An empirical analysis of the Co-movement of Crude, Gold, Rupee-Dollar Exchange rate and Nifty 50 Stock Index during Sub-prime and Coronavirus crisis periods

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Abstract

The present study empirically investigates the inter-linkages and co-movement between different asset class namely Crude, Gold, Nifty 50 Stock Index and Rupee-Dollar Exchange Rate during the two crisis periods viz. the Sub-Prime and the Coronavirus Crisis. The methodology employed for ascertaining inter-relationship includes Johansen Co-integration technique and Toda & Yamamoto Causality model. Besides this, the entire model has been set up under the VAR Framework with Variance Decomposition and Impulse Responses giving useful insight into the relationship amongst the stated variables. The results of the study however failed to identify any co-integration amongst the assets during any of the two crisis periods , however there was evidence of short run cause-effect relation amongst some of the variables. The causality flow was uni-directional from Nifty 50 to both crude and exchange rate in Period I(Sub Prime Crisis Period) while in Period II(Coronavirus Crisis Period) it was bi-directional between Gold and Nifty 50. Causality was also seen from Foreign Exchange to Gold in Period II. Further ADF Breakpoint showed all the variables were I(1) stationary and the VAR Model was also proved stable as shown by AR Characteristics Root Plots. The impulses showed that Period II or Coronavirus Crisis Period retained the innovations of other variables for longer periods than Period I (Sub Prime Period).

Keywords : Sub-Prime Crisis, Coronavirus Crisis, ADF Breakpoint, Co-integration , VAR, Impulse Response

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1. Introduction

The movement of Stocks, Crude, Gold and Exchange rate has been a topic of interest amongst researchers for long, however the extremely high level of co-integration during the turbulent times often gives sleepless nights to the investors around the world. This is mainly because during these times almost all the financial markets start moving in tandem, thereby leaving no scope of any portfolio diversification for the investors at large. However before we understand why there is a high uniformity in the direction of markets during a crisis period, there is a need to understand what exactly happens if any uncertain event occurs.

Now, whenever any uncertain event or simply a shock occurs in any country , there is a tendency amongst investors to adjust or rebalance their holdings not only in the country where shock has occurred but other countries or markets as well. Usually this rebalancing of portfolios is undertaken even without considering the country's macros and the inter-linking tendency or contagion in markets spreads even to those markets where the macros are quite different or markets are still not efficient.(Calvo and Mendoza, 2000; Fleming et al.,1998; Kallberg et al., 2005). The overall impact of such an event on markets may be restricted to few days or a couple of weeks after which there is a tendency to move back towards normalcy, however sometimes the impact is for a longer period and if a solution to the crisis is not immediately visible, it might convert to a full fledged crisis.

The spread of a shock to other markets can be a fundamental contagion, if it can be explained by macros or a pure contagion if it is due to irrational behaviour of investors e.g. herd mentality (Lin et al. 1994; Dornbusch et al. 2000) .According to Dornbusch et al.,(2000) shocks due to fundamental contagion get transmitted to a country because of trade and financial linkages which act as the channels of spillover of shocks to that country. On the other hand the same shock might lead to investors to act irrationally due to imperfect information and informational asymmetries. This may lead to herd type of behaviour and the investors become more risk averse thereby resulting in an overall loss of confidence amongst these investors. In such a situation there are only handful of investors who invest after gathering relevant information while most investors just tend to follow the crowd.

Coming to the present study: 'An empirical analysis of the Co-movement of Crude, Gold, Rupee-Dollar Exchange rate and Nifty 50 Stock Index during sub-prime and Coronavirus crisis periods' has been undertaken with a specific motive; the motive being to compare the inter-linkages between different asset classes during the crisis periods and by making an analysis from the angle of both short and long run. The outcome of this paper would also assist us in examining a more common phenomenon i.e. during a crisis all asset classes tend to move in tandem i.e. in the same direction. The current study can be approached either by investigating into the factors affecting the demand, supply and market structure in each of these class of markets leading to the price formation in these markets or by establishing a statistical inter-relationship among the markets (Malliaris and Malliaris, 2013). Clearly since the period of current study is restricted to the period which revolves around a crisis, first approach is easily ruled out. Hence for investigating the co-movement of Stocks, Crude, Gold and Exchange rate during sub prime and Coronavirus crisis periods we would be focusing on the second approach which includes establishing statistical inter-relationship among the movement of the markets of these asset class. The daily closing prices for all the four variables has been collected from the websites; www.investing.com, www.nseindia.com and www.mcxindia.com and the two crisis periods included in the study are Period I : Jan 1, 2008-June 30, 2009 (Sub Prime Crisis) & Period II : Jan1,2020-June 30, 2020 (Coronavirus Crisis).

The entire paper has been structured as follows: Section 1 or the current section gives the introduction to the co-movement of Nifty 50 Stock Index, Crude, Gold and Exchange rate . Section 2 reviews the existing literature on the inter-linkages between Stocks, Crude, Gold and Exchange rate during different time frames including the crisis periods. Section 3 discusses methodology employed under the study followed by the Section 4 which gives the empirical results of the study. The next section i.e. Section 5concludes the study and also gives the policy recommendations & study limitations. Finally at the end we have two more sections, Section 6 and 7 for references & appendices respectively.

2. Review of Literature

There is no dearth of existing literature on linking of different segments of financial markets; most research studies have formulated their approach by picking up one or two alternate assets and then investigating such asset's movement against the movement of the stocks or their movement against each other. The first category of papers focus on Crude and stocks where researchers like Anoruo and Mustafa (2007), Park and Ratti (2008), Sadorsky(1999), have shown that there exists a negative relation between stock returns and Crude. Few researchers like Cong et al. (2008) have however failed to establish a significant relation between stocks and crude. The second category of papers link country's exchange rate to stock returns and here most studies have shown that there exists a contagion between exchange rates of a country and its stock market return. These prominent studies include research work by Hashimoto and Ito (2004), Rjoub (2012) and Caporale et al.(2014). Studies like Kanas (2000) on the other hand have tried to compare stock's volatility to volatility of exchange rates and found a positive relation between the two. The argument put forth by the study was that while investing in a foreign market equities, international investors need currency of that country and therefore any rise in the volatility of its currency is bound to have some impact on volatility of country's equity market.

Under the next category we have studies which relate gold to stocks and here the research work has mainly focused on the hedging and safe haven capacity of the yellow metal (Baur and Lucey 2010;Baur and Mc. Dermott, 2010; Dee and Zheng 2013). A section of researchers have also focused on empirically testing the inter-linkages between Crude and precious metals including gold, silver (Hammoudeh et.al 2008, Le & Chang, 2011) and Crude and base metals (Korhonen & Ledyaeva 2010; Zhang., et.al.,2018). This is based upon the presumption that a host of common macro-economic variables influence the movement of such commodity prices and these include interest & exchange rates, inflation, GDP growth and so on.

A lot of recent studies instead of focusing on just two segments have picked up three or four segments of financial markets together and tried to study their co-movements and inter-linkages . Thuraisamy.et al.(2013) found that there was a spill-over from equities to mainly two commodities ; Crude and gold in mature markets while some of the immature markets gave the evidence of its reverse or spillover from commodities to equities. Le and Chang (2011) concluded that for Japan there was a substantive evidence of co-integrating relation between crude, gold, exchange rate , stock prices and interest rates . Further the interest rates had positive impact on both gold and stock prices. Samanta and Zadeh (2012) in their study of interlinkages between price of Gold, Crude, DJIA Stock Index and US Dollar real exchange rate concluded that there was evidence of co-integration between exchange rate and stocks. Also both exchange rate and stocks impacted crude and gold. On the other hand a study using same variables carried out by Kim and Dilts (2011) found that US dollar was negatively related to both crude and gold during the period 1970 to 2008. Further, since the time period also saw the depreciation of dollar, the results showed that there was a flight from dollar towards alternative assets during the period the currency saw a fall in its value.

Morema, and Bonga-Bonga (2018) investigated the impact and spillover of crude and gold on South African stocks and found a significant return spillover from crude to stocks especially stocks of the industrial sectors and again gold to stocks mainly in stocks of resources sector. The spillover however was uni-directional either from gold or crude to stocks . The paper strongly recommended that for minimising risk, investors should include crude and/or gold as a part of their investment. Malliaris and Malliaris (2013) found two way relation between crude and euro and also between crude and gold. Chang (2013) however observed that for Taiwan, the movement of three variables crude, gold and Taiwan exchange rate were more or less independent even though positive long run co-integration was revealed amongst all the three variables from the results. The VAR analysis showed that the variable which was least impacted due to movement of others was gold.

