may be expressed as follows.

\[
F_1 = \ln \left( \frac{\sum (\epsilon_t)}{\sum (\epsilon_t)} \right)
\]

(8)

The \(F_1\) statistic in Eq. (8) represents the ratio of two error variance/covariance matrices. If the log ratio is significantly larger than zero, then the variables X partially Granger causes the variables Y, conditioned on the variables Z. As is the case for CMGC, the \(H_0\) distribution of no causality is unidentified. Hence, resampling techniques must be used to construct confidence intervals around the \(F_1\) estimator. CMGC controls for the latent and/or exogenous influences to some extent as the determinant of the error covariance matrix is sensitive to the residual correlations. But PMGC considers even more correlations, particularly to minimize the influence of the sources of the variation outside the model. When such influences are expected to be strong and uniform over all variables in the model, PMGC is to be preferred over CMGC (Barrett et al., 2010). When no conditional variables are included in the model, PMGC and CMGC will produce the same MGC measure.

Moreover, another type of the GC test was presented in the work of Roebroeck et al. (2005), Geweke (1982) advocated a measure of the linear dependence \(F_{xy}\) between X and Y that implements GC in terms of the VAR models. \(F_{xy}\) consists of sum of three components of directed influence:

\[
F_{xy} = F_{x\rightarrow y} + F_{y\leftarrow x} + F_{x\leftrightarrow y}
\]

(9)

where \(F_{x\rightarrow y}\) is the directed influence from X to Y, \(F_{y\leftarrow x}\) is the directed influence from Y to X, and \(F_{x\leftrightarrow y}\) is the contemporaneous influence (see Eq. (9)). Roebroeck et al. (2005) used the difference between \(F_{x\rightarrow y}\) and \(F_{y\leftarrow x}\) as a GC measure for the influence region X has on region Y. A drawback of this approach is that the feedback connections are not modelled. The difference conditional Granger causality computes the difference between the multivariate GC measures \(F_{x\rightarrow y|z}\) and \(F_{y\leftarrow x|z}\). It shows the difference between the CMGC from variable X to variables Y and Z minus the CMGC from variables Y and Z to X.

2.2. Frequency domain rolling window analysis

The Granger causality (GC) test introduced by Granger (1969) is widely used in the literature to analyse whether one variable X (Y) happens before another variable Y (X) which helps in the prediction. The GC test is usually conducted in a VAR framework, considering a single
is described in Eq. (10) as:

\[ \omega \beta \] 

2014, 2015, and the references therein). Therefore, we provide a small introduction of this approach. There are several studies who used this approach (for example, Tiwari et al., 2014, 2015, and the references therein). Therefore, we provide a small introduction of this approach.

Under a stationary VAR model, the relation between gold and silver is described in Eq. (10) as:

\[
\begin{align*}
d_{gold} &= a_0d_{gold,t-1} + \ldots + a_p d_{gold,t-p} + \beta_1 d_{silver,t-1} + \ldots + \beta_p d_{silver,t-p} + \epsilon_t \\
d_{silver} &= b_0d_{silver,t-1} + \ldots + b_p d_{silver,t-p} + a_0 d_{gold,t-1} + \ldots + a_p d_{gold,t-p} + \mu_t
\end{align*}
\]

where \(d_{gold}\) and \(d_{silver}\) are the first difference of gold and silver, respectively; and \(a_0\) and \(\beta_0\) are coefficients, while \(\epsilon_t\) and \(\mu_t\) are the error terms.

