Interaction Dynamics of Arbitrage, Hedging and Speculation with Spot Volatility: Evidence from Crude Oil Market

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ABSTRACT

We attempt to look at the dynamics of speculation, hedging and arbitrage and spot price volatility in crude oil market in Japan, Europe, India, USA and UAE. We use daily data for the period 2010-2017 and analyze the interlinkage using Vector Auto-Regression model. We observe bidirectional relationship between speculation and volatility (US, India, Europe) and arbitrage and volatility (US, India, Europe) and hedging and volatility in (US and Europe). There is unidirectional relationship impact of hedging, speculation and arbitrage on volatility in Japan, and hedging impacts volatility in India and UAE. The link between (i) arbitrage and speculation and (ii)arbitrage and hedging are almost non-existent in all the markets. Our results show that arbitrage, speculation and hedging and spot volatility are interlinked in the context of commodity futures markets, but the direction of the impact varies from country to country.

1 INTRODUCTION

This paper investigates the impact of trading activity on spot market volatility and examines the dynamics among the types of trading in the crude oil market. We analyze the interlinkages between speculation, hedging and arbitrage and their impact on spot volatility in prominent exchanges across the globe. As put forward by Working (1960), different trading activities in the market such as speculation, hedging and arbitrage are not isolated events but are interlinked to each other. The study enhances the existing literature on crude oil futures market dynamics and provides insight on whether the fluctuations in spot market volatility are explained by the varying levels of trading activity(Watugala, 2019).

Several reasons make this study pertinent, firstly volatility dynamics is one of the key components in crude oil futures markets, as it contributes to efficient fund allocation and strategic derivatives trading strategies. Understanding whether levels of trading contribute to volatility can help both the producers and consumers of the futures markets to gauge optimal trading strategies. Additionally, in the futures market, destabilizing trades are often of interest to the market stakeholders and regulators. Trading activity such as speculation in futures market is conventionally believed to contribute to market volatility leading to uncertainty in the market while arbitrage minimizes mispricing error and hedging mitigates. However, in the context of commodity futures, the impact of different trading activities on spot market volatility remains elusive relative to the extant literature pertaining to stock and index futures. Several countries use crude oil futures to offset the price risk associated with raw material-based inventory. However, studies (Bessembinder and Seguin, 1993; Ripple and Moosa, 2009; Floros and Salvador, 2016) document that increased trading in futures is associated with increased volatility. Thus, it is worthwhile to examine the *type of trading activity* in the futures market that contributes to spot price volatility. Secondly, several regulators gain from a better understanding of spot volatility dynamics and trading activity. Hence, for the sake of objectivity we examine volatility dynamics and trading activity; enabling policymakers to consider other regulatory possibilities. Finally, the commodity futures markets are primarily meant for price discovery risk mitigation. The role of speculators in the markets is to provide short-term liquidity to hedgers. While hedgers go long by rolling over their futures to retain open positions, speculators square off positions at the end of the day, contributing to daily traded volumes. On the other hand, arbitrageurs reduce mispricing between the spot and futures markets. Our findings can provide insights into the price discovery process and risk management for practicing investors.

Prior studies consider speculation, hedging and arbitrage as distinct activities in the commodity futures markets. However, in this paper we posit that these market activities are inter-dependent and also play a role in explaining spot market volatility. Hence, we examine the interlinkage among speculation, hedging and arbitrage and their impact on spot price volatility across five prominent commodity exchanges across five countries in the context of crude-oil futures.

Crude Oil futures are one of the most widely traded non-agricultural commodity futures popularly used for hedging against erratic oil price movements. We explore whether these activities exert an influence on the spot market volatility. Our sample focuses on the crude oil futures traded at the top exchanges (by volume) in five countries, namely, the United States of America, United Kingdom (Europe), United Arab Emirates, Japan and India[1] for the period spanning from 2010-2017.

Our results capture the impact of the different trading activity in time-varying volatility along with the inclusion of lags in the VAR model. We observe that the Granger-caused relationships vary across exchanges in different countries. Additionally, variance decomposition results reveal speculation contributes to spot market volatility; however, the level of impact varies across the exchanges. We also capture the impact of shocks on the various trading activity on spot-market volatility to support our findings.

2 LITERATURE REVIEW

Predominant literature analyzing trading activities in the futures markets considers them as distinct groups, not accounting for interlinkages existing among them. Based on the trading motives in the futures markets, trading activity is classified into speculation, hedging and arbitrage. Prior literature states that information-based trading improves derivative pricing and introduces more efficiency in the market. However, the impact of each of these activities and its value-creating effect on the market remains unexplored in the context of commodity futures.

2.1 Speculation and Volatility

Speculation is known to provide short-term liquidity in commodity markets. In futures markets, investors speculate using ‘bets’ on expected future prices of the contracts. The ability of speculators to maintain price equilibrium and provide liquidity makes speculation is desirable for an efficient crude oil market. However, when the number of speculative trades dominates the market, it can have a destabilizing effect on the spot prices (Alquist and Kilian, 2010). Increased speculative trades in the futures market translates to increased risk of spot market inventory shortage due to naked futures' inability to meet the delivery obligation. Empirical evidence in the commodity markets suggests that the impact of speculation on volatility is mixed. Some studies find that speculation enhances liquidity and stabilizes the market by reducing volatility (Büyükşahin and Harris, 2011; Bohl and Stephan, 2013), these studies state that speculation increases depth which in turn improves market quality and the process of price discovery at a commodity exchange. Another vein of literature finds that speculation increases volatility (Black, 1986; Bohl, Siklos, and Wellenreuther, 2018). According to these studies, speculation creates noise in the market resulting in a synthetic rise in the value of the asset; this kind of trading based on imperfect information leads to increased volatility in the markets. We know that speculators (or non-commercial traders) trade to realize profits. Speculators follow trends rather than taking the lead during periods of high volatility. Prior literature focuses on speculation and its impact on volatility; however, they assume that speculation is independent of other trading activities. The seminal work by Working shows that speculation needs to be measured relative to the level of hedging in the markets (Working, 1960). According to Working, speculation in manageable quantities in the futures market is acceptable but, hedging must be dominant for a functional market. Several papers show that speculating and hedging work in tandem to support the markets (Acharya, Lochstoer, and Ramadorai, 2013; Cheng, Kirilenko, and Xiong, 2015). Cifarelli and Paladino (2015) examine five commodity futures; they state that the futures price depends on interactions between hedgers and speculators. Master's hypothesis[2] finds that increased spot price volatility is due to increased trading in futures causing an increase in the number of profit-seeking speculators. While Fattouh, Kilian, and Mahadeva (2013) posit that speculation does not govern spot price volatility as it is driven by market fundamentals like demand-supply and inventory costs. The work by Tokic (2011) finds that destabilizing forces in the Crude Oil market are due to arbitrage by commercial traders and producers rather than speculative forces. These studies highlight that each trading activity must not be studied discretely but together.