Moving in the same direction, the present study too focuses on making a thorough assessment of the co-movement of Stocks, Crude, Gold and Exchange rate but with a purpose; the purpose being to restrict its analysis to the two crisis periods viz. the sub-prime crisis of 2008 and the Coronavirus crisis of 2019. The analysis has been restricted to these two periods only to get a useful insight about the comparative co-movements amongst the financial assets during these two crisis periods. Only a few attempts have been made in the past, however here the researchers have compared the movement of financial variables during normal and crisis periods. The following section discusses some of these findings.

Lin et al.,(1994) found an evidence of a high uniformity in the direction of markets during a financial crises. The cross-market connections were seen to increase quite significantly after any major shock to any individual or a group of countries. Chan et al.,(2011) using Markov Regime Switching Model conducted their study on two states viz. ‘‘tranquil” & ‘‘crisis” and observed that during the ‘‘tranquil” period funds mainly moved from gold to stocks. Moreover this state also was characterized by lower volatility and positive return on stocks. On the other hand, during the “crisis” period things actually reversed i.e. this state was characterized by sharp negative stock returns coupled with high volatility. Further during the “crisis” there was evidence of fund movement from stocks to bonds . Also there was sufficient evidence of contagion between stocks, crude, & real estate. Baig and Goldfajn (1999) studied for existence of contagion across East Asian economies in same segments of financial markets. The study which was carried out during the period of East Asian crises could identify substantial contagion in the debt markets. The cross-country correlations were also found to be significant in both currency and equity markets after controlling few variables. Singh and Sharma (2018) studied inter-linkages between Gold, Crude, Dollar and Sensex for pre, during and post sub prime crisis periods. The results showed co-integration between crude and sensex during pre crisis period while causality was present during crisis and post crisis periods. The relation was negative between stock and rupee-dollar returns while it was positive in case of gold and crude during all three periods . Leung, et al.,(2017) used high frequency hourly data to study volatility spillover for equity and currency markets for normal and two crisis periods viz. the sub prime and euro debt crisis. The results revealed that there was an overall increase in spillover during the crisis periods. Further volatility spillover during the euro crisis was substantially lower than what it was during the sub-prime and reason for given the same was that both government and firms had learnt from their experiences and taken steps like hedging to reduce volatility risks in event of any crisis.

Research Gap

The above literature review which started with exploring research in the area of inter-linkages amongst different segments of financial markets in varying time periods ultimately got refined to the co-movements of these segments during more specific crisis periods. Further, during crisis periods there appears to be a consensus amongst researchers about volatility i.e. volatility rises across asset classes during this period. Another important point which was put forth by almost all the papers was that return on stocks is mainly negative during this period. Most of the existing research studies have taken a single crisis period and moreover have included the crisis in these studies in addition to normal periods.

On the other hand the present study which focuses exclusively on crisis period is an attempt to compare the behaviour of the financial market segments during the two major global crisis periods viz. the sub-prime crisis of 2008 and the Coronavirus crisis of 2019. There was a widespread impact of both these crisis and this was clearly visible when we look at the movement of global financial markets during the crisis periods. The present study therefore has been undertaken to compare the response of the financial variables during these two crisis periods. The study gathers daily closing prices of the four financial variables ; Nifty 50 stock index, Rupee-Dollar exchange rate, Gold and Crude for two period of study , Period I : Jan 1, 2008-June 30 2009, the sub-prime crisis period and period II : Jan 1 2020-June 30 2020 the Coronavirus crisis period.

3. Methodology

Under this section, first we would discuss the statistical properties of our four variables viz. Gold, Crude, Foreign Exchange and Nifty 50, followed by examination of a long term relationship amongst them variables using Johansen Co-integration approach and also setting up a vector autoregressive model for the same.

3.1 Descriptive Statistics

To begin with the present study compares the financial variables on statistical parameters which include Mean, Median , Standard Deviation and some distributional characteristics which include Skewness, Kurtosis and JB test statistic for Normality. The Closing Prices of the four financial variables namely return on gold, crude, foreign exchange and Nifty 50 have been converted to relative returns using the formula $\frac{P_t - P_{t-1}}{P_{t-1}}$ and the statistical description of data for all these four variables is depicted in Table I.

Table I : Statistical Description of Variables during the two crisis periods								
	Period I: SUB Prime Crisis				**Period II: Coronavirus Crisis**			
	(Jan 1, 2008-June 30, 2009)				***(Jan1,2020-June 30, 2020)***			
Parameter	**Nifty 50**	**Gold**	**Rupee-Dollar**	**CRUDE**	**Nifty 50**	**Gold**	**Rupee-Dollar**	**CRUDE**
Mean	-0.0006	0.0004	0.0006	-7.88E-05	-0.0010	0.0014	0.0005	0.0078
Median	0.0001	0.0010	0.0006	-5.51E-05	-0.0006	0.0009	0.0006	-0.0004
Standard Dev.	0.0288	0.0191	0.0068	0.0418	0.0266	0.0158	0.0048	0.1474
Kurtosis	8.6011	5.2938	6.5068	5.1559	8.4873	5.8055	5.4470	28.6165
Skewness	0.2324	0.3028	-0.2546	0.3836	-0.9829	0.3795	-0.3363	2.2454
Minimum	-0.1413	-0.0588	-0.0349	-0.1265	-0.1298	-0.0464	-0.0194	-0.7340
Maximum	0.1774	0.0903	0.0266	0.1783	0.0876	0.0576	0.0141	1.0597
No. of Obser.	352	352	352	352	120	120	120	120
JB Statistics	463.2989	82.5479	184.1737	76.8019	169.8776	42.2350	32.2003	3381.85

A look at the table 1 reveals that mean daily return on Stock Index is negative for both the crisis periods viz. Period I (Sub Prime) & Period II (Coronavirus) , however negative return is much more in the Period II (-0.1 % daily or -36.5 % annually) than in Period I (-0.06 % daily or -21.9 % annually). On the other hand Gold has remarkably done well in Period II (+0.14 % daily or +51.1 % annually) as compared to Period I (+0.04 % daily or +14.6 % annually) with average return being positive in both periods. The other commodity, crude behaves differently in two crisis periods i.e. it gives a negative return on Period I while it is positive in Period II. Interestingly the Crude has also been the best performer in terms of returns in Period II giving an annualized return of 284 % during the period. The movement of the fourth variable i.e. rupee-dollar exchange rate is more or less similar in the two crisis periods. Coming to variability, the Crude has the highest variability in period II, followed by stocks, gold and rupee-dollar exchange rate. Exactly the same scenario is seen for period I, where Crude again seems to be the most volatile of all the four variables.

The distribution characteristics of the four variables with respect to skewness and kurtosis reveal that the distribution of rupee-dollar is negatively skewed in both the periods. On the other hand, highest positively skewed distribution is crude in both the periods; none of these four distributions being symmetric in either of the two periods. Again with respect to kurtosis or peakedness of the distribution, all the distributions are leptokurtic, with distribution of Crude during Period II having the highest peak of all the four distributions. Further JB Statistics for normality (JB Statistics = $\frac{n}{6}\{S^2 + \frac{1}{4}(K-3)^2\}$; where 'S' and 'K' denote the Skewness and Kurtosis of respective distributions , does not reveal that any of the distribution either for period I or II being anywhere close to normal. Therefore considering the shape of our distributions, it was decided that for further analysis we would be considering the closing prices of all the four variables at natural log levels.

3.2 Stationarity of Variables

A test of stationarity of a variable is usually applied before developing any research model and its outcome lays the foundation in developing necessary research tools for subsequent analysis. A time series is considered as stationary if there is no change in characteristics of its parameters i.e. mean, variance etc. over a period of time. Under the present study we have applied two different tests of variable stationarity, first is the popular Augmented Dickey Fuller Unit Root test , a parametric test which has been augmented to include a single break point duly constructed using innovative outlier method as given by Perron (1997). The second stationarity test is the KPSS , a non parametric test which augments the low power of the first test i.e. ADF unit root test. The KPSS test follows a different set of hypothesis i.e. here the Null is Stationary with a deterministic trend only while the alternative is unit root . To put it in different words , for this test one side of the coin we have non stationary due to trend and on the other side we have non stationary due to unit root. The Null Hypothesis of KPSS, if accepted would confirm that the time series has absence of stochastic unit root but has a trend. Thus our time series is trend stationary, which is acceptable for our study as trend stationary is mean reverting and therefore we may proceed with analysis using this variable.
The equations used for the Augmented Dickey Fuller Unit Root test and KPSS non parametric test are given below as equation (i) and (ii):-

$$\Delta X_{i,t} = \beta_{1,i} + \beta^*_{1,i} D_{i,t} + (\beta_{2,i} - 1) X_{i,(t-1)} + \sum_{j=1}^{m} \beta_{3,j} \Delta X_{i,t-j} + \beta_{4,i} t + u_{i,t} \quad \text{.......eq.(i)}$$

