TRANSMISSION & SPILLOVER DYNAMICS AMONGST THE BASE METALS IN INDIA DURING AND PRIOR TO THE COVID 19 PERIODS

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ABSTRACT

The present study makes an attempt to investigate the dynamics of transmission and spillover of return and volatility amongst three important base metals of India namely aluminium, copper and lead. The daily closing (log adjusted) prices for these three metals has been collected from the MCX India and the period of study has been two years i.e. Dec 3, 2018-Dec.1 2020, split into two periods; period before the Covid 19 crisis and period during the Covid 19 Crisis. The study uses the word 'transmission' for contemporaneous relation amongst metals while it is 'spillover' if the relation is proved at different lags. The study follows spillover model given by Masson (1998) & Dungey and Martin (2007) with slight modification. The results of the study reveal that contemporaneous relation amongst base metals was more documented than spillover for both pre and during covid periods. Limited spillover was however noticed from aluminium to both lead and copper during the DC period giving some indication that aluminium may be discovering the prices changes to be followed by other metals. The study also tested model pre requisites as stationarity, autocorrelation and heteroscedasticity and carried out model modifications wherever required to make the results robust.

Keywords: Transmission, Spillover, Contemporaneous Relation, Stationarity, Autocorrelation, Heteroscedasticity

INTRODUCTION

In the area of empirical finance, contagion & co-movement amongst the financial markets has been one of the favourite research areas amongst the researchers. Most research studies in this field have shown inclination towards a comparative assessment of two or more financial markets, these may belong to same segment e.g. exploring the movement of stock indices of any two countries or across two or three market segments within the country e.g. currency & stock markets. The popular tools to explore this type of relation have been the either the causality test (exploring the cause-effect relation) or to carry out short and long run co-integration with error correction if any, or to carry out an analysis of spillover of return and/or volatility from one type of market to another or these may be some mixture of these tools.

A very important segment of any financial market is the commodities market which is a composite of energy, agriculture and metals. The main focus of researchers here has been to study the interlinkages between energy mainly crude), agricultural crops and precious metals (mainly gold). Little empirical research has been carried out for rest of the commodity market segments including base metals. Base Metals include important metals like aluminium, zinc, lead, copper, tin etc. The reason for the ignorance of base metals by most researchers has been mainly due to lack of interest towards this segment from the investors who still do not recognize the base metals as an asset class giving them satisfactory return and playing an important role in risk diversification and asset allocation.

Now in such a scenario the question which arises is: What are the ingredients which an ordinary investor looks for before making any investment decision and how much of this is satisfied by base metals? The answer to this is an investor would only recognize the base metals as an asset class if they demonstrate high degree of interlinkages with any of the existing assets and also respond to shocks as others assets have responded (Ciner *et. al.,* 2020). Another reason why investors shy away from base metals is that their prices are heavily dependent upon the production of these metals and any shortfall makes a big impact on their prices and therefore considering these as equivalent to other assets becomes a challenging task. On the other hand if this is so, then the same is also true for agricultural crops, however this has not resulted in researchers showing lesser interest in carrying out research in this commodity.

Limited research on base metals has shown that these do have all the important characteristics which an asset class should possess. Further there has been some evidence that base metals also do qualify as a hedge and/or safe haven a characteristic very much common to precious metals especially gold (Agyei-Ampomah *et. al.*, 2014). Further there is again some evidence of asymmetry in the returns of the base metals as shown by Lien & Yang (2008) where they found that for aluminium and copper, spot and futures were behaving differently to positive and negative events. On the other hand there seems to be some doubt about whether or not the base metals follow random walk just like other assets including stocks. The non-randomness was proved when results showed some evidence of cyclicality in some of the base metals and this was concluded by Roberts, M. C. (2009). We shall be discussing more on the existing research on base metals in the next section i.e. Section 2: Review of Literature.

The base metals market has been dominated by London Metals Exchange (LME) and this was examined in detail by Li & Zhang (2013) when they found that the prices were moving from LME to Shanghai Futures exchange, however they also concluded that the dominance of LME was on a decline.