As the method of Breitung and Candelon (2006) has been applied in several recent studies (e.g., Huang et al., 2016; Batten et al., 2017; Ciner, 2013), we restrict ourselves to the presentation of the primary conclusion drawn from this study. In the present study of the context, the Granger causality from silver (gold) to gold (silver) at any frequency (\(\omega\)) can be tested under the linear restriction given by:

\[ H_0 : R(\omega)\beta = 0 \]  

where \(\beta = \beta_1, \beta_2, \ldots, \beta_p\) and

\[
R(\omega) = \begin{pmatrix} \cos(\omega) & \cos(2\omega) & \cos(p\omega) \\ \sin(\omega) & \sin(2\omega) & \sin(p\omega) \end{pmatrix}
\]  

According to the approach of Breitung and Candelon (2006), an ordinary F-statistic for Eqns. (11) can be used to test the null hypothesis at any frequency interval (i.e., \(\omega \in (0, \pi)\)) since it is approximately distributed as \(F(2, T - 2p)\). Further, for the purpose of the interpretations in the time framework, the frequency parameter \(\omega\) (omega) can be used to obtain the time period of the causality in months (\(T\)) by using formula \(T = 2\pi/\omega\).

Further, we used macroeconomic variables including the stock market index (BSE), the interest rate and the rate of inflation as control variables to examine the causality between gold and silver returns in a conditional set up.

3. Empirical analysis

3.1. Data and preliminary statistics

The data used in this paper consist of the monthly average prices of gold and silver in Mumbai, monthly average of the BSE sensitive index (BSE), weighted average monthly call money rate as a proxy for interest rate (\(INTR\)) and inflation rate (\(INFL\)) estimated using the wholesale price index (\(WPI\)). The data are collected from the Handbook of Statistics published by the Reserve Bank of India for the period May 1991 to June 2018. The selection of the time period is based on the availability of the data.

| Variable | Mean | Median | Std.Dev. | Skewness | Kurtosis | L-B(10) | Jarque-Bera | KPSS | ZA |
|----------|------|--------|----------|----------|----------|---------|------------|------|----|
| Gold Return | 0.659 | 0.547 | 1.024 | -0.046 | 0.463 | 11.800 | 30.100 | 0.235 | -6.451 |
| Silver Return | 0.406 | 0.293 | 1.457 | 0.000 | 0.434 | 28.679 | 55.920 | 0.134 | -6.885 |
| BSE Stock Return | 13.423 | 5.349 | 6.701 | 0.317 | 0.356 | 35.528 | 6.881 | 0.054 | -6.971 |
| Interest Rate Change | -10.917 | -19.328 | -27.887 | -10.470 | -1.891 | 20.490 | 34.422 | 0.050 | -8.291 |
| Inflation Rate | 3.156 | 0.434 | 6.701 | 0.076 | 0.0431 | 20.490 | 34.422 | 0.718 | -5.377 |

Notes: KPSS is the Kwiatkowski–Phillips–Schmidt–Shin test and ZA is the Zivot–Andrews unit root test. L-B is the Ljung–Box correlation test.

\(\alpha\) Denotes the statistical significance at the 1% level.
Causality reveals a one-way causality from silver to gold at the low (10 percent) level of significance. The rest of the Granger Causality tests (Conditional and Partial Granger Causalities) reveal no causality between gold and silver. But the presence of heterogeneity in the markets is crucial in explaining the relationships between the examined variables. Therefore, we have also conducted the Frequency domain analysis based on the spectral analysis to capture the heterogeneity behaviour of investors in distinct markets and explore the results in great detail.

3.2. Frequency domain analysis

The usual time domain causality explains the relation between the variables by estimating a fixed coefficient which is constant at all frequencies. In contrast, the spectral-causality approach of Breitung and Candelon (2006) decomposes the directional causal relationship at different frequencies using the spectral method and helps us to explore in details if the sensitivity of a variable (i.e., gold returns) to transitory high frequency shocks in another variable (i.e., silver returns) is equal to permanent-low frequency-shocks. This method allows us to decompose the causality test statistic into different frequencies.

In Fig. 1, we show the unconditional relationship between gold and silver prices returns—the full sample period. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Note:** The frequencies (\(\omega\)) are placed on the x-axis, whereas the y-axis shows the F-statistics testing the null hypothesis of no Granger-causality.