{In eq(i), $\Delta X_{i,t}$ is the change in variable 'X_i' in period 't' 'i' =i^{th} variable ; 1 to 4 variables namely Natural Log of Closing Prices of NSE Nifty 50 Index, Crude ,Gold and Exchange rate. $\beta_{1,i}$ represents the constant term, $D_{i,t}$ is the intercept Dummy representing a likely break in the intercept in the i^{th} variable. The Dummy has been constructed using innovative outlier method as given by Perron (1997). This Dummy takes the value of '1' if the observation falls after the break date and '0' before and on the break date. In case the break exists, then the coefficient $\beta^*_{1,i}$ is expected to be statistically significant. The next coefficient term is ($\beta_{2,i}$ – 1) which represents the stationary coefficient and is put to test for null hypothesis of $\beta_{2,i} = 1$. The value of the computed 't' statistics of the stationary coefficient is compared with ADF table value. The next term i.e. $\sum_{j=1}^{m} \beta_{3j} \Delta X_{i,t-j}$ denotes change in variable X_i in period t-j (j is the lag) & this term has been added to stationary 'X' equation to take care of serial-correlation. The summation of the term indicates that the term adds up 'm' lag times till the serial-correlation is removed. The next term $\beta_{4,i} t$ is the trend variable and takes care of possible deterministic trend in the variable 'X_i' so that only stochastic trend can be detected by the test and the final term is $u_{i,t}$ which is random error term.}
The testable hypothesis for ADF Stationarity test of our variable X_i (eq (i)) would be

(H_0) : Coefficient ($\beta_{2,i} - 1$) =0 (Variable X_i is not stationary)
(H_a): Coefficient ($\beta_{2,i} - 1$) ≠0, (X_i is stationary)

Acceptance of Null Hypothesis given above would mean that the variable has a unit root.

$$\text{KPSS}(u_t) = n^2 . \{ (\sum S_{it}^2) / \sigma_{u_t}^2 \}, \text{ n is the no. of observations ....eq.(ii)}$$

{ in the above eq.(ii) ; S_{it} is the partial sum of residuals and is defined as

$S_{it} = \sum_{t=1}^{n} \sum_{i=1}^{t} u_{it}$ *(i=1,2,3,…t, t=1,2,3,..n).* $\sigma_{u_t}^2$ is the variance of the error term}

The testable hypothesis for KPSS Stationarity test of our variable X_i (eq. (ii)) would be

(H_0) : KPSS(u_t) < Critical LM (Presence of a trend)
(H_a): KPSS(u_t) > Critical LM (Stochastic Unit root, absence of trend)

Now with stationarity being tested using two different ways, we would be able to comment on stochastic stationarity of our variable in a far better manner. Again we may get the similar or conflicting results from the two types of tests. In case the results from tests are similar and both the tests confirm that the variable is stochastic stationary at the same level, there won't be much of a problem in deciding the level of the variable for further analysis, however in case of conflicting results, we would take the decision considering the results obtained from ADF unit root test rather than the KPSS test as KPSS is only a supplementary test.

3.3 Test for Co-integration of Variables

The examination of a long term relationship amongst the variables is usually carried out by applying an econometric tool of co-integration. The checkpoint for applying this technique is to determine whether the time series have common level of integration. Thus even if two or time series are non-stationary at levels, there can be a linear relation at levels (called co-integrating regression) between the time series when these series become stationary at I(I). Under the present set up we use the Johansen (1998) Co-integration Model which has developed using a simple VAR Model given below as eq.(iii) :-

$$\mathbf{X_{it} = \mu + \lambda_{i,1} X_{i,(t-1)} + \lambda_{i,2} X_{i,(t-2)} + \ldots\ldots + \lambda_{i,k} X_{i,(t-k)} + e_{i,t} \ldots\ldots\ldots\ldots (iii)}$$

{ μ = constant, k= no. of lags, e_t the error term and $\lambda_{i,1}$, $\lambda_{i,2}$, $\lambda_{i,3}$ .... are the coefficients of VAR terms. 't' is the time period and 'i' is i^{th} variable }

The above model (ii) may be written as

$$\mathbf{\Delta X_{it} = \mu + (\lambda_{i,1} - 1)(X_{i(t-1)}) + \lambda_{i,2} \Delta X_{i(t-1)} + \lambda_{i,3} \Delta X_{i(t-2)} + \ldots + \lambda_{i,k} \Delta X_{i(t-(k-1))} \ldots\ldots (iv)}$$

Now Let $\boldsymbol{\theta}_\mathbf{i}$ = $(\boldsymbol{\lambda_{i,1}}\mathbf{-1})$ represent a matrix of coefficients signifying long term relation among the variables

i.e. $\boldsymbol{\theta}_\mathrm{i} = \begin{pmatrix} \boldsymbol{\alpha_{11i}} & \boldsymbol{\alpha_{12i}} & \cdots & \boldsymbol{\alpha_{1mi}} \\ \boldsymbol{\alpha_{21i}} & & \cdots & \vdots \\ \boldsymbol{\alpha_{m1i}} & & \cdots & \boldsymbol{\alpha_{mmi}} \end{pmatrix}$ is the fundamental matrix of the co-integration.

In the above matrix $\boldsymbol{\theta}$, all the vectors need not be co-integrated therefore our main interest lies in the rank of the matrix θ. If there is no co-integration, Matrix θ has a rank '0', while if co-integration is detected, we proceed towards computation of characteristic roots and eigen values.

3.4 Setting up a VAR Model, Causality Model, Impulse Response and Variance Decomposition

The VAR Model (eqs. v, vi, vii & viii) has been set us as a Standard VAR and includes the lagged endogenous variables as independent variables. The number of lags for each of the variables has been fixed by applying lag selection criteria tools which include AIC, SC,FPE and HQ with broad consensus being the consideration. The VAR model would also assist in developing a causality model, impulse response function and variance decomposition.

$$\text{Gold}_{t,(p)} = \sum_{i=1}^{t-1} \beta_{1,i,(p)}\ \text{Gold}_{t-i,(p)} + \sum_{j=1}^{t-1} \beta_{2,j,(p)}\ \text{CRUDE}_{t-j,(p)} + \sum_{k=1}^{t-1} \beta_{3,k,(p)}\ \text{Exc. Rate}_{t-k,(p)} + \sum_{l=1}^{t-1} \beta_{4,l,(p)}\ \text{Nifty}_{t-l,(p)} + u_{1t,(p)} \quad \text{..................Eq. (v)}$$

$$\text{CRUDE}_{t,p} = \sum_{i=1}^{t-1} \lambda_{1,i,(p)}\ \text{Gold}_{t-i,(p)} + \sum_{j=1}^{t-1} \lambda_{2,j,(p)}\ \text{CRUDE}_{t-j,(p)} + \sum_{k=1}^{t-1} \beta\lambda_{3,k,(p)}\ \text{Exc. Rate}_{t-k,(p)} + \sum_{l=1}^{t-1} \lambda_{4,l,(p)}\ \text{Nifty}_{t-l,(p)} + u_{2t,(p)} \quad \text{..... Eq. (vi)}$$

$$\text{Exc. Rate}_{t,(p)} = \sum_{i=1}^{t-1} \theta_{1,i,(p)}\ \text{Gold}_{t-i,(p)} + \sum_{j=1}^{t-1} \theta_{2,j,(p)}\ \text{CRUDE}_{t-j,(p)} + \sum_{k=1}^{t-1} \theta_{3,k,(p)}\ \text{Exc. Rate}_{t-k,(p)} + \sum_{l=1}^{t-1} \theta_{4,l,(p)}\ \text{Nifty}_{t-l,(p)} + u_{3t,(p)} \quad \text{..................Eq. (vii)}$$

$$\text{Nifty}_{t,(p)} = \sum_{i=1}^{t-1} \gamma_{1,i,(p)}\ \text{Gold}_{t-i,(p)} + \sum_{j=1}^{t-1} \gamma_{2,j,(p)}\ \text{CRUDE}_{t-j,(p)} + \sum_{k=1}^{t-1} \gamma_{3,k,(p)}\ \text{Exc. Rate}_{t-k,(p)} + \sum_{l=1}^{t-1} \gamma_{4,l,(p)}\ \text{Nifty}_{t-l,(p)} + u_{4t,(p)} \quad \text{..................Eq. (viii)}$$

{ eq.(v), eq.(vi), eq.(vii) and eq.(viii) are the four VAR equations developed as Standard VAR Model . Consider VAR eq.(v) ; where variable Gold is regressed against past lags of Gold, Crude, Exchange Rate and Nifty 50 variables . ‘t’ is the time period, ‘p’ represents the period which can take the value as ‘I’ or ‘II’, value ‘I’ represents the Sub prime crisis period and ‘II’ represents the Coronavirus crisis period. The parameters $\beta_{1,i}$, $\beta_{2,j}$, $\beta_{3,k}$ and $\beta_{4,l}$ are the coefficients of the four variables Gold, Crude, Exchange Rate and Nifty 50, where ‘i’, ’j’, ’k’ and ‘l’ represent the number of lags for each of these four variables respectively. The last term ‘u_1’ is the residual error term of VAR eq.(v). On similar lines we build up VAR equations (vi),(vii) & (viii).}

3.4.1 The Causality Model

The traditional popular causality model given by Granger(1969) would work only when variables are integrated at level , however since in our case we have all the variables integrated at 1st difference in both the periods of study we would be applying Toda, H. Y., & Yamamoto, T. (1995) causality model which is simply a modified Wald test (MWALD) based upon augmented VAR.

