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BANKING & FINANCE | RESEARCH ARTICLE

Volatility integration of crude oil, gold, and interest rates on the exchange rate: DCC GARCH and BEKK GARCH applications

Shailesh Rastogi¹, Jagjeevan Kanoujiya² and Adesh Doifode^{3*}

Abstract: Literature is replete with evidence of market integration between crude oil, gold and interest rates (IR) with the exchange rate (ER) due to varied reasons. However, it is observed that the explored market integration is limited for the price and return volatilities. Bivariate GARCH models (BEKK-GARCH and DCC-GARCH) are used in this research to ascertain the conditional volatility association of gold, crude oil and yield (or IR) on the ER (the price of US\$ in Indian rupee). The daily basis data from January, 2000 to December, 2022. Except for a few cases, it is found that the conditional covariance association of gold, crude oil and the yield on the ER are significant for both shocks and persistence. It confirms the economic theories of market connectivity. The results are as expected (from the previous literature) for conditional volatility, whereas findings regarding volatility spillover effects (VSE) and are surprising. The findings of the study imply the separation of price or returns integration from volatility integration. Co-movement of the prices has a limited impact; however, volatility integration has a larger and long-term impact. Therefore, the study endorses the views that gold, crude oil and IR markets can be treated separately from the ER markets with respect to the risk management of the ER. Studies involving volatility integration from these markets on the ER are not easily available. Therefore, there is a lack of knowledge about the nature of association with respect to the volatility among these markets, especially with respect to the ER market. The findings give key implication that government should consider these macroeconomic variables (gold-oil-interest) resilient against ER volatilities.

Subjects: Economics; Finance; Business, Management and Accounting

Keywords: bivariate GARCH; volatility; gold; crude oil; interest rates; exchange rate

1. Introduction

Market integration of assets and commodities is an important phenomenon and is obvious for various reasons. After globalization and opening up of the markets across the world, market integration is obvious (Garrett, 2000). Academicians and practitioners are also intrigued by this alike. Literature has profusely captured the phenomenon (Bekaert & Harvey, 1995; Bekaert et al., 2005; Carrieri et al., 2007; Pukthuanthong & Roll, 2009). The integration is seen not only across countries in the same market (Rastogi, 2010) but it is also witnessed across different markets (different commodities or between commodities and macroeconomic indicators) in the same

country or in the different countries (Ghosh & Kanjilal, 2016; Kanjilal, 2011; Kanjilal & Ghosh, 2017). Volatility integration of markets means the transmission of VSE from one market to another market. It shows a temporal effect like shock effect or price effect that transmits from one market to another (Ghosh & Kanjilal, 2016; Kanjilal, 2011; Kanjilal & Ghosh, 2017).

Exchange rate is at the centre stage especially for the 21st century when the markets are well connected and integrated (Albuquerque et al., 2005). It plays an important role in “international trade” and “balance of payments”. Hence, determinants affecting exchange rate needs to be explored as of its prime importance (Ozturk, 2006; Sugiharti et al., 2020). The literature is quite vibrant to delineate the role of ER and its impact on a various and varied aspect of any economy including on India (Bahmani-Oskooee & Mitra, 2008; Berdiev et al., 2012; Khandare, 2016).

The exchange rate is and should be well connected to gold and crude oil as both usually have a high chunk of export and import bill of countries, which are denominated in foreign currencies (Arfaoui & Bem Rejeb, 2017). However, the nature of association, which are explored between ER and other items (mainly gold, crude and IR), have certain limitations. Firstly, studies between ER and said commodities are usually of correlation, cointegration or regression. The volatility integration or VSE is conspicuously absent from the arena for no valid reason or justification (Shiva & Sethi, 2015; Zhang & Wei, 2010). Secondly, studies investigating IR with ER are few and mostly inconclusive (Benigno & Benigno, 2008; Cadenillas & Zapatero, 2000; Hnatkovska et al., 2013). In addition to this, the direction of these researches examining linkages of exchange rate with interest rates are unidirectional, i.e. from exchange rate to interest rates and not the other way round (Flood & Jeanne, 2005).

The nature of integration is varied across markets, commodities and macroeconomic indicators. The market integration has been usually captured using: 1) correlation (Dumas et al., 2003; Longin & Solnik, 1995, 2001); 2) regression (Bekaert & Harvey, 1995; Bekaert et al., 2005); 3) cointegration (Ghosh & Kanjilal, 2016; Rastogi, 2016b); 4) regime switching (Kanjilal & Ghosh, 2017); and 5) volatility integration (or VSE) (Du et al., 2011; Lu et al., 2014). The lack of volatility integration from these markets to the ER market is an appropriate research gap and therefore same is explored in the current study.

The objectives of the current study are as follows: 1) to explore conditional covariance between exchange rate and other items (crude, gold and IR); and 2) to examine the volatility spillover impact from crude oil, gold and IR on the ER.

The motivation of the current research is apparent as the literature shows all type of association between exchange rate and commodities but an association of their volatilities are missing. Investigation of volatility connection between the markets is important to reveal both short-term and long-term effects transferring from one market to another. All the four markets, taken into consideration in the present study have one common platform that all these markets affect internal and external sectors of any economy including of Indian economy. Moreover, the existence of the association of other type (cointegration and regression) also encourage to explore untapped or unexplored association of volatility among them. As discussed earlier, volatility effects transferring from gold, crude, and IR to ER are not examined. Thus, we believe that this study is novel both in exploring volatility connection between these markets with the application of advanced multivariate GARCH models (BEKK-GARCH and DCC GARCH on the daily sample data of 20 years, January, 2000- December, 2020). Hence, the current outcomes give fresh and more reliable evidence.