![Breitung-Candelon Frequency Domain Unconditional GC Test](image1)

In Fig. 2, we provide the conditional relationship between the two precious metal variables where the behaviour of other control variables like inflation rate, interest rate and stock market is considered. The frequency band parameter (\(\omega\)) on the horizontal axis is taken to calculate the length of the period \(T\) measured in months, which corresponds to a cycle where \(T = 2\pi/\omega\). The results from the frequency domain causality test give a broader view of the direction and strength of causality in different markets.

![Breitung-Candelon Frequency Domain Conditional GC Test](image2)

**Note:** The frequencies (\(\omega\)) are on the x-axis, whereas the y-axis shows the F-statistics testing the null hypothesis of no Granger-causality.
frequencies, which one cannot find using other methods. Fig. 1 suggests that silver Granger causes gold for a short span of time that is within the frequency bands 0.88 to 1.34, which correspond to wave lengths between 5 and 7 months. It implies that silver price returns affect gold price returns for a very short span of time and a medium cycle length. However, it can be seen from the figure that gold causes silver for the whole sample period and for all frequency bands considered in our analysis.

In Fig. 2, the relationship between gold and silver returns is conditional on the behaviour of other macro-economic variables such as BSE, interest rate and inflation. It reveals that gold Granger causes silver in the short to the medium terms that is, within the frequency bands 0.02 to 1.43, corresponding to wave lengths of around 7 to 9 months. Contrary to the unconditional relation in the conditional relationship, we find that silver Granger causes gold for all the frequency bands considered in this work. Therefore, we confirm a bi-directional causality between gold and silver returns. This is clear that shocks in gold returns can also spread quickly to silver returns. The feedback effect holds good for the shorter intervals. This implies that the macroeconomic information, i.e. under the conditional set up, the causal relationship between gold returns and silver returns turns out to be robust and significant. Our findings support the semi-strong form of market efficiency as the macroeconomic information seems to be fully transmitted to these precious metal markets.

3.3. Out-of-sample rolling causality

To examine whether the bi-directional causality findings are significant in the out-of-sample forecasting exercises, we apply a rolling causality analysis in the frequency domain. The out-of-sample forecasting exercises incline to be more robust to structural changes than is the case in the in-sample causality analysis (Batten et al., 2017). Therefore, a fixed window size of 24 months having 24 observations is considered in our analysis. The short-term causality tests are conducted at the frequency 2.5, corresponding to a wavelength of 1.2 months. The long-term causality tests are conducted at the frequency 0.5, corresponding to a wavelength of 24 months. The results are reported for the unconditional relationship between gold and silver for the frequencies 0.05 and 2.5 in the respective panels (a) and (b) of Fig. 3.
Fig. 3(a) depicts the bi-directional causality between silver and gold in the long run. The frequency curve showing the causality from silver to gold has three dominant peaks, i.e. from February 1994 (because of the implementation of floating exchange rate regime by the Indian government) to October 1998 (the East Asian financial crisis); May to December 2008 (the global financial crisis), and September 2011 (Arab Spring) to February 2012 (debate on potential economic growth in India). It has also three short-lived peaks that occurred in February 2001, August 2006 and June 2015 (the stock market crash in India due to the increase in the levels of net performing assets during 2015). On the other hand, the frequency curve showing the reverse causality from gold to silver has three dominant peaks in July 1993 to February 1994 (decline in per capita GDP in India), December 1997 to October 1999 (Asian currency crisis), and April to September 2013. On September 14, 2012, gold broke all its previous records to touch the Rs. 32,900 mark for 10 g in the spot market and reached a new high in the futures market in April 2013. It has also ten short-lived peaks.