2.2 Hedging and Volatility

Hedging is done in the market to mitigate or ideally eliminate risk by market participants who have exposure to the underlying. In volatile markets, futures contract provides traders an opportunity to hedge themselves from adverse price movements. In futures markets, hedging is identified based on exposure to spot markets that is the derivative contract is linked to a position in the cash market; then, it qualifies as a hedge (Lebeck, 1978). The impact of hedging on the market has also been empirically studied. Several papers find that hedging increases, especially during volatile periods in the market. Futures are popularly used to hedge exposure during high volatility periods(E. Chang, Chou, and Nelling, 2000). Studies also suggest that this relationship varies across commodities. It is documented in studies that the demand for crude oil futures for hedging increases during periods of high market volatility (Ranganathan and Ananthakumar, 2014; Junttila, Pesonen, and Raatikainen, 2018). The work by Acharya *et al.* establishes the links between speculation/arbitrage and hedging in the context of oil spot and futures. According to the authors, the shortfall in speculator's capital affects hedging demands in the market. With constrained speculators liquidity declines and the cost of hedging increases; this adversely impacts the value of producer inventory causing them to scale back. As a result, the spot price of commodities falls and expected future prices increase. Nevertheless, in their work (Acharya et al., 2013), speculation is used interchangeably with arbitrage. According to the authors, speculators indulge in arbitrage. Again, the relationships among hedging and volatility, speculation and arbitrage are noted in the literature. However, these relationships remain elusive due to lack of empirical studies combining all the three activities. Therefore, it becomes pertinent to examine all the trading activities together rather than separately.

[2] Masters, Michael W. 2010. Testimony before the Commodity Futures Trading Commission, March 25

2.3 Arbitrage and Volatility

Arbitrage is a riskless trading strategy with no net investment. In practice, arbitrage refers to low-risk trading during temporary price deviations in the market for identical instruments, returning non-negative gains (Poitras, 2010). Arbitrageurs exploit the gaps in basis (mispricing) to realize profits (Kumar and Seppi, 1994). Tu, Hsieh, and Wu (2016) find that increased volatility in the market reduces arbitrage resulting in increased mispricing for S&P500 index futures. This is because higher volatility increases the risk of assured pay-offs for debt-constrained investors (Limits of Arbitrage) who capitalize on persistent price discrepancies (Gromb and Vayanos, 2012). Similarly, Chen *et al.* (1995) find a reduction in basis (arbitrage) during periods of high volatility. Contrary to the limits of arbitrage theory, Lu *et al.* (2012) posit that increased volatility gives more opportunities for arbitrage in the Chinese stock markets as higher volatility leads to mispricing allowing arbitrageurs more significant opportunities to trade. Prior literature is vague regarding the impact of arbitrage on prevailing volatility. In crude oil markets, arbitrage opportunities can arise from intra-commodity price differences (example: between crude and gasoline) or inter-commodity (example: crude futures and crude spot) price differences. This paper focuses on the price difference caused by the latter. Several papers (Karbuz and Jumah, 1995) find proof of arbitrage in the commodity markets; they state that arbitrage helps bring about commodity price equilibrium in the markets. However, the paper by Tokic (2011) finds that arbitrage is destabilizing in Crude Oil futures. This raises the question again whether arbitrage, speculation and hedging are linked in the markets along with their combined impact on volatility.

2.4 Speculation, Hedging, Arbitrage and Volatility

2.4.1 Existing Theories

2.4.2 Speculation & Volatility

According to Master's hypothesis (2010) an increase in spot price volatility is attributed to increased number of speculative trades (Tokic, 2011). While Li *et. al*. (2015), posits that speculation has no impact on volatility as it only promotes short-term liquidity, thereby highlighting the '*liquidity enhancing role of speculation'* (Li *et. al.*, 2015)

2.4.3 Arbitrage & Volatility

Theory of limited arbitrage during volatile periods states that, higher volatility increases the risk of assured payoffs for debt-constrained investors (Gromb and Vayanos, 2012; Chen *et. al.*, 1995; Tu *et. al.*, 2016). Contrary views of Lu *et al.* (2012), illustrates that higher volatility facilitates mispricing providing windows of opportunities for arbitrageurs to trade. This theorizes that arbitrage acts as a stabilizing force in the market.

2.4.4 Hedging & Volatility

Works by Ranganathan and Ananthakumar, (2014) and Junttila *et. al.* (2018) shed light on the fundamental need for hedging during volatile periods; as it increases perceived risk driving up hedging demand. While theory of limits to hedging/arbitrage by Acharya *et. al.*(2013) shows that a shortfall in speculator's capital during periods of high volatility has a negative impact on hedging demand due to increased cost of hedging.

2.5 Focal Point of Research

Extant literature examines hedging, speculation, or arbitrage separately (Cifarelli and Paladino, 2015; Andreasson, Bekiros, Nguyen, and Uddin, 2016). However, studies have stated that hedging and speculation are two sides of the same coin. Bourses offer risk-mitigating futures only for producers, industries etc. who have exposure to the spot market via hedging. Hedging is done for longer horizons and is less frequent; therefore, liquidity in derivative markets is introduced by speculators (both short and long) who are willing to assume the price risk of the underlying. Arbitrage enhances price discovery. These risk-less profit opportunities help revert prices to market equilibrium. We observe that all these activities are interlinked in the markets, but there is no empirical evidence investigating their combined impact. This paper attempts to empirically examine this trading activity inter-linkage and its impact on market volatility for crude-oil futures at a country level. Thus, we formulate the hypotheses:

H_{01}: There is no dynamic interactions among hedging, speculation, arbitrage and spot market volatility in the Crude Oil market

3 DATA AND METHODOLOGY

This study focuses on the most liquid futures among commodities, namely, Crude Oil, and examines daily data from 2010-2017. **Error! Reference source not found.**, shows that various grades of crude futures traded globally has more than doubled during a period of ten years. We examine the top five crude oil futures-based contracts globally from the exchanges in five different countries, namely, United States of America, Japan, United Arab Emirates, United Kingdom and India. Chinese crude oil futures were introduced recently and hence, excluded from this analysis due to the lack of data. A snapshot of the specifications for each contract and their respective sizes are presented in Table 2. The table also presents the different grades of crude oil contracts with different lot sizes across the international markets. Our study is performed at a country level and each contract examined is treated as a mutually independent sample to investigate the interlinkages in the trading activities. Since the focus of the study is to examine trading activity inter-linkage, crude oil futures were chosen as they have high liquidity internationally. Additionally, historical data suggests that Crude Oil futures have a consistent supply and demand and are widely used by hedgers to cover exposure in a volatile market. Transitory traders such as scalpers and day-traders also use crude futures to speculate on spot market prices and gain profits during price swings. Arbitrageurs aim to make profits by exploiting the market microstructure deficiencies and thereby bringing prices to an equilibrium. The data series for all crude oil futures contracts (that is open interest, volume and the daily settlement prices) and their respective spot prices were sourced from

Bloomberg[3]. The spot prices of Western Texas Intermediate, as well as Brent Crude Oil, were obtained from U.S Energy Information Administration (EIA), US Department of Energy. Since Brent Crude Oil and WTI futures are used as benchmarks in the market, they were chosen to represent different grades of crude oil.

Table 1 Total volume and total open interest of different crude oil futures (2008-2017)[4].

Year	Volume	Open Interest
2008	287003538	33301403
2009	310601303	34747895
2010	375283850	37027989
2011	429913293	38402345
2012	394191146	42496126
2013	407269501	50917486
2014	394127931	48065765
2015	569983696	55472235
2016	721264615	62326187
2017	772328486	72736947

Source: Collected from Futures Industry Association

Quantifying the type of trading activity is challenging, as the motive behind trades is unknown. While Commodity of Futures Trading Commission (CFTC), publishes a Commitment of Traders (COT) report which records the position of traders in prevailing open interest and a similar report is generated by London Metals Exchange (LME), such data is not available for India. According to the explanatory notes of the disaggregated COT report[5] of the CFTC - "*Staff will generally know, for example, that a trader is a "producer/merchant/processor/user" but we cannot know with certainty that all of that trader's activity is hedging"*. Therefore, we use indirect measures to capture the types of trading activity based.