Consider two variables X_1 and X_2 and we wish to test cause-effect relation; variable X_2 is causing X_1 i.e. $X_2 \rightarrow X_1$. To test this we would be developing the following two models: Model (ix) : the restricted model and Model (x) : unrestricted model. We would be using AIC to determine the optimal length of each of the two variables. Let us assume ‘h’ as the optimal length for our variable X_1 & ‘k’ as the optimal length for variable X_2.

(i) ***Restricted Model :***

$$X_{1t} = \lambda_0 + \sum_{j=1}^{Imax} \alpha_j X_{2,(t-j)} + \sum_{i=1}^{h+Imax} \beta_j X_{1,(t-i)} + u_t \text{......(ix)}$$

The above restricted model (ix) has a constant λ_0 and lags of both variables; independent variable X_2 and dependent variable X_1. These lags sum up to 'Imax' for independent variable X_2 and 'h+Imax' for dependent variable X_1. 'h+ Imax' is the maximum no. of lags for dependent variable X_1 ; 'h' is already defined as the optimal no. of lags as per AIC. 'Imax' on the other hand is the maximum order of integration of two variables .Finally the model has u_t as the error term.

(ii) ***Un-Restricted Model***

$$X_{1t} = \lambda_0 + \sum_{j=1}^{k+Imax} \alpha_j X_{2,(t-j)} + \sum_{i=1}^{h+Imax} \beta_j X_{1,(t-i)} + v_t \text{...(x)}$$

The Un-restricted Model (x) has a constant λ_0 and has augmented lags i.e. maximum number of lags of dependent variable X_1 given by 'h+ Imax' (same as restricted model) while the lags of X_2 shall be 'k +Imax'. 'k' is optimal lags as per AIC for Independent variable X_2 and 'Imax' is the maximum order of integration of two variables. We have v_t as the error term for the unrestricted model (x).

Null Hypothesis: Lagged values of X_2 do not influence X_1 i.e. $\alpha_1 = \alpha_2 = \alpha_3 \ldots = 0$
Alt Hypothesis: Lagged values of X_2 influence X_1 i.e. $\alpha_1 = \alpha_2 = \alpha_3 \ldots \neq 0$

Decision Criteria: For this we compute Modified 'F' Wald and we reject the Null Hypothesis if $F_{\text{M. Wald}} > F_{\text{Table}}$ at 5 %.

$$F_{\text{'Wald Mod'}} = \frac{(RSS_{rest} - RSS_{unres})/k}{RSS_{unres}/(n-k)}$$

{RSS_{rest} : Residual Sum of the Squares of Model (ix), RSS_{unrest} : Residual Sum of the Squares of Model (x), 'k' is the degree of freedom of the numerator which is equal to number of parameters to be estimated , 'n' being number of observations}

3.4.2 The Impulse Response function and Variance Decomposition

The VAR Model Interpretation is usually carried out by analysing the Impulse Response function and Variance Decomposition. The impulse function traces the response of dependent variable when a unit shock (1 SD) is applied to current value of one of the error terms. When a shock is applied, the first variable to be impacted is the Dependent variable where the error term is located and over time this impacts all other variables.

Another useful result from the VAR Mechanics is the Variance Decomposition. Using VAR, we can easily decompose the total fluctuations in the dependent variable which is due to lags of own variable (we call this own shock) and also due to lagged other variables (other shocks). Variance Decomposition actually answers a simple question? What proportion of Var (x+y) can be explained by x (or y) if x & y are two independent variables . We know that for independent variables ; Var.(x+y)= Var. x + Var. y. Dividing both sides by Var. (x+y) we get ; $1 = \frac{\text{Var x}}{\text{Var (x+y)}} + \frac{\text{Var y}}{\text{Var (x+y)}}$; Now the terms of RHS are now variance decompositions.

The results of the Impulse Response function and Variance Decomposition are given in Appendix IV and V. Further, the validity of the results displayed for the Impulse Response and Variance Decomposition depends upon how stable the VAR Model is. Therefore it becomes important to test for the stability of the VAR Model and the common procedure adopted is by inverse roots tests of AR Characteristic Polynomial. Under this test, if all the characteristic roots lie in region ± 1, it would give an indication of stability / stationarity of our VAR model. This is also the necessary and sufficient condition for stability of VAR.

4. Empirical Results of the Study

The section discusses the empirical results of the study; the tabular format for the same is given in Section 7 ; the appendices. The first appendix, Appendix I gives the results of ADF Breakpoint Unit root and KPSS Non Parametric stationary tests of all the four variables under study viz. Crude, Nifty 50, Rupee-Dollar Exchange Rate and Gold . Whereas Appendix I-A gives the stationarity results for Period I (Sub-Prime Crisis Period), Appendix I-B gives the same for Period II (Coronavirus Crisis Period). Out of the two stationary tests viz. ADF & KPSS; ADF Breakpoint Unit Root test shall continue to be our main test for stationarity testing while KPSS shall be a supplementary test which has been included to give more power to the ADF Breakpoint Unit root test. The model applied for ADF Breakpoint test is *'intercept with trend with a single breakpoint at trend'* using innovative outlier approach of Perron(1997). The Lag Specification has been decided using AIC Lag Selection Criteria. For both the tables (Appendix I-A & I-B), the results of the study have been COMPUTED at level as well as at 1^{st} difference and these results have been compared with the critical values at 5 % and 1 % levels, given as a foot note below each of these tables. The breakpoint for each of the four variables as identified by the ADF test is given in column 2 of both the tables. The last column of each of these tables show acceptance or rejection of Null Hypothesis under the two tests viz. ADF breakpoint and KPSS.

Appendix I-A which gives the stationarity results for Period I i.e. the sub prime crisis period , reveals that all the four variables reject the Null of No Stationarity using ADF at 1^{st} difference only. On the other hand in case of KPSS test, the three variables namely Nifty 50, Gold and Exchange Rate accept the Null Hypothesis at 1^{st} difference reflecting that the time series has absence of stochastic unit root but has a trend for these three variables at 1^{st} difference. The only variable which has a different result under KPSS test is Crude which rejects the Null Hypothesis of KPSS thereby showing the presence of stochastic unit root both at level and 1^{st} difference. This is quite contradictory to Breakpoint ADF test result which was rejecting the Null at 1^{st} difference for this variable. Since we have very little option but to decide the level of stationarity for further analysis, a decision can easily be made for three of the variables viz. Gold, Nifty 50 and Foreign Exchange since both Breakpoint ADF and KPSS give consistent results of stationary at 1^{st} difference, however for Crude where the two results are contradictory we would be going ahead with the result of Breakpoint ADF unit root test which is a parametric test and also this modified ADF test is much superior to the traditional ADF unit root. Therefore we conclude that for Period I i.e. Subprime period all the variables are considered stationary at 1st difference.

Coming to Appendix I-B which gives the results of stationary tests for same four variables for Period II (Coronavirus Crisis Period), the results clearly reveal that all the four variables are stationary at 1st difference as revealed by both the tests or there is consistency w.r.t level of stationary for all the variables using both breakpoint unit root and KPSS tests. One interesting feature of this period i.e. Coronavirus Crisis period is that three of the four variables have identified a near consensus break point in their data. Thus whereas Nifty 50 has identified 25th March 2020 as breakpoint date, Gold and Exchange Rate have their breakpoints at 24th and 26th March 2020 respectively. On the other hand ,variable Crude has shown a break date almost one month after the above dates i.e. 23rd April 2020.

Appendix II gives the results of the Johansen Co-integration test for all our variables in two tables; Appendix II-A : Unrestricted Co-integration Rank Test Results (Trace and Max Eigen value) during Period I (Sub-prime crisis) and Appendix II-B :Unrestricted Co-integration Rank Test Results (Trace and Max Eigen value) during Period II (Coronavirus Crisis). The two tables have been constructed by taking log closing prices and the results of both these tables do not reveal any co-integration either in Period I or Period II and the Hypothesis of no co-integration is accepted in both the cases.