The findings of the study are important part of the contribution in the field of market integration, volatility integration and conditional covariance which hitherto remained untapped. The major implication of the study is for the policymaker who can decide on the kind of OMO (Open Market Operation) and other intervention to adjust the market forces and adjust the prices of one market

without worrying for its adverse consequences on the other markets. In the present context, policymakers can take care IR, crude oil and gold-related issues without worrying about their adverse impact on the volatility of the ER.

The paper is organized into five sections. Starting with introduction followed by the second section on the review of literature. The third section is about Data and Methodology. In the fifth section, results and discussion are presented followed by fifth section with the conclusion and future scope.

2. Literature review

The studies on the topic are variously varied. A thematic literature review is presented in the paper. Studies on the exchange rates are in focus and studies having gold, crude oil are IR having any kind of association with ER are captured and discussed in this section.

Exchange rate risk originates from ER volatility, which influences the amount of foreign trade and, consequently, the balance of payments in specific ways (Ozturk, 2006; Sugiharti et al., 2020). Theory-based evaluations of Hooper and Kohlhagen (1978) and a few other economists did research on the connection between higher ER volatility and international trade transactions. The following is the argument: less international trade and higher costs for risk-averse traders are the outcomes of more volatile currency rates. This is because, although the ER is chosen at the time of the trade, money is not transferred until the future delivery is actually fulfilled. Unpredictable changes in ER reduce the benefits of commerce by casting doubt on the potential gains.

However, recent theoretical advancements imply that there are circumstances in which it could be expected that the ER volatility will either be consequences on the amount of trade, or favourable or adverse. According to De Grauwe (1988), there can be a correlation between trade and ER volatility that is favourable if income benefits outweigh substitution effects. This is due to the fact that an increase in ER volatility will raise the expected marginal utility of export earnings, which will encourage exporters to increase their exports if they are sufficiently risk averse (Ozturk, 2006; Sugiharti et al., 2020). According to De Grauwe, the impact of ER uncertainty on exports should be determined by the level of risk aversion (Ozturk, 2006; Sugiharti et al., 2020). De Grauwe opined that the degree of risk aversion should determine how the consequences of ER uncertainty will be on exports (Ozturk, 2006; Sugiharti et al., 2020) like gold, IR and oil among the most popular trading commodities in international trade market. Thus, these markets (gold, interest rate and oil) can influence the ER. However, empirical evidence on volatility-based studies are not available in significant amount.

There are several theoretical perspectives on the connectivity of gold, crude oil and interest rates to exchange rate. The monetary theory of gold and oil prices posits that gold and oil prices are influenced by monetary factors such as ER and vice versa (Akbar et al., 2019; Kumar et al., 2023; Sujit & Kumar, 2011). There exists a theory popularly known as “International Fisher Effect Theory”. This theory advocates that IR affects the exchange rate of two currencies (Akbar et al., 2019; Kumar et al., 2023).

Two other economic theories on the connectivity of macroeconomic factors are “Substitution Effect Theory (SET)” and “Income Effect Theory (SET)” (Giannellis & Koukouritakis, 2019). In SET (substitution impact), investors might choose to invest in currency instead of gold when the value of the latter is on the rise (Giannellis & Koukouritakis, 2019). In IET, wherein an increase in the real value of the currency (which reflects improved macroeconomic performance) may encourage greater investment not only in money but also in gold. According to data, the income effect (i.e., the positive association) is proven to be more significant for low misalignment rates, but when the misalignment rate approaches the upper regime, the substitution effect takes precedence (Bhutta et al., 2022; Giannellis & Koukouritakis, 2019). Some researches such as Asad et al. (2020), and Tabash et al., (2022) have there foundation on “Arbitrary Price Theory” for Gold-oil-exchange

rate connectivity. This theory says that assets and commodity prices are triggered by unanticipated economic phenomena (Christofi et al., 1993).

There are many studies which cover gold and exchange rates. However, application of bivariate GRACH family of models to study the association between the two are non-existent. Corollary of this observation implies that no study made an attempt to explore the association of either conditional co-variance or volatility spillover between the two markets. Capie et al. (2005) present gold as the hedge for the ER and find evidence of strong association of gold with ER. Asad et al. (2021) and Sheikh et al. (2020a) have also found the significant association of gold and ER. The role of gold and ER is anachronistic and is redolent of gold-based ER system prevailed in the world (Bordo, 1981; Bordo & Schwartz, 2009). Baur and Lucey (2010) also explore gold as the hedge against different investment options. But, in both the case, there is no discussion of co-variance or volatility spillover between the two markets. Dooley et al. (1995) evince the findings that gold is the determinant of the ER(s). They use multiple regression and cointegration to examine the interconnection between ER and gold; however, any discussion on the volatility front was skirted. Sjaastad (2008) explores the impact of ER on the gold price but discussion on the volatility between them is eluded.

Only a study by Zagaglia and Marzo (2013) uses Bivariate GARCH model to study the linkages between gold and ER. However, the method as well as analysis of the paper does not provide much information about the VSE in detail. They confine the study to talk about impact of financial turmoil during 2007–2008 on the volatility of gold and ER. Hence, the methods and the purpose of the current paper justify this study. Thus, following hypotheses in alternate form are framed:

H1: There is a conditional covariance between gold prices and exchange rates.

H2: There is a volatility spillover effect from gold to exchange rates.

H3: Volatility spillover effect exists from exchange rate to the gold rates.