Table 2 presents the information regarding the Crude Oil futures in the sample. The contract size represents the lot size traded in the contract. The exchange is based in the country of interest.

Futures Contract	Currency	Contract Size	Exchange	Global Ranking (Energy Contracts) *	Volumes 2008-17 (contracts)
Oman Crude Oil	USD	1000 Barrels	Dubai Mercantile Exchange, UAE	> 40	12540581
Light Sweet Crude Oil	USD	100 Barrels	Multi-Commodity Exchange, India	9	412373325
Crude Oil	USD	50 Kiloliter	Tokyo Commodity Exchange, Japan	35	21872087
Brent Crude Oil	USD	1000 Barrels	Inter-Continental Exchange, Europe	3	444083704
West-Texas Intermediate	USD	1000 Barrels	New York Mercantile Exchange, USA	2	1838184227

Note: Global Ranking is based on Futures Industries Association, USA
**The ranks are assigned from a sample of all energy futures and options contracts by FIA, however, amongst crude oil futures these contracts represent the top tier.*

[3] The authors express their appreciation to Dr. Venkatachalam Shunmugam and Mr. Debojyoti Dey, Multi-Commodity Exchange, Research, India for the help provided during data collection.
[4] The authors wish to thank Mr. Chris Mendelson, Data Analyst, at Futures Industry Association(FIA) for providing the relevant data.
[5] Explanatory Notes of COT by CFTC:
https://www.cftc.gov/sites/default/files/idc/groups/public/@commitmentsoftraders/documents/file/disaggregatedcotexplanatorynot.pdf

3.1 Measurement of Variables

Our model comprises of three variables which represent different trading activities, namely arbitrage, hedging and speculation. Furthermore, we examine their impact the spot volatility in the crude oil markets.

3.1.1 Arbitrage

We have used a 'basis' spread as an indicator of arbitrage opportunities in the market. The method of calculation is based on the cost-of-carry model (Johnson, 1960; Roll, *et al.*, 2007). It is defined as the difference between the observed futures price and the fair futures price at a time 't'. Theoretically, the fair price of futures is calculated according to the cost-of-carry model. As per the cost-of-carry model, the fair futures price equals the sum of the spot price and the prevailing transaction costs. However, the inventory cost-related data is unavailable. We measure basis as:

$$Basis_{x,t} = Fut\ Price_{x,t} - Spot\ Price_{x,t} \quad (1)$$

Equation (1) gives the basis or arbitrage opportunity measure at a given time 't' for a given contract 'x'.

3.1.2 Hedging

Hedging in the market requires exposure to the spot market. Subsequently, investors who hedge using futures roll over positions in the market (Choudhry, 2004; Lucia and Pardo, 2010); this is captured by open interest. Open interest is the number of contracts that are still open to delivery at the end of the day. The raw series of open interest was de-trended per the procedure followed by Fung and Patterson (1999) and Illueca and Lafuente (2003) to make the data more robust for analysis. The method for de-trending the data over a 100-day window is given in equation (2).

$$OI(DT)_{x,t} = \frac{OI_{x,t}}{\left[\frac{\sum_{t=t-1}^{t=(t-1)+100} OI_{x,t-1}}{100}\right]} \quad (2)$$

In equation (2), the de-trended open interest that is OI(DT) of a futures contract 'x' at a given time 't' is equal to the observed daily open interest of 'x' at time 't' divided by the 100-day average of the open interest from time ''t-1'.

3.1.3 Speculation

We use the standard method to detrend volume in this study and use the total volume of contracts traded as a proxy for speculation.

$$V(DT)_{x,t} = \frac{V_{x,t}}{\left[\frac{\sum_{t=t-1}^{t=(t-1)+100} V_{x,t-1}}{100}\right]} \quad (3)$$

In equation (3), the de-trended volume that is V(DT) of a futures contract 'x' at a given time 't' is equal to the observed daily volume of 'x' at time 't' divided by the 100-day average of the volume from time 't-1'. Again, this equation is derived from the work of Campbell *et al.* (2011) and used in other papers as well (Fung and Patterson, 1999; Illueca and Lafuente, 2003).

3.1.4 Spot Price Volatility

Spot price volatility is of concern to most hedgers, as instability in its prices are drivers of hedging. Large swings in the spot market prices create speculative opportunities and price discrepancies across markets. Hence, we calculate returns on the spot market using a formula given in equation (4) and for volatility, the conditional variance estimated by GARCH (1,1) is used as a proxy. GARCH (1,1) estimates are relatively consistent when compared to traditional measures such as standard deviation or high/low range estimators as it accounts for the presence of heteroscedasticity in the time series data.

$$Ret_{x,t} = \log\left[\frac{P_{x,t}}{P_{x,t-1}}\right] \ (4)$$

$$Ret_{x,t} = \ Ret_{x,t-1} + \ \varepsilon_t \ , \varepsilon_t/\varepsilon_{t-1\ldots} \sim N(0, \sigma_t^2) \ (5.1)$$

$$\sigma_t^2 = \ \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \ \alpha_2\sigma_{t-1}^2 \ (5.2)$$

According to equation (4), daily returns (Ret) for a commodity future contract 'x' at a given time 't' is the log difference of the spot prices (P) of the contract at a given time 't' and 't-1' is the time lagged by one day. Equations (5.1) and (5.2) depicts the GARCH (1,1) model proposed by Bollerslev (1986) where 'σ^2_t' is the conditional variance at time 't'(proxy for spot price volatility) The GARCH (1,1) model is represented two equations: a mean equation (5.1) and a variance equation(5.2). The mean equation states that returns are conditional on the mean returns proxied by Ret_{t-1} and ε_t is the error term. The variance equation states that conditional variance has three parts represented by the coefficients of the variance equation α_0 is the mean, α_1 is the news from past volatility and α_2 is the variance from the previous period. The conditional volatility series generated by the GARCH (1,1) model is used as a proxy for spot market volatility for further analysis.

3.2 Stationarity and VAR Stability

Stationarity is a crucial characteristic implying stability in time series data when $|z| \leq 1$. If the data is stationary, its first and second moments are time-invariant. Stationarity is an essential property of time-series data required for Vector Auto-Regressive (VAR) models. Therefore, the stationarity of data was examined. The Augmented Dickey-Fuller Test was employed, and the data series (post-detrending) were found to be stationary at level; the results are presented in Table 3. The results also confirmed that a classical VAR model could be used for further study as the series are stationary at level.

Table 3 Unit Root Test Results

	Europe		UAE		USA		India		Japan	
	t-Stat	*p value*	*t-Stat*	*p value*	*t-Stat*	*p value*	*t-Stat*	*p value*	*t-Stat*	*p value*
Speculation	-6.7947	0.0000	-13.6010	0.0000	-5.7927	0.0148	-6.1159	0.0000	-25.4497	0.0000
Hedging	-5.8228	0.0522	-5.5961	0.0000	-7.7473	0.0000	-10.2473	0.0000	-7.9970	0.0000
Arbitrage	-5.5259	0.0000	-18.0142	0.0000	-5.4703	0.0000	-45.1733	0.0001	-12.8422	0.0000
Volatility	-2.8456	0.0522	-3.3604	0.0125	-3.3051	0.0148	-4.0224	0.0013	-3.1964	0.0204

Note: The table gives the results of unit root tests performed on time series data to confirm stationarity. Augmented Dickey-Fuller test was used. The null hypothesis for the test states that the series has a unit root and is non-stationary. For the series to be stationary, the null has to be rejected and the results in the table show that all the series are stationary at level.