Keeping in view of the above, the present study has been developed to empirically investigate the whether or not there is any return or volatility transmission and/or spillover amongst the three important base metals; aluminium, copper and lead. The data for these three metals has been collected from the MCX Commodities Market of India as daily closing prices (F_t) and converted to natural log; ln (F_t/F_{t-1}). The period of study has been two years i.e. Dec 3, 2018-Dec,1 2020, however since the period also includes the period of corona crisis, we have split the data into two periods; period before the covid crisis or pre crisis period(PC) and period during the Covid 19 Crisis (DC).

The importance of the three metals comes from its applications in our day to day life. Whereas aluminium is primarily used in building and construction, consumer electronics, aircrafts, cars and packaging (cans), copper is extensively used in electrical and electronic products, construction and power transmission. Since copper plays an important role in country‟s infrastructure, any disruption in copper supply impacts the economy at large and therefore this metal is also dubbed as Dr Copper. The third metal included in our study is lead which is primarily used for manufacturing batteries used in automobiles. A lot of factors play their role in determining the prices of these three metals and these include spot rates in India and abroad, Rupee-Dollar exchange rate, freight and custom duties, trade agreements, inflation, industrial production, commodity specific events, government economic and trade policies and so on. (Source: www.mcxindia.com).

The entire paper has been structured as follows: Section 1 or the current section gives the introduction to the three variables viz. aluminium, lead and copper, their importance and factors impacting their prices. Section 2 reviews the existing literature on empirical research on base metals with a section on Indian research papers in this area. Section 3 discusses research objectives which flow from the main objective of return or volatility transmission / spillover amongst the three base metals. The section also discusses the methodology employed .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.

REVIEW OF LITERATURE

As already mentioned that the empirical research on base metals has been extremely limited and this being so many researchers have included base metals in addition to other popular commodities like gold and oil. Some of the researchers have compared the price movement of metals with stocks of companies which trade in these metals or use these metals extensively to produce their final products. A popular research area has always been spot vs. futures and whether futures determine the spot prices and here some of the researchers have extended this to base metals. Co-movement of different base metals and spillover of return and volatility has also been explored by some researchers. Some of these papers and their key findings are discussed under this section. The section also has papers on base metals where studies have examined base metals from India‟s perspective.

Ciner, Lucey and Yarovaya (2020) tested for inter-linkages amongst different base metal markets with respect to intensity and dynamics relating to spillover for seven metals for the period 1994–2016. The tools employed were spillover analysis and wavelet framework. High degree of return as well as volatility spillover was noticed across markets which increased during financial crisis of 2008. Their findings showed that metals have now become an asset class for investors similar to other assets like equities or bonds. On the other hand Jacobsen, Marshall & Visaltanachoti, (2019) showed that apart from being asset class, base metals could also predict the stock prices. They used state switching model and the results were able to prove that metal prices could predict prime movement in equity markets, this was shown as decline in stocks the following month after the prices of metals were on the rise. Further returns from metals were found to gradually diffuse to stocks using discount rate and cash flow channels. An interesting study was carried out by Aktaş, Acar and Güzel (2016) where they empirically tried to examine relation between stocks of mining companies listed on Istanbul and metal prices (gold, copper and silver) for the period, Dec 2014 - May 2016.The results showed causality moving from copper prices towards stock prices while no causality was seen to flow from other two metals to stocks.

Some researchers have tried to explore volatility and spillover amongst metals, however there have been generally mixed results where some studies showing a general rise in volatility and also positive spillover, while others getting opposite results. Watkins & McAleer (2008) applied a rolling AR (1)-GARCH (1,1) on daily returns of future prices to model volatility processes of aluminium and copper for two different periods; Oct 1982 - 24 July 2006 for aluminium and Jan76 - July 2006 for copper. The findings showed that volatility in the metals under study was time varying, however volatility process as such was not found to increase. On the other hand, Todorova, Worthington and Souček (2014) tested for volatility dynamics/spillover amongst the base metals using multivariate HAR Model along with high frequency data for period June 2006 - Dec 2012. The markets of metals were found to be inter-dependent and therefore significant spillover existed especially in the long run. Hammoudeh & Yuan (2008) examined volatility behaviour of gold, silver and copper due to oil shocks and short-term interest rates. The results revealed gold and silver had persistence more than copper and for copper, its transitory component was seen to converge to zero at a much faster rate than for gold and silver. On the other hand it was seen that in the long run, all the metals had equal persistence as demonstrated by permanent volatility component. The researchers also tested for the leverage effect and found that it was present only with respect to copper and no leverage was detected in case of other metals.