The association between oil and ER is also of very strategic importance. Crude is one of the most traded commodities in the world and most of the time the invoicing is done in the foreign currencies (Kumar et al., 2023; Zhang et al., 2008). The studies on the mutual association have usually been limited to non-volatility discussion and if volatility discussion are included, the methodology remains weak (Zhang et al., 2008) and usually uses univariate GARCH model to the most. However, the use of bivariate GARCH family of model are essential to truly capture the spillover effect in volatility from one market to the another (Aggarwal et al., 2021a; Bauwens et al., 2006). Patil and Rastogi (2020), Rastogi and Agarwal (2020), and Rastogi and Athaley (2019) have also advocated to implement the GARCH applications to observe the volatility effects between these markets. Chang et al. (2013) do find some evidence of the interaction between crude oil and ER in their study in Taiwan during 2007–2011. Ghosh (2011) uses univariate GARCH model to discuss the volatility influence on both the markets. Neither of the studies seems to be conclusive nor the method used is adequate to address the issue of VSE between both the markets. However, the study was done during the same time period (2007–08) but the results are of different nature. Hartley and Medlock (2014) use cointegration to advocate a long-term influence of ER on oil prices in the USA. Akram (2004) uses non-linear model to explore the negative long-term association between oil and Norwegian currency. Asad et al. (2021) and Sheikh et al. (2020a) explore the linkage between crude oil prices and ER with a support to the arbitrary price theory.

The literature is copious with the studies between oil and ER (Al-Abri, 2013; Ciner et al., 2013; Rastogi, 2016a). However, either study on the volatility aspect between the two markets are not done and if it is done, it uses inferior methodology. Therefore, following hypotheses are framed for the empirical testing in the current paper:

H4: There is a conditional covariance between crude prices and exchange rates.

H5: There is a volatility spillover effect from crude prices to exchange rates.

H6: Volatility spillover effect exists from exchange rate to crude prices.

The relationship between IR and ER is inconclusive. Against the popular belief and some accepted research work to confirm the association between the two (Benigno & Benigno, 2008; Cadenillas & Zapatero, 2000; Flood & Jeanne, 2005), most of the studies remain inconclusive between the two markets (Hnatkovska et al., 2013). The inconclusive nature of the relationship is not limited to developed economies (Meese, 1990; Meese & Rogoff, 1988) but to the developing nations as well (Calvo & Reinhart, 2002). Sheikh et al. (2020b) have also indicated that macroeconomic variability of interest rate influences money support. This signals indirect connectivity of IR and ER. In addition to these, there are other evidence as well which postulate the same concern regarding the association between IR and ER. However, the thing which remains to be empirically tested is the volatility between these two markets especially from IR to the ER markets. Thus, following hypotheses are framed for the empirical testing between the two markets:

H7: There is a conditional covariance between exchange rates and interest rate.

H8: There is a volatility spillover effect from interest rates to exchange rates.

H9: Volatility spillover effect exists from exchange rate to the interest rates.

The connectivity of gold, crude oil, IR to ER is evident from the above discussion and their theoretical underpinnings. However, the earlier studies lack in exploring volatility integration of these markets. Mostly studies on these markets are focused in developed economies. Therefore, this study looks for the association of gold, crude oil, IR to ER considering volatility effects using advanced GARCH models (BEKK-GARCH and DCC-GARCH). Table A1 in Appendix summarises some important existing studies with their findings.

3. Data and methodology

3.1. Data

The study uses daily data from January 2000 to December 2022. Bond yield data (yield on a 5-year gilt-edged bond in India) as a proxy for interest rates (Casassus & Collin-Dufresne, 2005; Hahn & Lee, 2006), the exchange rate (USD/INR), crude oil daily close prices (Brent crude oil price per barrel in USD), and daily gold prices (USD per ounce) are used. Excluding those days when all the four markets are not operating, we got a total of 4949 observations each for all the four variables. The COVID-19 period of 2019 and 2020 is also skipped to have consistency in results. Log return of all the four-time series is taken ensuring stationarity in all the variables, which is a prerequisite for further econometric analysis (Ghysels et al., 2006).

The 5-year bond yield and exchange rate data are taken from the official website of the “Reserve Bank of India” (RBI), the Indian central bank. Indian imports comprise a significant portion of Brent crude, thus is used to represent the crude oil movements (Singhal & Ghosh, 2016). Crude oil data are taken from the official website of the “US Energy Information Administration” (EIA). Gold prices are collected from the Intercontinental Exchange benchmark (ICE) database. Table 1 reports the variables, and Tables 2 and 3 describe the correlation and descriptive statistics of the variables, respectively.

The correlation results in Table 1 indicate a positive but insignificant relationship of crude and yield with all variables used in this research. An inverse relationship is observed only between gold and USD/INR which is also insignificant.

Non-normality is observed in the data of all the variables, which is tested by rejecting the null hypothesis of the Jarque-Bera test. Augmented Dickey-Fuller and Phillips—Perron tests are conducted showing stationarity in the logarithmic data of all four variables at 1% level. As seen in Table 2, data used in the research exhibits the existence of the ARCH effect in all four variables.

Table 1. Variable description

Name	Description
Crude	Logarithmic value of Brent Crude Oil Spot Price
Gold	Logarithmic value of Gold Spot Price
Yield	Logarithmic 5-year bond yield (India)
USD/INR	USD/INR Currency Spot Price

Table 2. Correlation matrix

	5 Jan 2000 to 30 Dec 2022			
	Crude	Gold	Yield	USD/INR
Crude	1.0000			
Gold	0.0645	1.0000		
Yield	0.0469	0.0106	1.0000	
USD/INR	0.0079	−0.1165	0.0667	1.0000

Note: Correlation coefficients among Crude, Gold, Yield and USD/INR. * signifies correlation coefficient having significant p-value at 5%.