3.3 Vector Auto-Regressive Approach

In order to examine the interlinkage among the different trading activities as well as spot volatility, we rely on VAR model (Sims, 1980). These models are regression systems which provide a multi-variate setting for examining the changes associated with a variable due to changes in its lags as well as changes in other variables and their respective lags. VAR also does not impose any restrictions and therefore, all variables in the system are treated as endogenous. Hence, we estimate the following system of equations:

$$Y_t = C + \sum_{k=1}^{L} \alpha_k Y_{t-k} + \varepsilon \quad (6)$$

In equation 6, 'Y_t' is the 4 x 1 column vector representing spot volatility, arbitrage, hedging and speculation at a time 't', 'C' is a 4 x 1 column vector of intercepts and 'α_k' is a 4 x 4 square matrix of coefficients of the lags of 'Y' (represented as 'Y_{t-k}'). 'α_k' measures the effect of change in lagged variable along with other variables on the dependent variable. 'L' stands for the appropriate lags for the model, 'k' represents the different lags and 'ε' is a 4 x 1 column vector or error terms. The error is a white noise process time-invariant positive definite variance-covariance matrix.

The resultant system of equations based on equation 6 are given below, where 'Vol' denotes volatility; 'Arb' denotes arbitrage; 'Spec' denotes speculation and 'Hed' denotes hedging at a given time 't' and 'α', 'β', 'γ' and 'δ' are the coefficients varying from 1 to n and 'C' represents the constant:

$$Vol_t = C_1 + \sum_{i=1}^{n} \alpha_i Vol_{t-i} + \sum_{j=1}^{n} \alpha_j Arb_{t-j} + \sum_{k=1}^{n} \alpha_k Spec_{t-k} + \sum_{l=1}^{n} \alpha_l Hed_{t-l} + \varepsilon_1 \; - (7a)$$

$$Arb_t = C_2 + \sum_{i=1}^{n} \alpha_i Vol_{t-i} + \sum_{j=1}^{n} \alpha_j Arb_{t-j} + \sum_{k=1}^{n} \alpha_k Spec_{t-k} + \sum_{l=1}^{n} \alpha_l Hed_{t-l} + \varepsilon_2 \; - (7b)$$

$$Spec_t = C_3 + \sum_{i=1}^{n} \alpha_i Vol_{t-i} + \sum_{j=1}^{n} \alpha_j Arb_{t-j} + \sum_{k=1}^{n} \alpha_k Spec_{t-k} + \sum_{l=1}^{n} \alpha_l Hed_{t-l} + \varepsilon_3 \; - (7c)$$

$$Hed_t = C_4 + \sum_{i=1}^{n} \alpha_i Vol_{t-i} + \sum_{j=1}^{n} \alpha_j Arb_{t-j} + \sum_{k=1}^{n} \alpha_k Spec_{t-k} + \sum_{l=1}^{n} \alpha_l Hed_{t-l} + \varepsilon_4 \; - (7d)$$

The VAR model required validation of lag lengths for each sample country; hence, various information criteria are used. The Schwarz Information Criterion (SC), Akaike Information Criterion (AIC), Final Prediction Error (FPE), Hannan-Quinn information criterion (HQ) and Likelihood Ratio (LR) was used to determine the appropriate lag lengths for the analysis.

3.3.1 Granger Causality

Granger causality tests (Granger, 1988) were employed to determine the chronological order of movement in series. The null hypothesis for the test assumes that lagged variables do not explain variation in 'Y_t'. The test results give insights into lead-lag relationships among speculation, arbitrage, hedging and volatility. The Wald test statistic used, which follows a chi-square distribution. If two variables are seen to Granger cause each other, it implies a bidirectional causality and feedback. It is to be noted that unidirectional Granger causality merely indicates precedence between two variables and not causation; this implies that a direct or inverse relationship along with a magnitude of impact cannot be determined using the Granger causality test. For determining the extent of the impact of the trading activity, the impulse response functions or variance decomposition is required.

3.3.2 Impulse Response Function and Variance Decomposition

IRF shows the response on the variable to an exogenous shock and in order to perform IRF the residuals of VAR must be orthogonalized; therefore, decomposition is used. This method allows a unit shock to be applied to the residuals to note the responsiveness of 'Y_t'. These allow us to understand the direction of movement, which is not captured in Granger causality.

While IRF determines the extent of shock transmission, the variance decomposition analyses the system dynamics of VAR by estimating the proportion of variation contributed by the system to the dependent variable; this allows us to understand the movement of shocks/information. Like IRF, the order of variables for this test has an impact on the outcome and hence was kept constant.

The stability of VAR models is further confirmed using a test of inverse roots of the characteristic AR polynomial (Lütkepohl, 2005) and this is done by verifying if all the inverse roots of the AR data series lie within a unit circle.

4 RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The descriptive statistics given in Table 4 show that the four variables: volatility, hedging, speculation and arbitrage are non-normal; this is evident from the significant p-values of the Jarque-Bera test across all countries and all data series. The skewness and kurtosis levels additionally deviate from normality. Higher kurtosis indicates heavy-tailed distributions. Detrending over 100 days is performed for volume and speculation to control for seasonal changes or any cyclical trends. The total number of observations per series for all five countries is 9535. Unit root tests (Augmented Dickey-Fuller Test) was performed to confirm whether the data was stationary. The results of the ADF test are presented in Table 3, it shows that the null hypothesis is rejected; therefore, the data series are stationary. Since, evidence of long-run relationships through co-integration was found to be non-existent, we used the VAR model to further examine the data.

Table 4 Descriptive Statistics for the Sample Series (Post-Detrending)

Trading Activity	***Volatility***	***Arbitrage***	***Hedging***	***Speculation***	***Volatility***	***Arbitrage***	***Hedging***	***Speculation***	***Volatility***	***Arbitrage***	***Hedging***	***Speculation***
Country	**UAE**				**USA**				**Europe**			
Mean	0.7563	0.0002	1.0333	1.0458	0.8448	0.0014	1.0207	1.0174	0.6861	0.0105	1.0256	1.0163
Median	0.5160	0.0009	1.0458	1.0083	0.5960	0.0001	1.1806	1.0481	0.5410	0.0068	1.1077	1.0476
Maximum	6.4400	0.1129	2.7244	3.7904	4.8800	0.0647	2.3314	2.4553	3.5900	0.1151	2.1424	2.6382
Minimum	0.0889	-1.0000	0.0000	0.0000	0.1670	-0.0385	0.0000	0.0378	0.1170	-0.0476	0.0000	0.0001
Std. Dev.	0.7930	0.0299	0.5711	0.3994	0.6999	0.0063	0.5364	0.3829	0.5285	0.0192	0.4794	0.3529
Skewness	2.9676	-19.7161	0.0473	0.9138	2.3311	3.5181	-0.4293	-0.3166	1.8252	0.8982	-0.2900	-0.4397
Kurtosis	15.2114	663.6503	2.1124	6.8017	9.5360	32.2800	2.0874	3.7182	7.3151	4.4000	2.2039	4.2182
Jarque-Bera	14510	34475334	63	1400	5138	72281	125	73	2557	415	78	181
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	1889	1889	1889	1889	1913	1913	1913	1913	1921	1921	1921	1921
Country	**India**				**Japan**							
Mean	0.8666	0.0028	1.0254	1.0181	0.8132	0.0013	1.0991	1.0839				
Median	0.6415	0.0024	0.9668	1.0266	0.5270	0.0000	0.9618	0.6807				
Maximum	5.9000	0.1473	2.8629	2.7826	6.4800	0.1437	7.7592	37.4646				
Minimum	0.2020	-0.0766	0.0681	0.0060	0.1080	-0.1135	0.0000	0.0000				
Std. Dev.	0.6949	0.0189	0.4389	0.4619	0.8667	0.0246	0.6252	1.6441				
Skewness	2.9386	0.8747	0.6217	-0.0931	2.9230	0.4945	4.0824	9.3737				
Kurtosis	14.7183	9.2257	3.4667	3.5645	14.1015	7.5661	31.7749	162.4439				
Jarque-Bera	14837	3610	152	31	11413	1582	64863	1868603				
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
Observations	2072	2072	2072	2072	1740	1740	1740	1740				