The next appendix gives the results of our short run causality tests; the short run causality can still exist amongst the variables, even though the co-integration was not proved in our study. The important consideration for causality is the level of integration of our variables and since our stationarity results reveal that all the four variables are I(1) integrated we have applied Toda & Yamamoto (1995) Causality test, the results of the same are given in Appendix III. Appendix III gives two type of results, first we have the two tables, Appendix III-A1 and Appendix III-A2 giving the Toda and Yamamoto Causality Test Results for the two crisis periods while second result pertains to Augmented VAR Estimation for our two crisis periods (follows AIC lag determination); VAR being augmented by maximum order of integration of our variables (see Appendix III-B). The causality results point out uni-directional causality from Nifty 50 to Crude and also from Nifty 50 to Exchange Rate for Period I (Sub Prime Crisis). On the other hand for Period II (Coronavirus Crisis) we find bi-directional causality between Gold and Nifty 50 and a uni-directional causality from Exchange Rate to Gold.

The next set of results relate to Variance Decomposition(VD) and Impulse Responses(IR) for our four variables .These are given in Appendix IV and Appendix V(Fig 1-8) respectively . First we discuss the results of Variance Decomposition given in Appendix IV whose first column provides information about the four variables to be decomposed i.e. Crude, Gold, Nifty50 and Exchange Rate. Column 3-10 of Appendix IV provides the explanation for each of these four decompositions. Beginning with VD of Crude we find that Crude as an explanatory variable explains 100 % of its one day ahead forecast error variance for both the periods (Period I & II) and 98.49 % of its ten day forecast error variance in Period I and 95.24 % of its ten day forecast error variance in Period II. The ten day ahead forecast error for crude explained by other variables viz. gold, exchange rate and Nifty50 are 0%, 0.12 % and 1.38 % respectively for Period I while these percentages are 0.6 %, 3.4 % and 1.38 % respectively for Period II. Thus the VD of Crude clearly shows that even on day 10th , the relative importance of innovation of other variables is only meagre as compared to own innovation in both the periods.

On the other hand, in case of VD of Gold, the one day ahead forecast error variance as explained by its own innovation is 90.9% and 98.5 % for the period I & II respectively. For Day10, there is an increase in error variance as explained by other variables which cumulatively account for 40 % of its variation for period II. The major contribution here is 16.9 % of Nifty 50 followed by Exchange Rate 14.9 % . This also gives an indication of short run causality moving from these two variables to gold in Period II (Coronavirus Crisis Period). However for Period I , there is no major change and own innovation of gold continues to explain 90 % of its variation even on day 10.

Coming to VD of exchange rate; 71.3 % and 76.9 % of its variation is due to its own innovation on day 1 for two periods I & II with a slight decline to 70.2 % and 69.9 % on day 10 for same two periods respectively. The other variable which contributes the maximum variation in exchange rate in both periods is Nifty 50 where the share of its innovation in two periods is 21.5 % & 19.6 % respectively. Again in case of Nifty 50, day 10 share remains almost unchanged from what it was on day 1. Thus we may conclude from here that short run causality is flowing from Nifty 50 to Exchange Rate in both periods.

Lastly we have VD of Nifty 50 which is explained by own innovation on day 1 ; 93.17 % & 95.63 % for Period I & II respectively. The share of own contribution is almost the same at 92.04 % for Period I on day 10^{th} while it falls to 78.6 % for Period II. In Period II, we see a rise in the explanatory power of all the three variables and the contribution of these variables on day 10 is 8.6 %, 6.7 % and 6.1 % for Foreign Exchange, Gold and Crude respectively.

To get a more comprehensive picture of VD, we compare the variations across variables by taking pairs. To begin with we take Crude and Gold, and we find that Gold explains 0 % and 0.55 % variation in Crude on day 10 for Period I & II respectively, Crude on the other hand explains 9 % and 8.4 % of gold on day 10 for the same two periods, indicating that Crude defines Gold more than what Gold defines Crude. Next we take the pair of Gold and Nifty 50 and here the Gold explains 0.5 % and 5.9 % variation in Nifty 50 on day 10 for Period I & II respectively while Nifty 50 on the other hand explains 0.1 % and 16.9 % of gold on day 10 for two periods respectively. The these figures show that the two variables Gold and Nifty 50 behave almost independently in Period I while in Period II, Nifty 50 explains more of Gold than what gold explains of Nifty 50.

The third pair we take into consideration is Nifty 50 and Exchange rate and the figures tell us that Nifty 50 explains more of exchange rate in both periods on day 10 which enables us to arrive at a conclusion that Nifty 50 causes exchange rate in short run. On the other hand, for pair between Nifty 50 and Crude, the result is almost the opposite to above i.e. for both periods, Crude explains more of Nifty 50 at day 10 while contribution of Nifty 50 to the explanation of crude on day 10 is negligible for both periods, however the variation is not to the extent that we would come to any conclusion about cause –effect behaviour in the short run amongst these variables. Amongst the crude and exchange rate pair , crude explains more of exchange rate than what exchange rate explains of crude in both periods and finally we have gold and exchange rate pair for which we find that V.D of Gold being explained by exchange rate in two periods is remarkably different i.e. in Period I, exchange rate almost does not explain any variations in gold, however in Period II around 15 % of variations in gold are explained by exchange rate. On other the hand gold explains only 2.3 % and 3.5% of variation in exchange rate in period I & II respectively.

Next we have the results for Impulse responses for which we have Appendix V-A : Impulses during Period I (Sub Prime Crisis) and Appendix V-B : Impulses during Period II

(Coronavirus Crisis). These impulse responses are depicted graphically (Fig1to Fig. 8) with 'X' axis being the time period in days and 'Y' axis being the response of the variable to 1σ innovation in another variable. The first four figures; Fig 1 to Fig 4 are for impulses pertaining to the Period I (Sub-Prime), while the next four , Fig 5 to Fig 8 pertain to Period II (Coronavirus). If we examine Fig 1 which is Response of Crude to 1σ innovation in other variables during Period I, we find that the effect of a unit shock in other variables on Crude gradually dies down and beyond Day 3 it does not result in more changes in Crude. This can be seen in Fig 1 where the plot becomes a straight line and merges with 'X' axis after the 3rd day. The same pattern is also witnessed for other variables during Period I where a unit shock in other variables also lasts only till Day 3 in case of Gold, Nifty 50 and also for Exchange Rate(Figures 2, 3 and 4 respectively). On the other hand in case of Period II (Coronavirus Crisis) we find that for almost all the variables, effect of a unit shock is taking a much longer time to die out completely i.e. the impact appears to be dying out in four to five days in case of gold and crude while for Nifty 50 and exchange rate this extends to five to six days.

The last set of results pertain to inverse roots of AR Characteristic Polynomial and these are given in Appendix VI; Fig 9 and 10 for two periods respectively. The results clearly reveal that all the characteristic roots lie within the circle in region ± 1 indicating stability / stationarity of our VAR model.

5. Conclusion, Study Limitations and Policy Recommendations

To conclude, the present study made an attempt to compare the inter-linkages and co-movement between different asset class namely Crude, Gold, Nifty 50 Index and Rupee-Dollar Exchange Rate during the two crisis periods viz. the Sub-Prime and the Coronavirus Crisis. The results of the study ruled out any possibility of co-integration amongst these assets during any of the two periods and therefore the hypothesis that all the assets move together during the crisis periods could not be validated from the results of the study. On the other hand , despite the results not reflecting any co-integration, there was some evidence of short run cause-effect relation amongst some of the variables. It was noticed that one way short run causality was flowing from Nifty 50 to both crude and exchange rate in Period I while in Period II there was bi-directional causality between Gold and Nifty 50. Also in Period II, one way causality was seen from Foreign Exchange to Gold.

The results of VAR-Variance Decomposition analysis pointed out that short run causality was moving from Nifty 50 and Exchange Rate variables to Gold in Period II (Coronavirus Crisis Period) as ten day ahead forecast error variance of Gold as explained by the innovations was 16.9 % by Nifty 50 and 14.9 % by Exchange Rate respectively. Similarly short run causality was seen flowing from Nifty 50 to Foreign Exchange Rate in both periods as the share of its innovation explaining the Foreign Exchange rate was 21.5 % & 19.6 % respectively in two periods respectively. Then Nifty 50 was found to be causing exchange rate in short run as explained by ten day ahead forecast error variance in both periods. The result of Impulses Response Function broadly gave an idea that the effect of a unit shock on all the variables during the Period I (Sub Prime Crisis) continued till Day 3 before dying out, however in case of Period II (Coronavirus Crisis) this effect took a much longer time to die out completely i.e. the impact continued for four-six days for different variables.