Table 3. Descriptive Statistics

	Jan 2000 to Dec 2022			
	Crude	Gold	Yield	USD/INR
Mean	0.013	0.038	−0.015	0.011
Maximum	37.474	10.452	11.808	3.694
Minimum	−29.444	−9.730	−10.831	−3.550
Standard Deviation	2.851	1.133	0.887	0.425
Skewness	−0.322	−0.306	0.609	0.155
Kurtosis	24.312	9.303	29.980	11.236
Jarque-Bera	93748.480***	8269.625***	150414.500***	14006.210***
Observations	4949	4949	4949	4949
ARCH	328.142***	38.836***	110.872***	494.490***
Unit Root Tests				
Augmented Dickey—Fuller	−19.995***	−16.436***	−17.055***	−19.402***
Phillips—Perron	−74.200***	−72.506***	−69.273***	−71.327***

Note: ***, **, * denotes the significance level at p-values of 1%, 5% and 10%, respectively. Unit Root Test is used considering constraint and trend having log return values of the timeseries variables. ARCH test signifies the autocorrelation of the heteroskedasticity in the data at 1 lag.

3.2. Methodology

Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models are effectively used for volatility estimation of different timeseries variables like strategic commodities, financial securities, macroeconomic indicators, etc (Bauwens et al., 2006). BEKK GARCH is used in this study to explore the VSE, while conditional covariance among the pairs of Bi-Variate estimation is examined using DCC GARCH (Aggarwal et al., 2021b). The multivariate GARCH (M-GARCH) model was proposed by (Engle & Kroner, 1995) for estimating volatility transmission between prices of different timeseries variables like strategic commodities, financial securities, macroeconomic indicators, etc. Using the M-GARCH model becomes complex with the increase in the number of variables in the research. To address this problem, (Bollerslev, 1990; Engle et al., 1990) proposed a constant conditional correlation GARCH (CCC-GARCH) model where the conditional correlation between variables is assumed to be constant.

Further to remove this subjective assumption of constant conditional correlation and to reduce the dimensionality and improve the cross-sectional dimensional estimation with a time-varying conditional correlation. Conditional correlation between timeseries variables can be thus effectively estimated using the DCC GARCH model (Engle, 2002). The number of parameters in the DCC-GARCH model increases linearly and not exponentially, thus tackling the dimensionality issue.

BEKK (Baba, Engle, Kraft, and Kroner) technique is deployed to estimate volatility spillover and shock transmission (Baba et al., 1990) of Interest Rates, Gold, and Crude Oil with Exchange Rate. The bivariate BEKK representation model is given below:

$$H_t = X'X + R' \varepsilon_{t-1} \varepsilon_{t-1}' R + P'H_{t-1}P \quad (1)$$

In equation (1), the conditional variance matrix is expressed as H_t , which is a 2×2 vector and X is a constant coefficient matrix. The coefficients R and P represent the conditional residual matrix and conditional covariance matrix.

$$X = \begin{pmatrix} x_{11} & 0 \\ x_{21} & x_{22} \end{pmatrix}, R = \begin{pmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{pmatrix}, P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} \quad (2)$$

The matrices R and P represent squared coefficients in the variance equation (2) above, whereas X stands for the triangular coefficient matrix.

In the above equation (2), the ARCH effect is represented by r_{11} and r_{22} in its own values, but r_{12} and r_{21} represent the ARCH with another variable shown in Table 4. As indicated in Table 4, p_{11} and p_{22} represent the GARCH effect in its own values, while p_{12} and p_{21} represent the GARCH with another variable. As a result, the equation “ r ” series variables explain how shocks are transmitted between variables, and “ p ” series variables explain how VSE between the prices of crude, gold, yield and the USD/INR.

In order to estimate the volatility impact between these macroeconomic variables considered for the study, Dynamic Conditional Correlation (DCC) GARCH is effectively applied (Engle, 2002). The model further explains the mean equation and variance estimation giving more insights about the variables.

$$d_t = \mu_t + \omega d_{t-1} + r_t \quad (3)$$

In the equation above, the vector of returns residuals is symbolised by the letter d_t , and the vectors of conditional mean and residuals are denoted by the letters μ_t and r_t , respectively. Below variance equation is provided:

$$k_t = c + x e_{t-1}^2 + y k_{t-1} \quad (4)$$

Table 4. Bivariate BEKK GARCH (1,1) estimation

	Crude (1) Yield (2)	Gold (1) Yield (2)	Crude (1) USD/INR (2)	Gold (1) USD/INR (2)	Yield (1) USD/INR (2)
Variance Equation:					
X ₁₁	0.346***	0.121***	0.323***	0.114***	0.098***
X ₂₁	-0.005	0.007	0.002	0.002	0.001
X ₂₂	0.099***	0.102***	-0.011***	-0.012***	0.012***
R ₁₁	0.255***	0.188***	0.231***	0.185***	0.333***
R ₁₂	-0.003	0.005	-0.001	-0.002	0.001
R ₂₁	0.032	0.016	0.028	0.010	0.011
R ₂₂	0.340***	0.362***	0.342***	0.356***	0.365***
P ₁₁	0.965***	0.980***	0.966***	0.978***	0.944***
P ₁₂	0.001	-0.001	0.000	-0.001	-0.001
P ₂₁	-0.007	-0.005	-0.006	-0.005	-0.002
P ₂₂	0.934***	0.930***	0.948***	0.945***	0.955***
Shape (t degrees)	3.917***	3.604***	5.093***	4.756***	3.273***
Model Diagnostics:					
AIC	6.325	4.700	4.930	3.273	10.278
Log Likelihood	-15636.387	-11616.623	-12184.404	-8084.219	-1322.167

Note: AIC refers to Akaike Information Criterion. ***, **, * denotes the significance level at 1%, 5% and 10%, respectively.

The conditional variance is indicated in the estimation above as kt , and c is the constant in the equation. In the equation, “ x ” stands for the ARCH effect, which represents the shock transmission (short-term effect) to the conditional volatility between the variables, and “ y ” denotes the GARCH impact, which represents the volatility spillover (long-term effect) to the conditional volatility of the variables. The BEKK-GARCH and DCC-GARCH are two models specifically applied to estimate the volatility connection between the variables. Both models have comparable features and widely used models for volatility co-movements (Chen & Chang, 2022). They have better fitting performance in the present timeseries data. Hence, they are suitable choice for the consistent analysis. “Granger Causality Test” is also performed to observe the predictive ability of the variables.