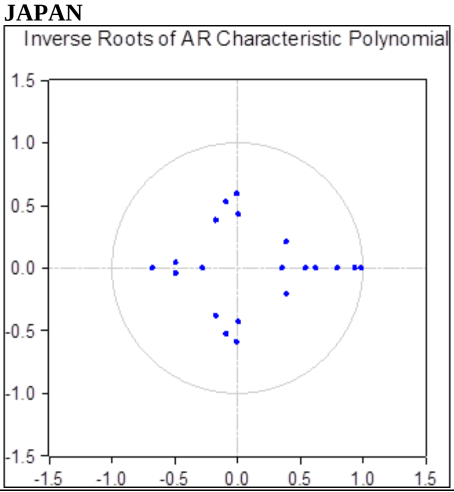
Note: The table presents the descriptive statistics of the five sample countries for the raw data series. Probability represents the p-value associated with the Jarque-Bera test statistic and based on the p-value none of the variables follow a normal distribution.

4.2 VAR Stability

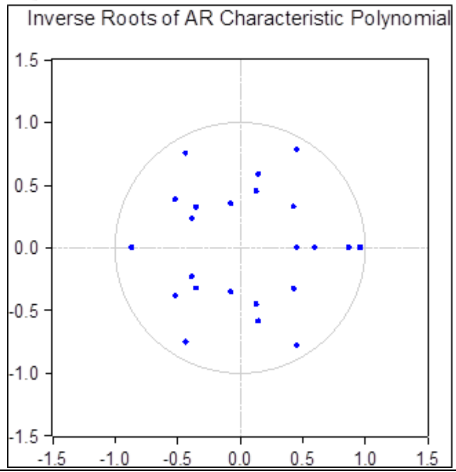
Furthermore, to determine the stability of using a VAR model, the inverse AR roots of the characteristic polynomial were examined. These inverse AR roots all lie within the unit circle in Table 5. This indicates that all series are stationary at level or *I(0)* hence, the VAR model is stable.

Table 5 VAR stability Test (AR Roots Graph)

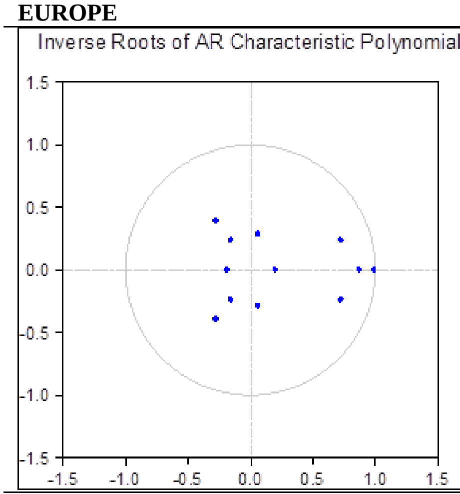
JAPAN



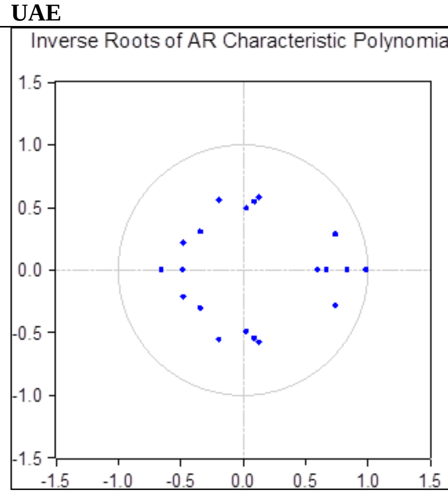
INDIA



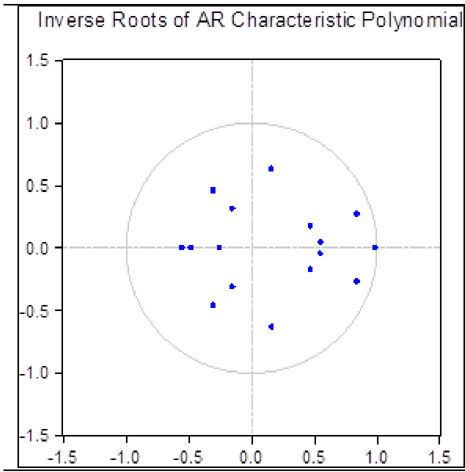
EUROPE



UAE



USA



Note: The estimated VAR model is stable if all the unit roots lie within the circle with unit radius. For all the countries no root lies outside the circle and this implies that the stability condition for VAR is satisfied.

4.3 Vector Auto-Regressive (VAR) Model Results

VAR results highlight the interlinkages between volatility, speculation, hedging and arbitrage. These VAR results are presented in Table 6; this describes the number of significant lags in each model for the selected countries. Key highlights of the table are given below:

In Japan, volatility is influenced by lagged hedging and speculation. Volatility is also influenced by its own lags upto an order of five. Whereas hedging, speculation and arbitrage are influenced by its own lags.

In India, volatility is influenced by upto two lags of hedging, speculation and arbitrage. Hedging is influenced by speculation and its own lags. Speculation is influenced by lagged volatility and hedging. Arbitrage seems least affected by the other types of trading activities.

In USA, all the three activities speculation, hedging and arbitrage impact volatility. Hedging is influenced negatively by speculation, positively by its own lags and lagged volatility. Speculation is also seen to be influenced by its own lags and arbitrage is influenced by lagged hedging.

European market volatility is influenced by lagged speculation and hedging but not arbitrage. Again, hedging is negatively influenced by lagged speculation and volatility. Speculation is influenced by lagged volatility, hedging and speculation. Arbitrage has the least influence on all the trading activities.

In UAE, lagged hedging negatively influences volatility. Hedging is unaffected by other trading activities and market volatility. Speculation is negatively influenced by lagged hedging and arbitrage is influenced by its own lags.

From the coefficients, we observe that speculation and hedging are negatively impacted by each other which is along the lines of views put forward by Working (1960) that speculation and hedging are two sides to the same coin. All the lagged trading activities influence volatility except in UAE.