The study also has a couple of limitations which we want to highlight, first the period of study being different under the two crisis periods may have some impact on results especially Period II (Coronavirus Crisis Period) which is of six months duration. However it is worthwhile to note that the present study was conducted during the period when Coronavirus

Crisis was still in existence and therefore it was not possible for us to increase the duration of the study and match it with the Sub Prime Crisis. Secondly the data for the four variables namely Nifty 50 stock index, rupee-dollar exchange rate, crude and even gold has been collected from domestic websites. Thus the prices of the four variables would be the prices at which they were traded on domestic bourses and therefore need not be exactly same as those in international bourses. Although this is taken as limitation by many researchers, still in our opinion this is not a limitation but only a difference in approach which is well recognized and accepted. Moreover it can always be argued that the movement of any of the four variables is not local but global even though information is collected from domestic sources and with the integration of domestic markets with international markets, the movement in their prices is in much line with global markets.

At the end considering the results obtained, we would like to give some policy recommendations. Firstly we found that impulse response was carried forward to a much larger time duration during the Coronavirus crisis than what it was in sub prime crisis. Now with Coronavirus crisis being a much recent crisis, this would imply that in times to come any change in other variables is likely to have a much deeper impact on a given variable which shall be spread over to a bigger time frame. Such a development could also impact asset portfolio construction and allocation of funds in times to come. Secondly the results of the study have rejected the hypothesis that all assets move together in crisis periods. These results may not be in line with results from existing research studies, however the deviation in any result is quite a common phenomenon as the dynamics of the markets is always changing. Further the result achieved would throw research opportunities on this front for detailed analysis of a bigger sample of crisis periods. It is important to add here that under the present study as already stated above, Period II (Coronavirus Crisis Period) has been taken to be of six months duration. Thirdly, another important takeaway of the Coronavirus Crisis period was that three of the four variables namely Gold, Nifty 50 and Rupee-Dollar Exchange Rate have a near consensus break point in their data. This however must not mean that the three variables are co-integrated but would only imply that all the three have a common date when their pattern of data has undergone a change. This could be yet another important and meaningful development for policy makers.

Lastly it was observed that Gold and Nifty 50 had bi-directional short run causality in Period II (Coronavirus Crisis) while Nifty 50 was seen impacting Crude and Exchange Rate but not Gold during Period I (Sub Prime crisis). In our opinion the possible reason for this could be that Coronavirus Crisis is actually a global crisis while Sub Prime was more inclined towards US and other developed economies. What actually happens in a global crisis is that each asset class takes clues from the movement of every other asset class. Now if we look at Gold's Demand , according to World Gold Council, the two countries of South Asia viz. India and China were consuming Gold at 53 % of the world consumption for the year 2018. Therefore when the whole world is at a crisis Stocks take clue from Gold's movement while Gold also looks at movement of Stock Markets which in a way justifies the short run causality while if the crisis is limited to a select few economies then all the variables do not get fully involved and therefore look for direction from the prominent variable like stocks. This kind of result and the interpretation could have very strong implication and also act as a guiding factor for fund managers who can modify their asset allocations keeping in view the kind and nature of the crisis.

6. References

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7. Appendices

Appendix I-A: Breakpoint Unit root & KPSS stationary test results of our variables for Period I (Subprime crisis) at Log Closing Prices
(All models with intercept & trend with breakpoint at trend , Lag Spec.: AIC)

Variable	Year & Month of Break (for stationary time series)	ADF Unit root Computed 't' * ('p' Values In Parenthesis)		KPSS Computed LM Values**		*Null Hypothesis: Accept / Reject*	
		Level	**1st Diff**	**Level**	**1st Diff**	*ADF*	*KPSS*
CRUDE	18th Dec 2008	-1.049545 (0.9344)	-19.93014 (0.0000)	0.278235	0.290190	Reject at 1st diff	Reject# at level and 1st diff
NIFTY 50	18th May 2009	-0.809834 (0.9627)	-18.49054 (0.0000)	0.329046	0.100812	Reject at 1st diff	Accept at 1st diff
GOLD	17th Sep 2008	-2.360225 (0.3999)	-18.32129 (0.0000)	0.330248	0.044860	Reject at 1st diff	Accept at 1st diff
EXCHANGE RATE	18th May 2009	-1.092601 (0.9277)	-18.99198 (0.0000)	0.304334	0.082945	Reject at 1st diff	Accept at 1st diff

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Critical Values for ADF at 5 % : -3.422679 and 1 % : -3.984420
*****Critical Values of KPSS test: 5 % : 0.146000 and 1 % : 0.216000***
 # Since the results of ADF & KPSS do not match , we consider the ADF Unit test result to be correct

Source: Authors' own computation

Appendix I-B: Breakpoint Unit root & KPSS stationary test results of our variables for Period II(Coronavirus Crisis) at Log Closing Prices

(All models with intercept & trend with breakpoint at trend , Lag Spec.: AIC)

Variable	Year & Month of Break (for stationary time series	ADF Unit root Computed 't' * ('p' Values In Parenthesis)		KPSS Computed LM Values**		*Null Hypothesis: Accept / Reject*	
		Level	1st Diff	Level	1st Diff	*ADF*	*KPSS*
CRUDE	23rd April 2020	-1.279532 (0.8880)	-17.70980 (0.0000)	0.261400	0.075148	Reject at 1st diff	Accept at 1st diff
NIFTY 50	25th March 2020	-1.022203 (0.9362)	-12.98084 (0.0000)	0.238223	0.121604	Reject at 1st diff	Accept at 1st diff
GOLD	24th March 2020	-3.265389 (0.0772)	-9.801503 (0.0000)	0.072403	0.037146	Reject at 1st diff	Accept at 1st diff
EXCHANGE RATE	26th March 2020	-1.461572 (0.8373)	-12.27904 (0.0000)	0.230239	0.121211	Reject at 1st diff	Accept at 1st diff

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***Critical Values for ADF at 5 % : -3.448021 and 1 % : -4.036983**

****Critical Values of KPSS test: 5 % : 0.146000 and 1 % : 0.216000**

Appendix II-A: Result of Johansen Co-integration between CRUDE, GOLD, Rupee Dollar and Nifty 50 during the sub- prime crisis (at closing prices)

Unrestricted Co-integration Rank Test (Trace & Max Eigen Value)

Hypothesized No. of CE(s)	Trace Statistic	Prob.	Max Eigen Statistic	Prob.
None	32.15976	0.6034	15.12932	0.7379
At Most 1	17.03044	0.6378	12.32119	0.5163
At Most 2	4.709252	0.8389	3.901100	0.8696
At Most 3	0.808151	0.3687	0.808151	0.3687

Appendix II-B: Result of Johansen Co-integration between CRUDE, GOLD, Rupee Dollar and Nifty 50 during the Coronavirus Crisis (at closing prices)

Unrestricted Co-integration Rank Test (Trace & Max Eigen Value)

Hypothesized No. of CE(s)	Trace Statistic	Prob.	Max Eigen Statistic	Prob.
None	35.95536	0.3986	22.37998	0.2015
At Most 1	13.57538	0.8636	7.665925	0.9230
At Most 2	5.909460	0.7062	4.220108	0.8354
At Most 3	1.689352	0.1937	1.689352	0.1937

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Appendix III-A1: Toda and Yamamoto (1995) CAUSALITY Test Results (SUB PRIME Crisis)

Type of Relation tested	Obs.	Observed Chi-Sq Value	Probability 'p' value	Result
GOLD→ CRUDE	351	0.160321	0.6889	No Causality
NIFTY 50→ CRUDE	351	4.884810	0.0271	Causality
EXC RATE → CRUDE	351	0.386348	0.5342	No Causality
CRUDE→ GOLD	351	0.153113	0.6956	No Causality
NIFTY 50→ GOLD	351	2.173645	0.1404	No Causality
EXC RATE→ GOLD	351	2.180651	0.1398	No Causality
CRUDE→ NIFTY 50	351	2.702265	0.1002	No Causality
GOLD → NIFTY 50	351	0.496618	0.4810	No Causality
EXC RATE→ NIFTY 50	351	2.268173	0.1321	No Causality
CRUDE→ EXC RATE	351	3.020647	0.0822	No Causality
GOLD→ EXC RATE	351	1.617226	0.2035	No Causality
NIFTY 50→ EXC RATE	351	4.833489	0.0279	Causality

Appendix III-A2: Toda and Yamamoto (1995) CAUSALITY Test Results (Coronavirus Crisis)