Fig. 3(b) depicts the bi-directional causality between silver and gold in the short run. The causality from silver to gold shows a higher magnitude, as compared to the reverse causality. The frequency curve showing the causality from silver to gold has three dominant peaks i.e. from July 2006 to January 2008 (the high commodity boom period);
August to November 2008 (collapse in oil prices), and October 2011 to March 2012 (new high oil prices). It is to be noted here that the causality from silver to gold arises for the first time in July 2006 which corresponds to a near peak in commodity prices. Our findings are similar to previous studies. For instance, Escribano and Granger (1998) show a considerable impact of financial crises on the cointegrating relationship between gold and silver prices and prove the impact to be time varying. Similarly, Baur and Tran (2014) also find a role and an influence of the financial crises and bubbles on the stable equilibrium relationships between gold and silver prices. The causality has also two short lived peaks that occurred in December 1999 and July 2015 which are down periods for commodities. The frequency curve depicting the reverse causality (i.e., from gold to silver) has three dominant peaks which are from March 2002 to February 2003 (the rise in oil prices due to using zone pricing by OPEC), August 2006 to April 2008 (the commodity boom years), and May to November 2013 which are declining months for silver. The RBI decided to lower the repo rate by 25 bps during the third quarter review of the monetary policy in January 2013. It has also six points that show short-lived peaks.

Our results of obtaining a bidirectional relationship both in the long run as well as in the short run are in accord with the previous studies. These results are in consonance with a previous work by Mishra et al. (2019) who have found a bidirectional causal relationship between gold and silver returns in the short run by employing the Granger Causality in a VAR framework. However, their results show a unidirectional relationship between the gold return to the silver return when the rolling window bootstrap approach, the wavelet-based causality framework and the non-linear Granger causality test were used. Our results also contrast with those of Liu and Su (2019) who find significant positive and negative time-varying effects from the gold return to the silver return only.

The conditional relationships between gold and silver for the frequencies 0.05 and 2.5 are reported in the respective panels (a) and (b) of Fig. 4. Fig. 4(a) depicts the bi-directional causality between silver and gold in the long run. The frequency curve showing the causality from silver to gold has eleven dominant peaks and eight short-lived peaks. On the other hand, the frequency curve exhibiting the causality from gold to silver has several dominant peaks with a higher magnitude. In Fig. 4(b), the frequency curve is showing the conditional causality from gold to silver in the short run. The short-run relationship between gold and silver returns is alike, with the long-run relationship establishing a bi-directional causality between those two precious metals.

To check the robustness of the results, we use the rolling-window analysis with a window size of 24 months. We also consider a 48 month-rolling-window analysis to examine the unconditional and conditional causality between gold and silver. The results are reported for the unconditional relationship between gold and silver for the frequencies 0.05 and 2.5 in the respective panels (a) and (b) of Fig. 5. In the
In the long run, the magnitude of causality from gold to silver (Panel (a) of Fig. 5) is more nuanced than the causality from silver to gold. However, in the short run (Panel (b) of Fig. 5), the magnitudes of causality from gold and silver and the reverse are similar.

The conditional relationships between gold and silver for the frequencies 0.05 and 2.5 are reported in the respective panels (a) and (b) of Fig. 6. In the long run, there is a one-way causality from gold to silver. However, in the short run, there is evidence of a bi-directional relationship between gold and silver. This implies that the forces that move those two precious metals are not the same in the short and long run. Central banks particularly in emerging markets purchase and sell gold but not silver. India holds about 10% of its foreign reserves in gold. Moreover, gold is more affected by the long run public debt than silver. Both metals have different physical characteristics which make them more suitable for different industries and new technologies (e.g., photovoltaic systems). Silver has more correlations with different asset classes than gold does.

Many studies have shown the association between commodity returns and inflation. For instance, Furlong and Ingenito (1996) explore the relationship between the returns of commodities and inflation. The authors find that the returns of commodity prove to be a significant indicator of inflation during the 1970s and in the early 1980s. However, this relation had lost its significance in the post 1980s. In contrast, Mahdavi and Zhou (1997) indicate that the cointegrating relationship between gold prices and the consumer price index is not as much important as with other commodity prices. Ye et al. (2019) find that CPI significantly Granger causes Chinese commodity futures prices. Belke et al. (2014), while controlling for the variations in monetary policies and interest rate changes, find that this aggregate factor influences the movements of goods and commodity prices in the long run. We find mixed results when we consider the unconditional causal relationship and conditional relationships between the gold and silver returns in the long run and in the short run.