Table 6 Estimates of the VAR model highlighting interconnections between volatility of spot prices, speculation, hedging and arbitrage

	Volatility Japan	Hedging	Speculation	Arbitrage	Volatility India	Hedging	Speculation	Arbitrage	Volatility USA	Hedging	Speculation	Arbitrage
V (-1)	0.9196***	-0.0158	0.4891	0.004	0.9801***	-0.0581	0.0498	0.0028	1.0403***	0.4364***	0.14	0.0031***
V (-2)	0.144***	0.0185	-0.6779	-0.006	0.0006	0.0202	0.0609	-0.0037	0.0435	0.1156	0.0145	--
V (-3)	-0.0706**	0.0127	0.2422	0.0026	0.0316	0.0454	0.0336	0.0063	-0.0171	-0.5001***	-0.172	-0.0049***
V (-4)	0.1463***	-0.0061	0.3097	0.0013	-0.0891***	0.0244	-0.195*	-0.0119**	-0.0765***	-0.0083	0.0427	0.0028**
V (-5)	-0.1496***	-0.0026	-0.4399	-0.0017	0.1175***	-0.0744	-0.1434	0.0061	--	--	--	--
V (-6)	--	--	--	--	-0.0621***	0.0343	0.1929***	0.0023	--	--	--	--
H (-1)	0.0349***	0.886***	0.1661	-0.0004	-0.033***	0.7136***	0.1778***	-0.0021	-0.0555***	0.7729***	0.1176***	0.0015***
H (-2)	-0.03**	0.0234	-0.1503	0.0009	0.0024	0.0728***	-0.0845**	0.0009	0.0412***	0.0679**	-0.0184	-0.0023***
H (-3)	-0.008	0.0302	0.0409	-0.0007	0.0149	0.0633**	-0.0003	-0.0014	-0.0083	0.2239***	0.186***	0.0001
H (-4)	-0.0033	-0.0002	-0.1869	-0.0013	-0.0012	-0.0034	0.0511	0.0013	0.0075	-0.1707***	-0.0367	-0.0004
H (-5)	0.0089	-0.0116	0.0921	0.0006	0.0252**	0.0206	0.0843**	0.0009	--	--	--	--
H (-6)	--	--	--	--	0.004	0.0013	-0.0555	0.0018	--	--	--	--
S (-1)	0.0099***	-0.0007	0.12***	0.0002	0.0301***	-0.0246*	0.1169***	0.0016	0.1123***	-0.2871***	0.4773***	0.0004
S (-2)	0.0007	-0.0058	0.0644***	--	0.0476***	-0.0129	0.0177	-0.0017	-0.0728***	-0.2192***	-0.0249	-0.0007
S (-3)	-0.0036	0.0027	0.0162	-0.0002	-0.0043	0.0139	-0.0112	-0.002	-0.0133	-0.3007***	-0.2076***	-0.0007
S (-4)	--	-0.0044	0.025	-0.0001	-0.0005	0.0067	-0.0117	-0.0001	-0.0128	0.2159***	0.2423***	-0.0006
S (-5)	-0.0025	-0.0013	-0.0212	-0.0001	-0.0079	0.0158	0.0439**	0.0009	--	--	--	--
S (-6)	--	--	--	--	-0.0158***	0.0254**	0.5035***	0.0001	--	--	--	--
A (-1)	0.2179	-0.1658	1.3888	0.6797***	0.4152***	-0.2673	-0.3864	-0.0024	-1.4027***	-0.6371	1.2557	0.5478
A (-2)	-0.2713	-0.4057	-2.039	0.0617***	0.8718***	-0.0061	0.2857	0.0308	1.4444***	1.7381	0.4041	0.2024
A (-3)	0.1641	0.4631	-2.9151	0.0566*	0.1314	-0.2195	-0.0551	0.0005	0.5199	-0.6156	-4.5271	-0.0875
A (-4)	0.0549	-0.4859	-0.9832	0.0367	0.0355	0.0007	-0.8231*	0.0277	-0.688	-0.0972	0.1719	0.0031
A (-5)	0.3535	-0.0734	5.4491	-0.0434	-0.2286*	-0.4155	-0.8802*	0.0387	--	--	--	--
A (-6)	--	--	--	--	-0.2123	-0.1169	-0.4441	-0.0173	--	--	--	--
C	-0.0001	0.0852***	0.9607***	0.0012	-0.0472***	0.1196***	0.1765***	0.001	0.0101	0.672	0.2503	0.0022
	Europe				**UAE**							
V (-1)	0.9822***	0.4045***	0.297***	-0.0003	0.9661***	-0.0918	0.0853	0.0008				
V (-2)	0.0178	-0.1356	-0.2803*	0.0042	0.1142***	-0.0114	-0.1035	-0.0052				
V (-3)	-0.0192	-0.2705***	-0.0249	-0.0003	-0.1228***	0.0909	-0.0165	-0.0014				
V (-4)	--	--	--	--	0.1552***	0.0967	-0.0878	0.0092				
V (-5)	--	--	--	--	-0.1231***	-0.0753	0.1234	-0.001				
H (-1)	-0.0305***	0.9805***	0.2459***	0.0003	-0.0137**	0.5757	-0.3119***	0.0005				
H (-2)	0.0122	-0.1169***	-0.0566	0.0005	-0.0021	0.1686	0.0627***	-0.0009				
H (-3)	-0.0081	0.0639**	0.036	-0.0011	0.0184**	0.059	-0.005	-0.0004				
H (-4)	--	--	--	--	-0.0052	-0.0389	0.067***	0.0015				
H (-5)	--	--	--	--	0.0065	-0.1018	-0.0502**	0.0004				
S (-1)	0.0644***	-0.4732***	0.2781***	0.0008	0.0005	0.3157	0.3194***	-0.0009				
S (-2)	-0.0293***	0.0191	0.0881***	0.0011	-0.0092	0.1455	0.1977***	0.0028				
S (-3)	0.003	-0.1176***	0.003	-0.0007	0.0089	0.0084	0.158***	0.0007				
S (-4)	--	--	--	--	-0.0002	-0.1049	0.1113***	-0.0001				
S (-5)	--	--	--	--	-0.0061	-0.0383	0.0336	0.0019				
A (-1)	0.1128	1.2172	0.6391	0.3504***	0.059	0.1552	-0.3256	0.0765***				
A (-2)	0.3379	-0.7658	-0.3594	0.2461***	-0.0634	0.295	0.0441	0.052**				
A (-3)	0.0782	0.5869	0.4884	0.2005***	-0.0706	-0.3692	0.0628	0.0502**				
A (-4)	--	--	--	--	0.0827	-0.3015	0.4768*	0.0572**				
A (-5)	--	--	--	--	0.0287	-0.1894	-0.2458	0.0571**				
C	-0.0045	0.6465***	0.4075***	-0.0011	0.0101	0.0012	0.4325***	-0.0073**				

*Note: The table presents the results of the VAR model. 'A','S', 'H' and 'V' stand for arbitrage, speculation, hedging and volatility respectively and the lags are given in parenthesis as suffix. '***', '**' and '*' denotes 1%, 5% and 10% level of significance, respectively. Appropriate lag-lengths for the VAR model was identified using AIC, SBIC, FPE and LR criteria. 'C' denotes the constant.*

4.3.1 *Granger Causality*

The results of the Granger causality test are tabulated in **Table 7**. Based on the test, we are able to determine interlinkages of both types unidirectional and bidirectional. Hedging and Speculation consistently show a strong link which is similar to Cifarelli and Paladino (2015) and speculative trades often provide short-term liquidity to hedgers. Volatility and speculation also show interlinkage relationships except in UAE. Arbitrage is also seen to contribute to volatility, however bidirectionality ceases in UAE and Japan. This can be attributed to regulatory changes or varying microstructures in markets. These findings (refer Table 8) are also supported by studies of Bessembinder and Seguin, 1993; Floros and Salvador, 2016.