Type of Relation tested	Obs.	Observed Chi-Sq Value	Probability 'p' value	Result
GOLD→ CRUDE	116	2.099959	0.7174	No Causality
NIFTY 50→ CRUDE	116	5.908739	0.2061	No Causality
EXCH RATE→ CRUDE	116	5.673758	0.2249	No Causality
CRUDE→ GOLD	116	6.732774	0.1507	No Causality
NIFTY 50→ GOLD	116	45.77966	0.0000	Causality
EXC RATE→ GOLD	116	30.25712	0.0000	Causality
CRUDE→ NIFTY 50	116	1.448692	0.8357	No Causality
GOLD → NIFTY 50	116	13.48145	0.0091	Causality
EXC RATE→ NIFTY 50	116	5.462646	0.2430	No Causality
CRUDE→ EXC RATE	116	3.670455	0.4524	No Causality
GOLD→ EXC RATE	116	3.816919	0.4313	No Causality
NIFTY 50→ EXC RATE	116	8.501435	0.0748	No Causality

Appendix III-B: VAR ESTIMATION RESULTS (Augmented for Toda, H. Y., and Yamamoto, T. (1995) CAUSALITY) (Period 1 :SUBPRIME CRISIS and Period 2 CORONAVIRUS CRISIS) (computed 't' values in parenthesis)

Variable	CRUDE Period 1	CRUDE Period 2	GOLD Period 1	GOLD Period 2	NIFTY 50 Period 1	NIFTY 50 Period 2	EX.RATE Period 1	EXC RATE Period 2
CRUDE(-1)	0.875785 [15.0012]	0.332579 [3.15331]	0.010490 [0.39130]	-0.004378 [-0.48917]	-0.066591 [-1.64386]	-0.000769 [-0.04161]	0.016674 [1.73800]	0.005038 [1.50063]
CRUDE(-2)	0.107660 [1.84372]	0.299134 [2.71288]	-0.019475 [-0.72633]	0.020398 [2.18009]	0.069557 [1.71675]	0.008056 [0.41704]	-0.017168 [-1.78915]	-0.002768 [-0.78859]
CRUDE(-3)		0.130364 [1.14414]		0.004760 [0.49229]		0.012000 [0.60117]		-0.004397 [-1.21226]
CRUDE(-4)		0.201633 [1.83471]		-0.008694 [-0.93229]		0.003344 [0.17366]		0.000626 [0.17907]
GOLD(-1)	0.049604 [0.40040]	1.079566 [0.91152]	0.993452 [17.4634]	0.910960 [9.06438]	0.060578 [0.70471]	0.333384 [1.60679]	-0.025890 [-1.27170]	-0.018191 [-0.48252]
GOLD(-2)	1.35E-05 [0.09520]	0.244299 [0.15734]	-4.35E-05 [-0.66627]	-0.117312 [-0.89038]	-3.83E-06 [-0.03885]	-0.113462 [-0.41712]	2.02E-05 [0.86490]	0.032580 [0.65918]
GOLD(-3)		-0.512501 [-0.35383]		0.049505 [0.40278]		0.353517 [1.39319]		-0.064623 [-1.40162]
GOLD(-4)		-0.473239 [-0.34334]		-0.233183 [-1.99370]		-0.733671 [-3.03837]		0.082133 [1.87196]
NIFTY 50(-1)	0.199851 [2.21016]	0.783323 [1.17389]	0.061217 [1.47433]	0.206392 [3.64505]	0.969780 [15.4566]	0.689092 [5.89471]	-0.032669 [-2.19852]	-0.003912 [-0.18417]
NIFTY 50(-2)	-0.182868 [-2.01328]	-0.296219 [-0.36951]	-0.048867 [-1.17162]	0.174227 [2.56122]	0.002212 [0.03510]	0.285152 [2.03041]	0.035450 [2.37502]	-0.005751 [-0.22539]
NIFTY 50(-3)		-1.848372 [-2.20140]		-0.346268 [-4.86011]		0.013792 [0.09376]		0.005678 [0.21245]
NIFTY 50 (-4)		0.318430 [0.37078]		-0.088642 [-1.21637]		-0.008878 [-0.05901]		-0.062715 [-2.29412]
EX.RATE(-1)	0.237889 [0.62157]	0.072419 [0.01994]	0.259521 [1.47670]	1.232037 [3.99820]	-0.399945 [-1.50605]	-1.220970 [-1.91920]	0.915748 [14.5603]	0.884351 [7.65033]
EX.RATE (-2)	-0.256424 [-0.66758]	0.724530 [0.15809]	-0.267143 [-1.51458]	0.047277 [0.12157]	0.378976 0.378976	1.592415 [1.98332]	0.082133 [1.30120]	0.065638 [0.44992]
EX. RATE (-3)		-6.964026 [-1.50256]		-0.373274 [-0.94912]		-0.636626 [-0.78407]		-0.026266 [-0.17804]
EX. RATE (-4)		-3.037297 [-0.66291]		-1.119801 [-2.88024]		0.250244 [0.31176]		-0.256259 [-1.75704]
C	-0.347385 [-0.43869]	9.934422 [1.00215]	0.049160 [0.13520]	-0.910817 [-1.08280]	-0.109880 [-0.19998]	1.856078 [1.06878]	0.145561 [1.11858]	0.383562 [1.21553]
Augmented Variables								
CRUDE(-2) Period 1 / CRUDE(-5) Period 2		-0.088499 [-0.83971]		-0.013890 [-1.55319]		-0.014196 [-0.76889]		0.003102 [0.92460]
GOLD(-2) Period 1/ GOLD(-5) Period 2		1.384775 [1.40076]		0.165010 [1.96707]		0.369598 [2.13410]		-0.027414 [-0.87115]
NIFTY 50(-2) Period 1 / NIFTY 50 (-5) Period 2		0.726690 [1.00248]		0.110243 [1.79225]		-0.094351 [-0.74297]		0.051200 [2.21889]
EX.RATE (-2) Period 1/ Ex. Rate(-5) Period 2		4.710908 [1.21107]		0.694422 [2.10384]		-0.536893 [-0.78787]		0.267789 [2.16271]

Appendix IV: Result of Variance Decomposition of the four variables during two periods (Period I : Sub- prime crisis & Period II : Coronavirus Crisis)

		EXPLAINED BY ↓							
Variance Decom. of ↓	**Lag**	**CRUDE**		**Gold**		**Exch. Rate**		**Nifty 50**	
		Period I	**Period II**	**Period I**	**Period II**	**Period I**	**Period II**	**Period I**	**Period II**
Crude	1	100	100	0.00	0.00	0.00	0.00	0.00	0.00
	5	98.49	95.2395	0.0009	0.35654	0.1247	3.15493	1.3841	1.2490
	10	98.49	94.6515	0.0009	0.55036	0.1247	3.41469	1.3841	1.38348
Gold	1	9.0859	1.4802	90.9141	98.5198	0.0000	0.00	0.0000	0.00
	5	9.0450	8.3105	90.0817	61.9970	0.7529	13.0173	0.1205	16.6752
	10	9.0450	8.2005	90.0817	59.9410	0.7529	14.9456	0.1205	16.9129
Exch. Rate	1	4.9325	2.5508	2.1986	0.9184	71.3356	76.8888	21.5334	19.6419
	5	5.1538	5.8716	2.3626	3.2906	70.2106	70.5737	22.2730	20.2641
	10	5.1538	5.8886	2.3626	3.5839	70.2106	69.9542	22.2730	20.5733
Nifty 50	1	6.4340	3.8466	0.3955	0.5208	0.0000	0.0000	93.1705	95.63266
	5	6.7387	6.1186	0.4932	5.9521	0.7277	8.3297	92.0403	79.5997
	10	6.7387	6.0455	0.4932	6.6940	0.7277	8.6037	92.0403	78.6569

APPENDIX V-A : IMPULSES DURING SUB PRIME CRISIS (Fig 1 to Fig 4)