4. Results and discussion

The results of the study are discussed in two sections. The estimated results of BEKK-GARCH and DCC-GARCH are exhibited and interpreted in section 3.2 and 4.2, respectively.

4.1. BEKK (1,1) GARCH

The results of the BEKK GARCH estimation are displayed in Table 4. The presence of the ARCH effect in the daily data of all the variables has enabled the further use of GARCH models for estimation and investigation of the volatility shocks between crude oil, gold, IR and their impact on the ER. Additionally, the volatility connection of crude oil and Gold with Yield (interest rate) is also estimated. Different pairs are investigated as shown in Table 4 to identify linkages between them.

In Table 4, the coefficients R_{11} and R_{22} explain that the past positive news will impact the current change in the variable positively and vice versa. Both the coefficients R_{11} and R_{22} have shown a significant positive correlation in all the variables, thus establishing shock transmission from own lagged values of crude, gold, interest rates (IR) and exchange rate (ER) to its conditional volatility.

Similarly, the coefficients P_{11} and P_{22} explain the past volatility will impact the current conditional volatility in the variable. Both the coefficients P_{11} and P_{22} have shown a significant positive correlation in all the variables, thus establishing VSE from own lagged values of crude, gold, IR and ER to its current conditional volatility.

The estimated coefficients exhibiting both short-term and long-term persistence in the variables are symbolised as R_{12} , R_{21} and P_{12} , P_{21} , respectively. Coefficients of these cross terms given in Table 4 are examined to identify the shock transmission and VSE between crude, gold, IR and ER. The coefficients R_{12} and R_{21} do not exhibit any significant relationship between the variables, indicating that the past news had no impact on the current change in the variables. Likewise, the coefficients P_{12} and P_{21} also does not exhibit any significant relationship between the variables, indicating that the past volatility had no impact on the current conditional volatility in the variables. Thus, there is an absence of short-term as well as long-term interconnectedness between crude, gold, IR and ER during the period of the study.

4.2. DCC (1,1) GARCH

The second stage results of DCC GARCH (1,1) models are reported in Table 5.

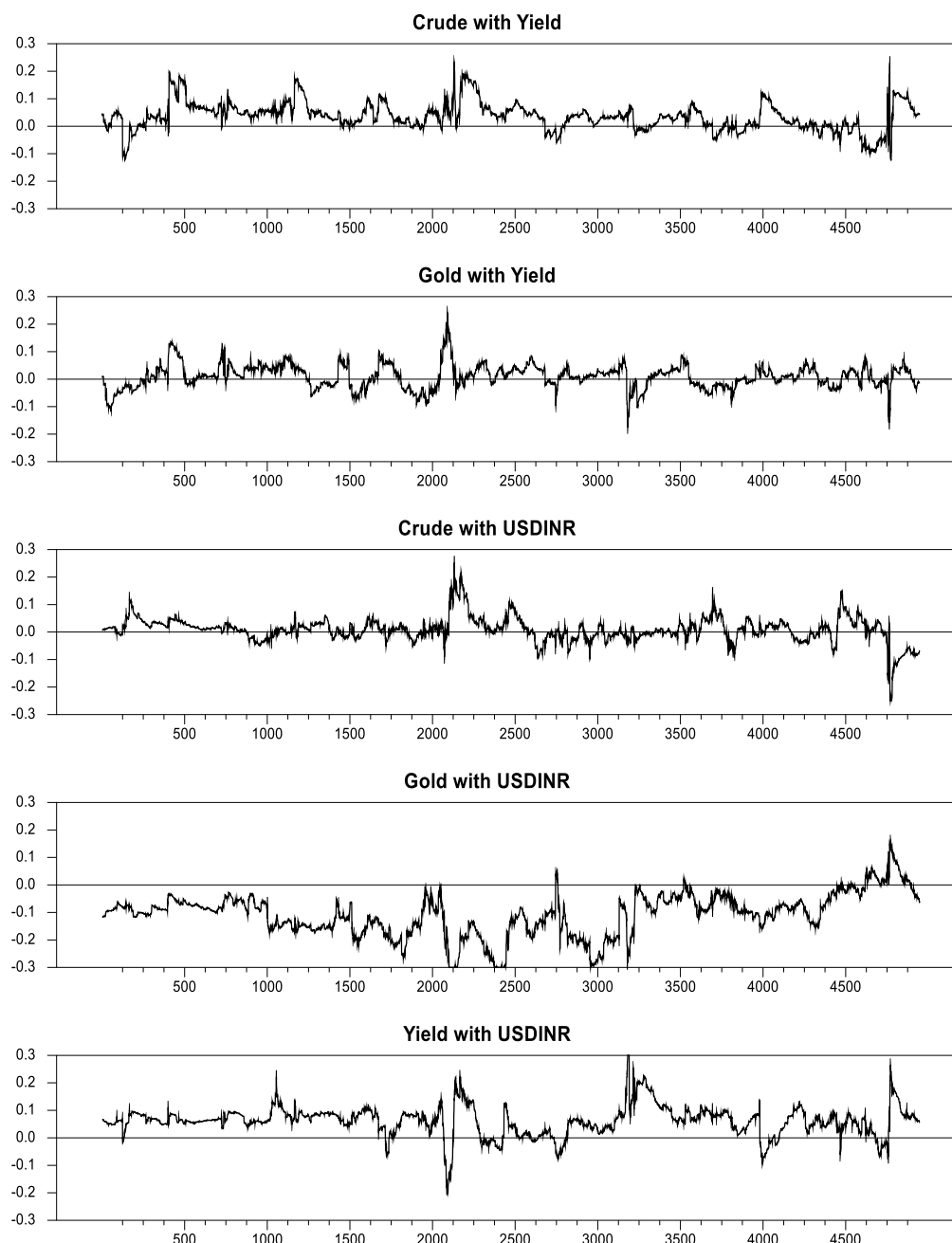
Both the combined ARCH and GARCH terms (DCC (A) for ARCH effect and DCC (B) for GARCH effect) are significant for all the pairs of bi-variate DCC GARCH (1,1) estimation except for 2 out of 10 cases (DCC (A) for Crude-ER and DCC (B) for Gold-Yield pairs) are not significant. This highlights that the dynamic conditional correlation is significant for all the cases except in the two cases of deviations. The conditional correlation is depicted in Figure 1 for all the bivariate estimation of DCC GARCH (1,1) model. This study also performs “Granger Causality test” (GCT) to ascertain if there exists a causality effect between the concerned timeseries variables (ER, crude oil, gold, and yield or IR). Table 6 presents the outcomes of GCT. All the three variables (crude oil, gold, and yield) have causal effect on ER. It is also obtained from GCT that ER also has causal effect on crude oil, gold and yield as all these variables have significant p-values at 10%, 5%, and 1%. It is also observed that yield is causally interconnected with gold and crude oil and vice versa. The volatility relationship between the variables is also obtained from the GARCH models. Therefore, GCT outcomes in Table 6 corroborate that crude oil, gold and yield also have predictive ability to forecast ER. Additionally, gold and crude oil are also found to have predictive ability for yield and vice versa.