Table 7 Granger Causality Test Results from VAR Model

		Dependent Variables/ Lags			
Country	***Independent Variables***	**Volatility**	**Hedging**	**Speculation**	**Arbitrage**
UAE	Volatility	-	13.1609**	2.874	2.8474
	Hedging	4.4727	-	240.0887***	4.2346
	Speculation	5.1575	355.6603***	-	6.1008
	Arbitrage	9.1678	1.2621	4.0357	-
Europe	Volatility	-	47.393***	118.3247**	26.6376***
	Hedging	25.6814***	-	553.1013***	10.7447**
	Speculation	8.9637**	170.2248***	-	3.8246
	Arbitrage	31.9695***	0.9331	1.8767	-
USA	Volatility	-	42.3313***	183.1734***	13.6615***
	Hedging	100.6148***	-	719.1486***	1.1314
	Speculation	11.8055**	215.6526***	-	11.1832**
	Arbitrage	50.0569***	40.333***	10.7608**	-
India	Volatility	-	25.1284***	115.8824***	60.2044***
	Hedging	3.8752	-	12.8181**	4.0348
	Speculation	15.259**	73.5054***	-	9.9959
	Arbitrage	15.2452**	5.9696	10.3891	-
Japan	Volatility	-	10.3012*	44.0224***	20.5227***
	Hedging	1.244	-	5.2849	7.8301
	Speculation	6.5397	2.2031	-	6.7895
	Arbitrage	2.3322	2.6429	1.7906	-

Note:

- *The table provides the results of the Granger Causality test for VAR method. The Wald Test statistic is given in the table (it follows a χ^2distribution). The null hypothesis in each case states that the lags do not cause changes in the dependent variable that is Null implies non-causality; for a causal relationship to exist, the null hypothesis must be rejected.*
- *For all p- values < 0.01, non-causality is rejected at 1% level of significance (***), p-values < 0.05 non-causality is rejected at 5% level of significance (**) and for p-value < 0.10 (*), non-causality is rejected at 10% level of significance.*

Table 8 Brief Snapshot of Hypotheses Results

Hypotheses	**Conclusion**	
Null	**Null Accepted**	**Null Rejected**
H_{011}: Volatility does not Granger cause arbitrage	UAE, Japan	India, USA, Europe
H_{012}: Volatility does not Granger cause speculation	UAE, Japan	Europe, USA, India
H_{013}: Volatility does not Granger cause hedging	UAE, India, Japan	Europe and USA
H_{014}: Arbitrage does not Granger cause volatility	UAE	Europe, USA, Japan, India
H_{015}: Arbitrage does not Granger cause speculation	UAE, Europe, India, Japan	USA
H_{016}: Arbitrage does not Granger cause hedging	UAE, USA, India, Japan	Europe
H_{017}: Speculation does not Granger cause volatility	UAE	Europe, USA, Japan, India
H_{018}: Speculation does not Granger cause arbitrage	UAE, Europe, India, USA, Japan	----
H_{019}: Speculation does not Granger cause hedging	Japan	UAE, USA, Europe, India
H_{0110}: Hedging does not Granger cause volatility	----	UAE, USA, Europe, India, Japan
H_{0111}: Hedging does not Granger cause arbitrage	UAE, Europe, India, Japan	USA
H_{0112}: Hedging does not Granger cause speculation	Japan	UAE, USA, Europe, India

Note: The table gives an overview of Granger causality results for the entire sample.

4.3.2 Impulse Response Function (IRF) and Variance Decomposition (VD)

The results of Variance decomposition analysis as given in 9 Shows that in Europe, speculation and arbitrage account for 9% and 4% of spot price variance, respectively. In India, speculation (5%) and arbitrage (3%) contribute to variance in spot price volatility as well. Similar results are found in Japan. In the USA, 4% of the variance in spot price volatility is explained by speculation. Overall, speculation and arbitrage contribute to changes in the volatility whereas hedging remains neutral. In the UAE, the variation in spot price volatility is predominantly explained by its innovations rather than trading activity.

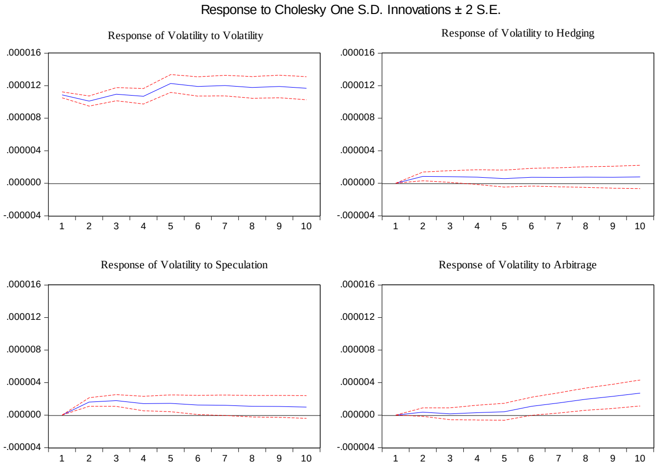
Table 9 Variance Decomposition Analysis of Spot Volatility

Country	UAE				Europe			
Period	*Volatility*	*Hedging*	*Speculation*	*Arbitrage*	*Volatility*	*Hedging*	*Speculation*	*Arbitrage*
1	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
2	99.8605	0.1249	0.0002	0.0144	97.0902	0.0389	2.8501	0.0208
3	99.6014	0.3387	0.0508	0.0092	95.8499	0.0582	3.8182	0.2737
4	99.6127	0.2938	0.0769	0.0167	94.5125	0.0550	4.8042	0.6283
5	99.6376	0.2580	0.0916	0.0128	93.0782	0.0583	5.8045	1.0590
6	99.6539	0.2121	0.1207	0.0133	91.6774	0.0683	6.6875	1.5668
7	99.6663	0.1805	0.1396	0.0137	90.3542	0.0864	7.4522	2.1072
8	99.6587	0.1796	0.1480	0.0137	89.1325	0.1122	8.0868	2.6685
9	99.6458	0.1937	0.1464	0.0142	88.0229	0.1434	8.5930	3.2407
10	99.6205	0.2231	0.1414	0.0150	87.0237	0.1774	8.9857	3.8132
Country	**India**				**Japan**			
1	100.0000	0.0000	0.0000	0.0000	100.0000	0.0000	0.0000	0.0000
2	99.0245	0.2389	0.4887	0.2478	98.4712	0.3153	1.1608	0.0528
3	95.2201	0.4955	2.6363	1.6482	97.8935	0.3966	1.6708	0.0392
4	93.2871	0.5493	3.6942	2.4694	97.8532	0.4170	1.6835	0.0463
5	91.9199	0.6381	4.3264	3.1156	97.9680	0.3655	1.6077	0.0588
6	91.7775	0.5708	4.4134	3.2383	97.9267	0.3670	1.5113	0.1950
7	92.1231	0.4966	4.2114	3.1689	97.7995	0.3649	1.4312	0.4044
8	92.0965	0.4653	4.3078	3.1304	97.5737	0.3690	1.3527	0.7045
9	91.6100	0.5372	4.8223	3.0305	97.2928	0.3685	1.2874	1.0513
10	91.0416	0.7128	5.3085	2.9371	96.9228	0.3732	1.2287	1.4752
Country	**USA**							
1	100.0000	0.0000	0.0000	0.0000				
2	95.6129	0.0450	4.1171	0.2250				
3	94.5888	0.1253	5.1213	0.1646				
4	94.2998	0.1243	5.4601	0.1159				
5	94.5226	0.1188	5.2578	0.1008				
6	94.6497	0.1642	5.0885	0.0977				
7	94.7814	0.2227	4.8895	0.1064				
8	94.9659	0.2735	4.6439	0.1167				
9	95.2061	0.3092	4.3555	0.1292				
10	95.4517	0.3313	4.0762	0.1408				