An interesting research on herding type behaviour was carried out by Demirer, Lee & Lien (2015) where they employed return dispersion testing methodology to detect herding behavior in commodity futures markets. They concluded that with changes in return and volatility in stock markets, commodities (including metals) follow the same pattern. In other words, herd mentality was revealed in their study and therefore they concluded that combining assets (like stocks) with commodities like metals, energy and agri would not assist in portfolio diversification. Yet another interesting study but with a different focus was carried out by Fernandez, V. (2016) who made a study of interest adjusted linkages between six base metals on LME. The findings showed that linkages between spot and futures for base metals were seen to increase when the stocks were higher, however the relation was found only at contemporaneous and not at lagged levels. Also like other asset classes, Granger Causality for metals was seen to move from future to spot.

There have been some Indian studies on base metals and their results are more or less consistent with their global counterparts. Sinha and Mathur (2013) examined price behaviour with respect to its volatility for copper, aluminium, lead, nickel and zinc by taking data from MCX exchange for the period Nov.2007- Jan.2013. Further the impact of implied volatility, India VIX was also considered on these five base metals. The findings showed short term persistence in price volatility of these metals. Also impact of Global Financial Crisis on volatility was clearly visible with positive impact of India VIX on metals. Tiwari & Gupta (2009) carried out a study to compare volatility of future prices of selected metals for the period 2006-09 on MCX India and found that volatility of Gold, Silver & Copper was lower than the benchmark index viz. MCXMETAL for the period 2006-07 but the same was higher during the subsequent two years i.e. 2007-2009. Further volatility of gold was found to be the least and copper the highest amongst all the three metals. Choudhary, Nair & Purohit (2015) investigated whether copper was capable of making any impact on economic activities in India with the period of study being May 2, 2005-Sep 30, 2013. The result showed that there was cause effect-relation flowing from sensex to copper when the copper volatility was compared to volatility of BSE Sensex. Also shocks in international markets were well absorbed in Indian copper market while shocks from Indian Markets were also seen to pass to international markets. The market for copper was also found to be efficient as futures dictated the spot prices. Further structural breaks in copper time series were noticed which indicated that their prices were strongly influenced by economic events. Purohit, Bodhanwala, & Choudhary (2015) made an investigation whether futures was playing a role in price discovery for metals including copper, aluminium, zinc , nickel and lead, their prices taken from MCX India. The results showed long run co-integrating relation amongst spot and future prices of metals with VECM adjustment mechanism. Strong bi-directional causality was also seen between spot and futures however instead of futures, here the spot prices seemed to play a role in price discovery. VECM deviations from equilibrium were restored faster by spot than by futures. On the other hand studies like Shahani, Sarin & Malhotra (2019) tried to compare the performance of index of metals with agri and energy indices and found that agri index was moving the metal index, however vice-versa was not found to exist.

The review of literature given above broadly reveals that base metals may be considered as an asset class in broad sense as they have shown similar traits and characteristics as shown by other assets and these have been confirmed by researchers using various econometric tools. However these metals shall be more risk prone as their prices are highly vulnerable to industrial production and commodity specific events and therefore caution is suggested while relying on them as an asset class. However such assets would not qualify as an hedge asset as they suffer from herding and follow the same pattern as other assets as revealed by one of these studies.

RESEARCH OBJECTIVES AND METHODS

The objective of ascertaining return and volatility transmission amongst the three base metals for India is examined in light of the following research objectives:

(i) To make a comparative assessment of three base metals by analysing the information obtained from various statistical parameters.

(ii) To test for possible return transmission and spillover from one metal to another.

(iii) To make a study of spillover and transmission of volatility from one metal to another.

(iv) To check for model pre-requisites including the stationarity of base metals, heteroscedasticity and serial correlation.