Table 5. Bivariate DCC GARCH (1,1) estimation

	Crude (1) Yield (2)	Gold (1) Yield (2)	Crude (1) USD/INR (2)	Gold (1) USD/INR (2)	Yield (1) USD/INR (2)
Variance Equation:					
X (1)	0.1227***	0.0187***	0.1032***	0.0156***	0.0097***
X (2)	0.0100***	0.0098***	0.0001**	0.0001**	0.0001**
R (1)	0.0908***	0.0564***	0.0787***	0.0492***	0.1464***
R (2)	0.1354***	0.1416***	0.1368***	0.1419***	0.1791***
P (1)	0.9112***	0.9431***	0.9114***	0.9418***	0.8628***
P (2)	0.8556***	0.8585***	0.8828***	0.8820***	0.8815***
DCC (A)	0.0130*	0.0047***	0.0035	0.0102***	0.0261***
DCC (B)	0.5318***	0.2248	0.6990***	0.9882***	0.9401***
Shape (t degrees)	3.9733***	3.6354	5.2902***	4.7945***	3.3878***
Model Diagnostics:					
AIC	6.307	4.685	4.900	3.258	2.266
Log Likelihood	-15596.782	-11581.779	-12113.487	-8050.642	-5595.201

Note: AIC refers to Akaike Information Criterion. ***, **, * denotes the significance level at 1%, 5% and 10%, respectively.

Figure 1. Conditional correlation.



4.3. Robustness check

The robustness test of empirical outcomes is essential to ensure stronger evidence. Hence, a multi-method approach is adopted to confirm robustness. We have applied BEKK GARCH and DCC GARCH on same set of variables. The estimation of both the models exhibits dissimilar results regarding volatility effects between exchange rate and oil, gold, and interest rate. The “Granger Causality Test” is also performed to observe the connection between the variables. This test gives signs that oil, gold and interest rate influence exchange rate. Hence, it ensures the robust outcomes.

4.4. Hypotheses testing outcomes

The first set of hypotheses between gold and exchange rate has mixed results. The common alpha and beta values in the DCC GARCH estimation (Table 5) are coming out to be significant which

Table 6. Granger Causality Test

Alternate Hypothesis	5 Jan 2000 to 30 Dec 2022
	P-value
Crude oil price has forecasting ability (causal effect) for ER.	0.056*
Gold has forecasting ability (causal effect) for ER.	0.078*
Yield has forecasting ability (causal effect) for ER.	0.003***
ER has forecasting ability (causal effect) for crude oil.	0.067*
ER has forecasting ability (causal effect) for Gold.	0.068*
ER has forecasting ability (causal effect) for Yield.	0.015**
Crude oil price has forecasting ability (causal effect) for Yield.	0.012**
Yield has forecasting ability (causal effect) for Crude oil.	0.079*
Gold has forecasting ability (causal effect) on Yield.	0.086*
Yield has forecasting ability (causal effect) for Gold.	0.062*

Note: Crude, Gold, Yield, and USD/INR (exchange rate [ER]) are the timeseries variables for “Granger Causality Test”. (Y) and (X) represent the dependent variable and the independent variable of timeseries. *, **, and *** signify significant p-value at 10%, 5%, and 1%. For lag structure, lag length 1 is taken as suitable for the timeseries.

confirms the conditional covariance between gold and ER. Therefore, H_1 regarding conditional covariance between the two cannot be rejected. However, the VSE between the two in either direction is insignificant (Table 4). Therefore, H_2 and H_3 are rejected.

The second set of hypotheses between crude oil prices and ER has also given the mixed results. The hypothesis 4 (H_4) regarding conditional covariance between crude oil prices and exchange rates is inconclusive as common alpha which signify the reactive tendencies is not significant but common beta for persistence due to change is significant (Table 5). The VSE between crude oil and ER are also not significant (Table 4). Therefore, H_5 and H_6 are rejected.

The third set of hypotheses between IR and ER has also given the mixed results. H_7 regarding conditional covariance between the two cannot be rejected as the common alpha and beta in DCC GARCH estimates are significant. However, the hypotheses H_8 and H_9 are rejected as the joint coefficient in BEKK GARCH estimate for both alpha and beta in both the directions are not significant (Table 4).