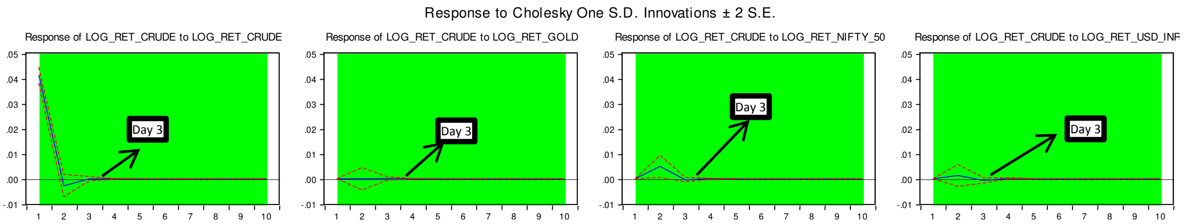

Figure 1 : Response of <u>Crude</u> to 1σ innovation in other variables

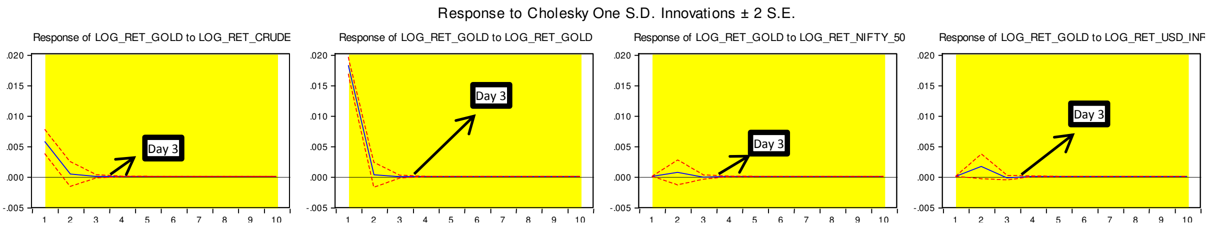

Figure 2 : Response of <u>Gold</u> to 1σ innovation in other variables

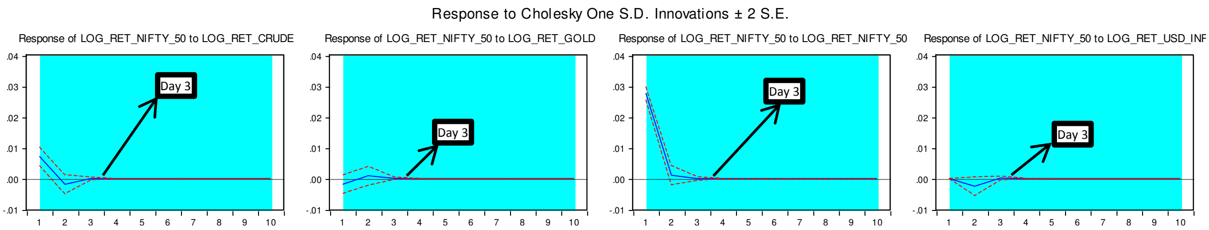

Figure 3 : Response of Nifty 50 to 1σ innovation in other variables

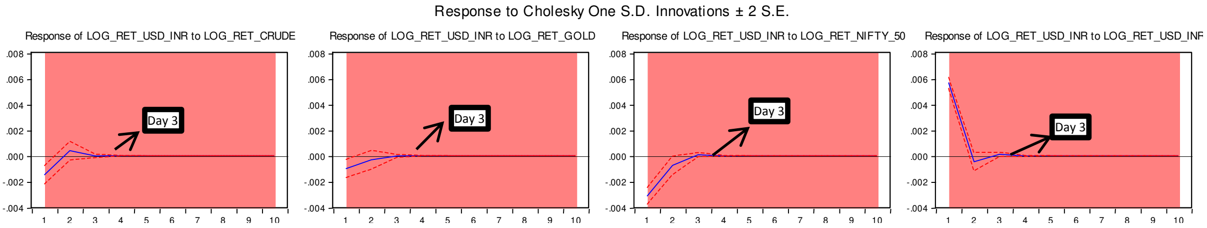

Figure 4 : Response of Exch Rate to 1σ innovation in other variables

APPENDIX V-B : IMPULSES DURING THE CORONAVIRUS CRISIS (Fig 5- Fig 8)

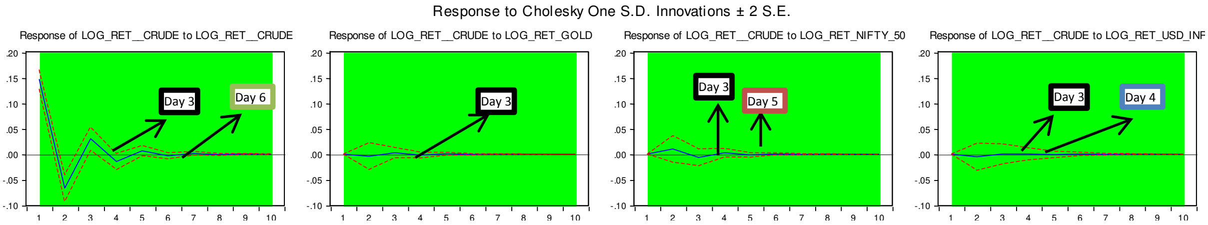

Figure 5 : Response of Crude to 1σ innovation in other variables

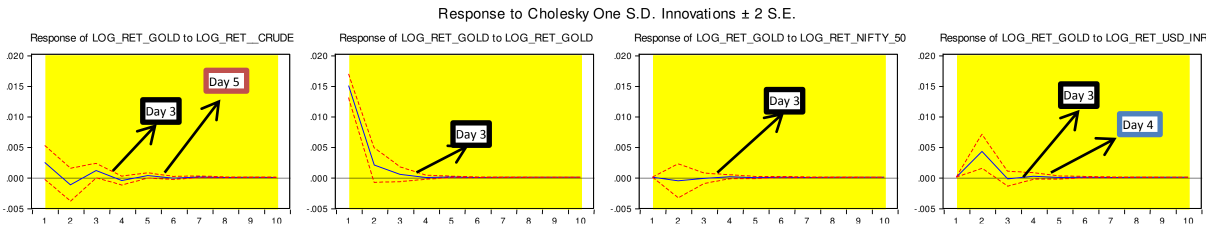

Figure 6 : Response of Gold to 1σ innovation in other variables

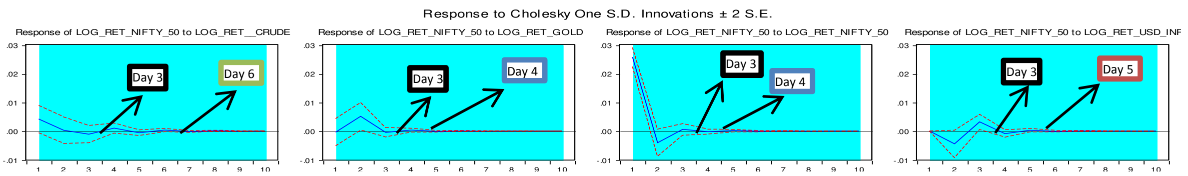

Figure 7 : Response of Nifty 50 to 1σ innovation in other variables

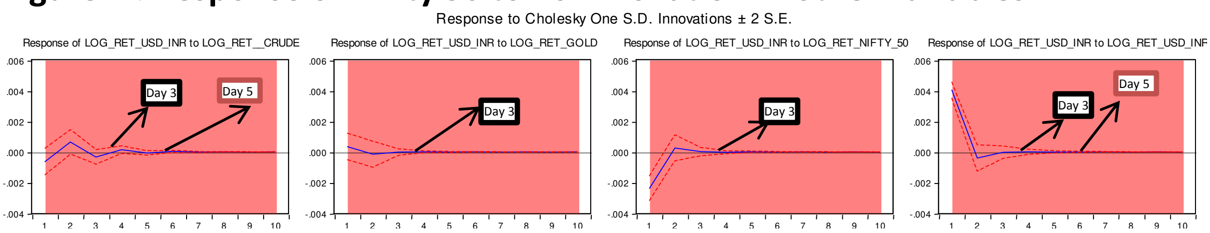

Figure 8 : Response of Exch Rate to 1σ innovation in other variables

APPENDIX VI : VAR STABILITY DURING SUB PRIME CRISIS AND CORONAVIRUS CRISIS PERIODS (Fig 9 and 10)

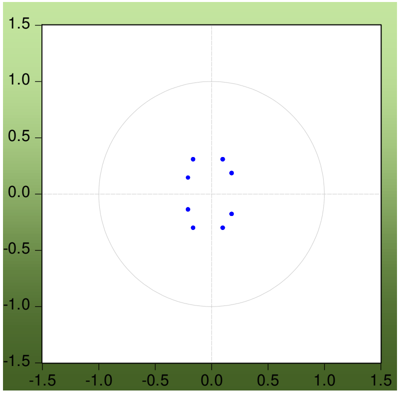

Fig 9 : AR Roots Plot Period I (Sub Prime Crisis)

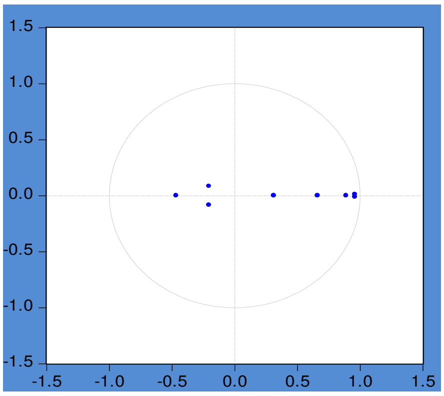

Fig 10 : AR Roots Plot Period II (Coronavirus Crisis)