The following methods have been employed to achieve these specified research objectives:

1. GARCH (p,q)Model, with lag adjustment based upon optimal model criteria.
2. DF GLS test of stationarity as proposed by Elliott, Rothenberg and Stock (ERS).
3. B-P-G Heteroscedasticity test

4. Serial Correlation through „Q" Statistics
5. Coefficient of Variation and JB Statistics of Normality.

Developing a Return and Volatility Spillover Model for Base Metals

Under this section we would be developing a contemporaneous contagion, contemporaneous volatility and one lag spill-over model for base metals for two periods viz, pre-covid(PC) and during covid(DC)periods . The level of integration has been chosen as contemporaneous only for pre-covid period and at lag 1 for during covid as shown by the VAR Model Lag Optimization Criteria (for details see Appendix III) which gives the optimal model to be I(0) for pre-covid and I(1) during covid period. The contagion and spillover has been ascertained as mean and/or volatility models and the exercise has been carried out separately for pre-covid and during covid periods. We would be focusing on the technique of spillover which follows the standardized residuals transmission as given by Masson, P. (1998) and Dungey, M. and Martin, V.L. (2007). Under this technique we would be using the popular GARCH(1,1) model and developing the conditional mean and variance equations, one each for the three base metals namely lead, copper and aluminum.

Conditional Mean and Variance Equations

We start by developing equation (i) which is given below and which represents the conditional mean equation for variable „m" *('m' =1 to 3, representing lead, copper and aluminium respectively)* . A closer look at the equation (i) shows that it has been developed as a usual AR (1) model with additional terms as contemporary standardized residuals $(e_{(s)m^*,t})$ showing contagion in returns and first lagged standardized residuals $(e_{(s),m^*,t-1})$ showing spillover in returns. However first lagged standardized residuals $(e_{(s),m^*,t-1})$ are restricted to during covid period only due to the optimal relation proved amongst the variables as stated above. The terms $(e_{(s)m^*,t})$ & $(e_{(s),m^*,t-1})$ have been obtained by running three OLS equations after making each variable stationary. The notation m^* $(m^* = 1,2)$ refers to the variable for which residuals have been generated and are being used in equation below. Clearly the residuals (e_{m*}) must be one less than the total number of variables.

Further $u_{m,t}$ is the residual error term of eq (i). The standardized residuals $(e_{(s)m^*,t})$ have been obtained by applying the formula $e_{(s)m^*,t} = \frac{(e_{m^*,t}) - \overline{(e_{m^*,t})}}{\sigma_{(e_{m^*,t})}}$; where $(e_{(s)m^*,t})$ is the residual of the „m" th base metal for time period **'t'** $\overline{(e_{m^*,t})}$ is the mean of the residuals of the „m" th base metal for the same time period while $\sigma_{(e_{m^*,t})}$ is the standard deviation of the residuals of the „m" th base metal for period „t". Similarly first lagged standardized residuals have been obtained by applying the formula $e_{(s)m^*,t-1} = \frac{(e_{m^*,t-1}) - \overline{(e_{m^*,t-1})}}{\sigma_{(e_{m^*,t-1})}}$. The variance equation under GARCH (11) model is developed as equation (ii) below. The conditional variance equation for m th variable has a constant term; θ_1, the ARCH term; $u^2_{m,t-1}$whose coefficient is θ_2 and a GARCH term; $\sigma^2_{u_{m,t-1}}$ with a coefficient θ_3. Like equation (i) , equation (ii) also includes additional terms as contemporary standardized squared residuals $(e^2_{(s),m^*,t})$ showing contagion in returns volatility and first lagged standardized squared residuals $(e^2_{(s),m^*,t-1})$ showing spillover in return volatility and these too are obtained in a similar manner by making square of the contemporaneous residuals and first lag residuals respectively.

$$Y_{m,t} = \beta_1 + \beta_2 Y_{m,t-1} + \beta_{3,m}\left(\sum_{m^*=1}^{2} e_{(s),m^*,t}\right) + \beta_{4,m}\left(\sum_{m^*=1}^{2} e_{(s)m^*,t-1}\right) + u_{m,t} \quad \text{............eq.(i)}$$

$$\sigma^2_{u_{m,t}} = \theta_1 + \theta_2 u^2_{m,t-1} + \theta_3 \sigma^2_{u_{m,t-1}} + \theta_{4,m}\left(\sum_{m^*=1}^{2} e^2_{(s),m^*,t}\right) + \theta_{5,m}\left(\sum_{m^*=1}^{2} e^2_{(s),m^*,t-1}\right) \quad \text{.......eq.(ii)}$$