4.5. Comparison with previous studies

It is observed that the existing literature is inadequate to address the concerns between gold and ER. Despite having legacy of strong association between the two (Diebold et al., 1991), subsequent studies have not found any meaningful association. Capie et al. (2005) is a legendary study on exploring gold as a safety cushion for ER fluctuations. They conclude that there are association between the two; however, lack of consistent association between the two renders them misfit for the hedging against each other.

The current study has also presented the findings in somewhere similar inconclusive way. The same result is also endorsed by other studies (Dooley et al., 1995; Sjaastad, 2008). Our study presents that conditional covariance between the two do exist but there is no evidence of the volatility spillover from either direction. In terms of conditional covariance, Zagaglia and Marzo (2013) have already presented the similar results. However, Zagaglia and Marzo (2013) failed to present cogent evidence for VSE. The current study uses the most popular and advanced technique to sniff out evidence regarding volatility spillover and highlights the lack of it in the either direction (from gold price to exchange rates and vice versa).

Akram (2004) finds evidence of negative association when uses the non-linear relationship model between oil prices and ER. The current study finds lasting impact of the shock in the crude oil to the ER, which supports the findings of Akram (2004). The same outcome is reported by Ghosh (2011) who reports the depreciation of rupee in terms of dollars whenever increase in the oil prices takes place. Chang et al. (2013) use VAR, Johansen's cointegration and GARCH models and find not only the oil but gold price also does not have any association with ER. The current study subscribe to the findings of Chang et al. (2013) in the context of VSE but do not approve of the results for long-term associations. The current paper finds strong support by Zhang et al. (2008) for VSEt between the two markets. They also do not find any VSE between the two markets in both the directions. However, their method of the analysis was univariate GARCH family of models, which are not supported by the literature for testing the VSE (Bauwens et al., 2006; Silvennoinen & Teräsvirta, 2009). The current study uses the bi-variate BEKK GARCH model (Bauwens et al., 2006; Silvennoinen & Teräsvirta, 2009) to test the VSE between oil and ER and endorses the findings of Zhang et al. (2008) of no effect.

Calvo and Reinhart (2002) are the best work to endorse the findings of the current paper. Their evidence that there are no floating interest rate regimes rather all the nations are scared of floating rates endorses our point of view. The current paper postulates that IRshocks impact the ER in short-run as well as in the persistence, which endorses the claims of Calvo and Reinhart (2002). The similar findings are also reported by other prominent studies that IR does influence the ER (Benigno & Benigno, 2008; Cadenillas & Zapatero, 2000; Flood & Jeanne, 2005). However, there are studies which advocate inconsistent (Meese & Rogoff, 1988) and inconclusive association between the two (Hnatkovska et al., 2013). Despite all the evidence, we did not observe any study to have the VSE between them. Our findings proclaim no VSE, and only significant conditional covariance with respect to response and persistence due to shocks have been found.

4.6. Contribution and implication

The current paper has three **main contributions**: 1) it endorses the earlier studies that there is inconsistent and inconclusive evidence of the linkages between gold, crude oil and IR with the ER; 2) it provides evidence of reaction and persistence due to shock in the gold, crude oil and IR on the ER, which was not evidently explained in the earlier studies; and 3) there is no VSE from gold, crude oil and IR on the ER, which was not observed earlier with such vividness due to the lack of the use of more effective methodology (Bivariate GARCH family of models). This study delivers theoretical contribution by giving fresh evidence on the existing theories such as APT, SET, IET, monetary theory of gold and oil prices, and international fisher theory.

The current study's practical contribution is both positive and negative association of gold-oil-interest rate with exchange rate. It confirms that government should consider these macroeconomic variables (gold-oil-interest) resilient against ER volatilities. In long-run, a blended connectivity is found between the gold-oil-interest and ER fluctuations. Therefore, investors, business managers and other stakeholders should not only rely on past values. They should take their investment decisions on current regime.

The findings of the paper have a few strong implications. Firstly, shock in gold price leads to reaction and persistence in the ER but there is no VSE due to each other. Therefore, the policymakers need not worry for the volatility in the gold market to have any concern for the ER except for reaction and persistence of the shocks in the gold market. Secondly, shock in the oil market can have long-term persistence on the ER but again there is no concern for the volatility in one market to impact on the volatility of the other market. Thirdly and lastly, shock in interest rate will have reaction and persistent on the ER but due to volatility in one market, there is no concern on the other market. If we recapitulate, this implies that for the effect of the shock in gold, oil and interest rate, it may be of the concern to have its relevance on the ER, however, volatility in gold, oil or interest rate will not have any impact on the volatility of the ER market. The findings of the paper can have long-term implication to the decision-making concerning gold, oil, IR with respect to the ER.

5. Conclusion, limitation and future scope

Conditional covariance between ER and crude oil, gold, interest rate yield, respectively, is significant. Moreover, short-term response to the shocks in gold and yield significantly impacts the conditional volatility of the ER. However, innovations or shock in the crude oil do not significantly impact the ER. In addition to this, the long-term change in the persistence of exchange rate due to all the three individuals (gold, crude oil and yield) are significant. Therefore, it can be concluded that conditional variance of ER is influenced by all the three individuals (gold, crude oil and yield). This is also observed by the “Granger Causality Test”.

However, there are no evidence to justify in any way that the spillover effect of volatility from any of the three markets on ER exist. These are startling revelation that gold, crude oil and yield influence the short-run reaction and long-term persistence in the ER but does not have any evidence of VSE on the ER markets.

The current study significantly contribute by validating the existing theories like monetary theory of gold and oil prices. APT theory for asset and commodity pricing having connectivity with ER. “International Fisher Theory” for IR and ER connections. The present study also gives practical contribution that is, in long run, a blended connectivity is found between the gold-oil-interest and ER fluctuations. Therefore, investors, business managers and other stakeholders should not only rely on past values. They should take their investment decisions on current regime.