4. Conclusion

In this paper, we employ several bivariate Granger-causality methods such as the Conditional, Partial conditional, Difference conditional, Toda Yamamoto, and frequency domain Granger Causalities methods, wherein the rolling-window approach is applied in the frequency domain causality analysis in order to examine the causality between gold and silver returns in India. All these diverse methods are applied to account for time scale, control variables, heterogeneity in both metals, and for getting robust results. In the bivariate causality analysis, we find a bi-directional causality between gold and silver as demonstrated by the Toda-Yamamoto Granger Causality test. The

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Fig. 6. Rolling-window frequency domain conditional causality between gold and silver returns. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Note: The dotted lines in Panels (a) and (b) represent the long run causality with $\omega = 0.05$ and the short run causality with $\omega = 2.5$, respectively.
difference conditional Granger causality reveals a one-way causality from silver to gold at the low 10 percent level of significance. The rest of the Granger Causality tests (Conditional and Partial Granger Causalities) reveal no causality between gold and silver.

Considering the heterogeneity issue in the gold and silver markets, we applied the spectral-causality approach of Breitung and Candelon (2006) in the frequency domain. The bivariate unconditional causality analysis reveals that silver Granger causes gold for a short span of time; that is within the frequency bands 0.88 to 1.34 corresponding to wave lengths of around 5–7 months. However, gold causes silver for the whole sample period and for all frequency bands considered in our analysis.

Next, we attempt to take note of the presence of the relevant macro-economic variables and examine the relationship between gold and silver conditional on the behaviour of variables like the stock index BSE, interest rate and inflation. We find that gold Granger causes silver in the short to medium terms, i.e. within the frequency band 0.02 to 1.43, corresponding to wave lengths of around 7–9 months. In contrast to the unconditional relation, in the conditional relationship we find that silver Granger causes gold for all the frequency bands considered in this work. Based on these results, we conclude that there is bi-directional causality between gold and silver returns in India.

In the long-run, using the unconditional framework, the result of the out-of-sample analysis reveals a causality from silver returns to gold returns during February 1994 to October 1998, May to December 2008, and September 2011 to February 2012. However, the causality from gold to silver is found during the periods July 1993 to February 1994, December 1997 to October 1999, and April to September 2, 013. In the short run, the causality from silver to gold is of higher magnitude as compared to the reverse causality. On the other hand, the out-of-sample analysis, using the conditional setup when macroeconomic factors are considered, confirms a bidirectional relationship between gold and silver returns.

Our results exhibit mixed forms of causality between gold and silver returns based on different frequencies. The mixed findings can have different policy implications for the investors. For instance, in the case of the unidirectional causality running from gold to silver, it is advisable for investors to invest in gold markets because this shiny metal has a spillover effect on the silver market. In a nutshell, investing in the gold market will be beneficial. This is because any instabilities in the silver market cannot impact the gold markets; as silver returns do not cause gold returns. Therefore, our results provide interesting insights from the perspective of portfolio diversification and the preparation of proper investment strategies.

The present findings substantiate the semi-strong form of market efficiency which explains that the transmission of macroeconomic information is getting absorbed and reflected in the prices of these precious metals. Thus, considering the out-of-sample analysis which shows a bidirectional causality, using the conditional setup when macroeconomic factors, we cannot predict gold returns using the silver returns as all information in the macroeconomic factors is quickly reflected in the gold prices, supporting the Efficient Market Hypothesis.

These findings help to explain the relationship between gold returns and silver returns in the context of regulatory framework adopted by the monetary authorities in India through changing the interest rate. Moreover, the behaviour of the stock market and the level of inflation, which comes in the form of financial news, could affect the relationship between gold and silver returns. The current results should be help market participants to carry out strategies related to optimal portfolio diversification, trading and hedging.

CRediT authorship contribution statement

Ashis Kumar Pradhan: Writing - review & editing.
Bibhuti Ranjan Mishra: Writing - review & editing.
Aviral Kumar Tiwari: Conceptualization, Data curation, Software, Validation, Supervision, Writing - review & editing.
Shawkat Hammoudeh: Supervision, Writing - review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2020.101744.

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