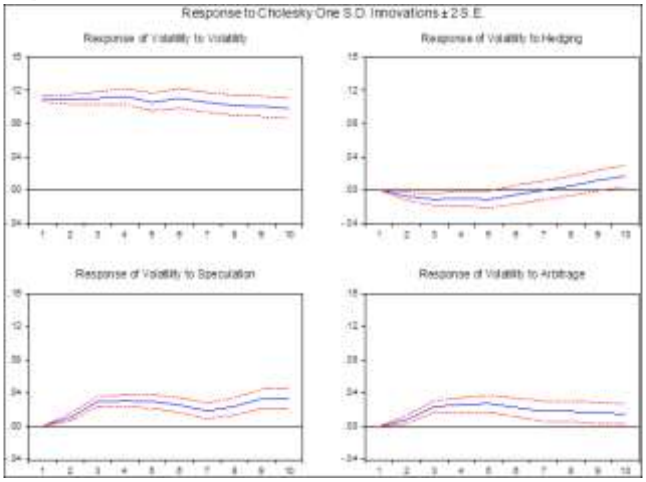
Note: The table illustrates the impact of shocks on spot volatility by providing the variance decomposition statistics for sample countries.

Table 10 Impulse Response Function for Spot Volatility

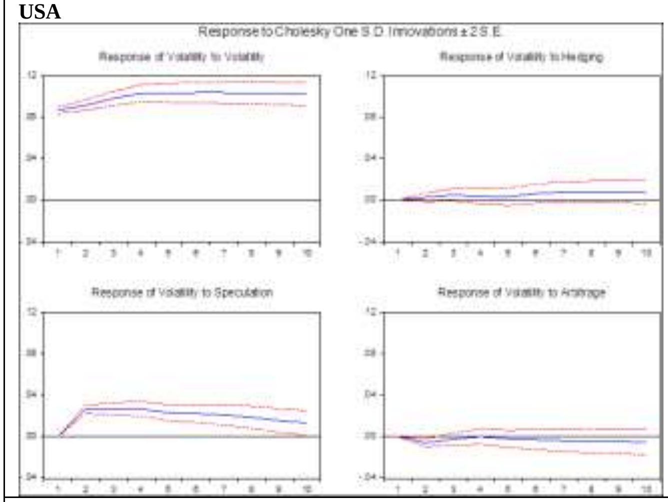
JAPAN



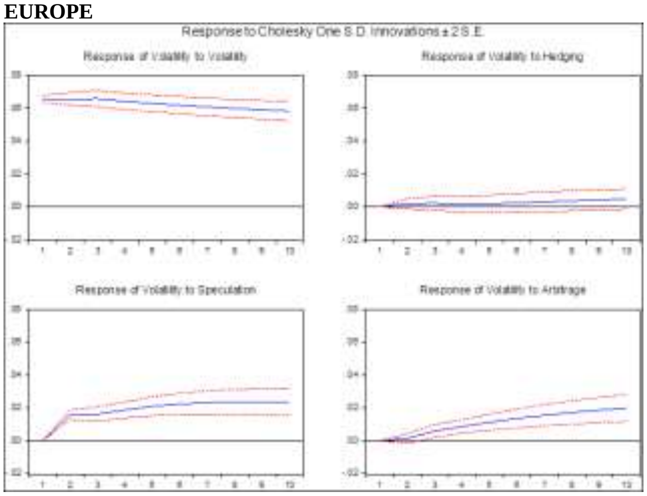
INDIA



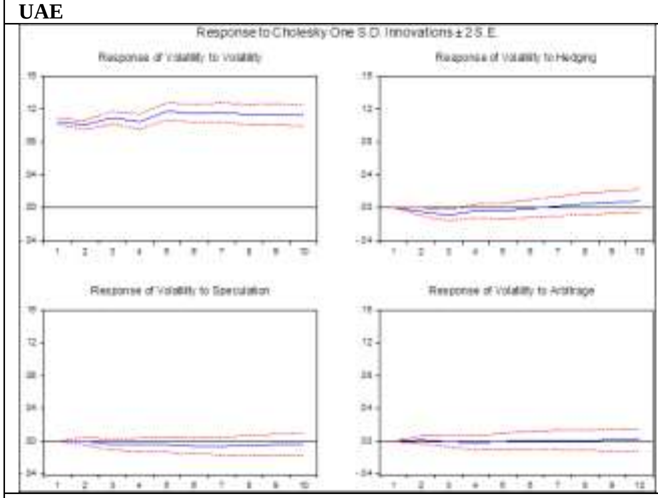
USA



EUROPE



UAE



Note: The above graphs in the table capture the response of volatility to one standard deviation shock in hedging, speculation, arbitrage and volatility for all the sample countries. The 'X-axis' of each graph represents the time lag while the 'Y-axis' represents the percentage change in spot volatility

In the case of IRF, hedging and arbitrage have a negative or low impact on spot volatility in all the countries except Europe, where arbitrage has a high impact on spot volatility (Table 10).

5 CONCLUSION

The study explores the interlinkage among hedging, speculation and arbitrage in the context of crude oil futures and their interrelationship with spot volatility. Time-varying volatility is estimated using the GARCH (1,1) model, whereas volume and open interest are detrended to capture speculation and hedging, respectively while arbitrage is measure using the basis.

The VAR model and Granger Causality confirm that speculation and hedging have a stronger link relative to that of arbitrage and lagged values of hedging, arbitrage and speculation trades are seen to drive spot volatility with the exception of UAE. There is bidirectional relationship between speculation and volatility(US, India, Europe) and arbitrage and volatility (US, India, Europe) and hedging and volatility in (US and Europe). There is unidirectional relationship impact of Hedging, Speculation and arbitrage on volatility in Japan, and hedging impacts volatility in Indian and UAE. The link between (i) arbitrage and speculation and (ii)arbitrage and hedging are almost non-existent in all the markets.

The impact of lagged volatility and lagged speculation on volatility is positive and increased trading volumes of futures leads to excessive speculation contributing to spot price volatility. The impact of arbitrage and hedging on volatility is negative or low, except in the case of Europe, where shocks to mispricing increases volatility. Again, country specific behavior is observed, and UAE appears to be unique due to its oil-producing and exporting status, whereas in India, hedging is seen to reduce volatility. In USA, Europe and Japan – hedging, speculation and arbitrage contribute to volatility Variation. Volatility in most of the countries is explained by its own lag as well as by speculation. Arbitrage is the second most crucial factor contributing to volatility; and finally, hedging contributes the least to spot volatility.

Overall, we have established that hedging, arbitrage and speculation are linked in the context of commodity futures markets. We also confirm that the activities together impact volatility, but the direction of the impact varies from country to country. While speculation and arbitrage contribute positively to volatility, hedging is seen to have a negative/low impact on volatility; this is also re-confirmed using variance decomposition where the variation in volatility is accounted for by speculation and arbitrage but not hedging activity. This insight for policymakers can help target both speculators and arbitrageurs to regulate market volatility and promote hedging using crude oil futures. Policies such as introduction of transaction taxes to contain levels of speculation will be more effective, if the interlinkages in the types of trading activities are considered..

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