This study limits itself to only exchange rate of price of dollar in terms of rupee. There are many other currencies which can also have equally significant impact on the association of gold, crude and interest rate yield with them. This study is limited to India. However, it might be useful for providing insights on relevant topics. A future study on the similar lines but involving other currencies and other nations can be the future scope on this topic. There might be other set of macroeconomic variables which can be influenced by exchange rate fluctuations. Such macroeconomic variables can be a future scope of investigation. This study also skips the 2019 and 2020 data due to inconsistencies of COVID-19. Thus, a study on the connection of these variables during COVID-19 can be done separately in future. An event-based study pre- and post-COVID-19 can be performed after having sufficient data availability.

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Appendix

Table A1. Some important researches in literature

Authors	(Year)	Variables Studied	Country Studied	Period of the Study	Methodology Used	Key Findings
Akram, Q. F.	(2004)	Oil, Norwegian exchange rate	Norway	1998–2000 (quarterly)	Linear and Non-linear root mean square forecasts error (RMSE)	Inverse relationship between oil prices and the value of the Norwegian exchange rate.
Albuquerque, R., Loayza, N., & Servén, L.	(2005)	FDI impacted by factors like Taxes, Wage Rates, and Tariffs, etc.	Worldwide	1985–1999	equilibrium model	Globalisation measure complements with capital market liberalisation measures, thus worldwide sources of risk present due to increased market integration.
Arfaoui, M., & Ben Rejeb, A.	(2017)	oil, gold, US dollar and stock prices	Worldwide	1995–2015	simultaneous equations system	Negative linkages between oil and stock prices, but oil is positively affected by USD and gold. The US dollar is negatively impacted by the stock market and positively by gold and oil price.
Bahmani-Oskooee, M., & Mitra, R.	(2008)	exchange rate, trade data	USA and India	1962–2004	cointegration and error-correction modeling	Exchange rate volatility impacts 40% of industries in the short run.
Baur, D. G., & Lucey, B. M.	(2010)	gold, stock, bond	USA, UK, Germany	1995–2005	Asymmetric GARCH	Investors who invest in gold as a hedge after/during a major negative shock/event for more than 15 trading days lose money.

(Continued)

Authors	(Year)	Variables Studied	Country Studied	Period of the Study	Methodology Used	Key Findings
Kanjilal, K., & Ghosh, S.	(2017)	crude oil and gold	Worldwide	2009–2015	threshold vector error-correction model	Relationship between gold and oil price is non-linear and asymmetric.
Singhal, S., & Ghosh, S.	(2016)	oil and stock prices	India	2006–2015	VAR-DCC-GARCH	No volatility spillover from crude oil to the Indian stock market at the aggregate level; however, volatility spillover is seen from crude oil to auto, power and finance indices.
Berdiev, A. N., Kim, Y., & Chang, C. P.	(2012)	exchange rate, forex reserves	Worldwide	1974–2004	Multinomial logistic regression	Government ideology, political institutions and globalisation are important determinants for choosing exchange rate regime.
Capie, F., Mills, T. C., & Wood, G.	(2005)	gold and exchange rate	UK	1971–2004	TGARCH, EGARCH	A negative, typically inelastic, relationship exists between gold and these exchange rates. The strength of this relationship has shifted over time.
Chang, H. F., Huang, L. C., & Chin, M. C.	(2013)	oil, gold, and exchange rate	Taiwan	2007–2011	VAR model, Granger causality	The oil price, gold price and exchange rate remain largely independent from one another
Ciner, C., Gurdgiev, C., & Lucey, B. M.	(2013)	Stocks, Bonds, Gold, Oil and Exchange Rates	US, UK	1990–2010	quantile regression	Gold can be regarded as a safe haven against exchange rates in both countries, highlighting its monetary asset role

(Continued)

Table A1. (Continued)

Authors	(Year)	Variables Studied	Country Studied	Period of the Study	Methodology Used	Key Findings
Du, X., Cindy, L. Y., & Hayes, D. J.	(2011)	Crude oil, corn and wheat prices	USA	1998–2009	Bayesian inference using Gibbs Sampling	Volatility spillover among crude oil, corn, and wheat markets after the fall of 2006
Muzaffar Asad, Mosab I. Tabash, Umaid A. Sheikh, Mesfer Mubarak Al-Muhanadi & Zahid Ahmad	(2021)	Gold-oil-exchange rate volatility, Bombay stock exchange	India	2003–2020	NARDL Model	Gold prices, oil prices, and currency values have an asymmetrical association with Bombay stock indexes as positive shocks to these variables have no impact on stock index.
Umaid A Sheikh, Muzaffar Asad, Zahid Ahmed, Umer Mukhtar	(2020)	oil prices, gold prices, exchange rate, and stock prices	Pakistan	2004–2018	ARDL Model	Mixed outcomes are observed between the variables.
Umaid A Sheikh, Muzaffar Asad, Aqeel Israr, Mosab I Tabash, Zahid Ahmed	(2020)	money supply, interest rates, consumer price index, terroristic disruptions, and Karachi stock exchange	Pakistan	2002–2015	ARDL model	All variables have significant impact on stock exchange.
Umair Saeed Bhutta, Aws AlHares, Yasir Shahab, Adeel Tariq	(2022)	real earnings management on investment inefficiency	Pakistan	2008–2018	Panel Data Analysis	Real earnings increase investment inefficiency
Suresh Kumar, Ankit Kumar, Gurcharan Singh	(2023)	crude oil, gold, exchange rate, and Indian stock market	India	1994–2019	NARDL model	crude oil has positive effect, exchange rate has negative effect, and Gold has no effect on stock market.