EMPIRICAL RESULTS OF THE STUDY

To begin with we analyse on a comparative platform the returns of three base metals viz. aluminium, copper and lead during pre–covid (PC) and during–covid (DC) periods. The details of the same are given in section -7; *Appendix I: Statistical Description of Data and Model Data Diagnostics.* The Appendix I has two parts, Part A gives information about the Mean, Median, Standard Deviation, Skewness, Kurtosis, Coefficient of Variation, test of normality and other parameters pertaining to the closing returns of aluminium, copper and lead for two separate periods *(Pre-Covid: 4th Dec 2018-31st Dec 2019) & (During Covid: Jan 1st, 2020 - Dec 1st, 2020)* covering 276 and 237 data points respectively. Par B of Appendix I includes information about model data diagnostics including results of stationarity heteroscedasticity and autocorrelation for all the three variables during the above periods.

A look at the Part A of Appendix I reveals that mean return on all the three metals is negative during pre-covid (PC) period while it is positive for all the metals during covid (DC) period. Copper had the highest return in DC while in the PC period the lead had the highest return (in terms of lowest negative). On the other hand risk as measured by standard deviation is highest for copper during both PC and DC periods, thereby making investment in copper, a high risk-high reward candidate. Another tool given in Part A of this appendix is coefficient of variation (C.V) which considers both standard deviation and mean return i.e. it tries to incorporate both risk and return aspects in a single figure. The C.V obtained clearly reveals that in the DC Period, lowest coefficient of variation is for aluminium, closely followed by copper, hence out of the three metals, aluminium should be the best bet from an investment angle as it scores high when this risk is combined with return *(for PC period we do not interpret coefficient of variation as negative coefficient of variation makes little sense)*

Part A of Appendix I also gives information about the distribution characteristics of our three base metals by making a comparison of their distributions to the normal distribution. The examination of skewness reveal that two distributions, copper and lead are negatively skewed in both PC and DC periods while aluminium being positively skewed. On the other hand, all the three distributions in both periods have fatter than normal tails (are leptokurtic). Further aluminium in DC period is the only distribution which appears to be normally distributed (Null of Normality being accepted). This shown by JB Statistics; $JB = \frac{n}{6}\{S^2 + \frac{1}{4}(K-3)^2\}$, *'n' is the number of observations, 'S' is the Skewness and 'K' is the Kurtosis*.

Coming to Part B of Appendix I, this gives results of tests of Model Diagnostics which includes results of stationarity ,heteroscedasticity and autocorrelation tests. For stationarity test, we have applied DF-GLS test given by Elliott, Rothenberg and Stock (ERS). The test is considered superior in terms of higher power and improved model performance. The test is similar to popular ADF unit root test however in DF-GLS case, ADF regression is built up on de-trended data which excludes constant term and the time variable. The model equation and the critical values for the DF-GLS test are given as a foot note (i) below the Appendix I. The results of the stationarity test reveal that all our three metals reject the Null Hypothesis of Unit root in both the periods PC and DC, thereby showing that return on three metals is stationary in both these periods. The second diagnostic given in Appendix I relates to test of Heteroscedasticity and in the study we have followed Breusch–Pagan-Godfrey Test (BPG) Hetroscedasticity test, details of the same are given as footnote (ii) below the Appendix I. The results of Heteroscedasticity test reveal that the Null hypothesis of No Heteroscedasticity is accepted for all the three metals in both the periods.

The final diagnostic test is autocorrelation coefficient for which we use „Q" statistics, details of the same are given as a footnote (iii) below the Appendix I. The Appendix gives computed values at Q (1), Q (7) and Q (10) lags along with their „p" values. A glance at the „p" values of three metals reveal that „p" value of aluminium at period PC is statistically significant at Q(7) and „p" value of copper again at period PC is statistically significant at Q(1), both showing the presence of autocorrelation. For rest of the metals in all periods, the „p" value of Q Statistics at all the three lags as mentioned above is not statistically significant reflecting absence of serial correlation. Next for the two significant „p" values the necessary corrective action has been taken by modifying the mean model under GARCH(1,1) in case of Copper by including additional AR term while in case of aluminium correction has been made by adding MA(1) in the mean equation to take care of autocorrelation(s) which was detected in these metals.

Thus the Mean Model for Copper and aluminium would be taking the following shapes:-

$$Y_{Copp,t} = \alpha_1 + \alpha_2 Y_{Copp,t-1} + \alpha_3 Y_{Copp,t-2} + \alpha_{4,Copp}\left(\sum_{m=1}^{2} e_{(s),m,t}\right) + \alpha_{5,copp}\left(\sum_{m=1}^{2} e_{(s)m,t-1}\right) + u_{Copp,t} \quad \text{...eq.(iii)}$$

$$Y_{Al,t} = \lambda_1 + \lambda_2 Y_{Al,t-1} + \lambda_3 u_{Al,t-1} + \lambda_{4,Al}\left(\sum_{m=1}^{2} e_{(s),m,t}\right) + \lambda_{5,Am}\left(\sum_{m=1}^{2} e_{(s)m,t-1}\right) + u_{Al,t} \quad \text{..eq. (iv)}$$

Coming to Appendix II which gives the results of transmission and spillover of return and volatility amongst the three metals; has three parts viz. Appendix II(a),(b) and (c) for lead, copper and aluminium respectively. These results are based upon conditional mean and variance equation developed as eq. (i) and eq(ii) under section 3. It is to be noted here that if the relation amongst these metals is developed at the contemporaneous level we use the word „**transmission**" while if the relation is proved at different lags, we use the term **'spillover'**. The results are given separately for each of the three base metals and also for pre-covid (PC) and during covid (DC) periods. Spillover however is not considered for pre-covid period (for all three metals) as relation between metals is established at contemporaneous levels only as per the optimal level shown by lag selection criteria, the details of the same are given in Appendix III.

Lead

Pre-Covid (PC): No transmission of return is seen towards lead during pre-covid period, however transmission of volatility is noticed from copper to lead during this period. *During Covid (DC)*: No return transmission and return spillover is seen towards lead during covid period, however transmission of volatility was seen from copper to lead during this period. Spillover from aluminium was also noticed during this period

Copper

Pre-Covid (PC): Transmission of return is seen towards Copper from both Aluminium and Lead during pre-covid period. The period also saw transmission of volatility from lead to copper. *During Covid (DC)* The period sees both return and volatility spillover; return spillover from lead while both volatility transmission and spillover from aluminium to copper.

Aluminium

Pre-Covid (PC): Aluminium sees only volatility transmission from both metals.*During Covid (DC)* Aluminium sees only volatility transmission from only lead.

CONCLUSION, IMPLICATIONS AND STUDY LIMITATIONS

The current study made an attempt to make a comparative analysis of the return and volatility dynamics of transmission and spillover amongst three important base metals of India namely aluminium, copper and lead. The daily log transformed closing prices for these three metals were collected from the MCX India and the entire period of study viz. Dec 3, 2018- Dec, 1 2020 has been split into two periods; period before the covid 19 crisis and period during the Covid 19 Crisis. The study uses the word „transmission" for contemporaneous relation amongst metals while it is „spillover" if the relation is proved at different lags. The study follows spillover model given by Masson (1998) & Dungey and Martin (2007) which has been slightly modified in view of the optimal model. The results of the study showed that there was more of contemporaneous relation rather than spillover amongst the base metals for both the pre and during covid periods thereby emphasizing that overall the relation amongst metals might only exist at contemporaneous levels. However the limited spillover noticed in the study was moving from aluminium to both lead and copper during the DC period only giving some indication that aluminium may be discovering the prices changes to be followed by other metals in this period. The also meant that the price discovery was only limited and that too was restricted to DC period. Amongst the other results of the study it was seen that aluminium also had lowest coefficient of variation out of the three metals thereby reflecting this to be the ideal choice amongst three metals when the aim is to achieve a balance in terms of the risk-return relation. This also makes aluminium somewhat suitable candidate for investment purposes and may be included by the investors when going in for asset allocation of funds and portfolio diversification.

In spite of present study providing a few interesting and valuable insights on base metals, there are some limitations of the current study which must be brought to light and these include: restricting the spillover to one lag only, however this was due to the optimal model which was considered in the study. Another limitation is that the period of study is restricted to two years only, however here too this was done to make a comparative assessment of metals during pre covid and covid periods. Yet another limitation of the study was to stick to just one model of spillover when quite a few models are available and finally considering prices of base metals only from one exchange viz. MCX India, which may not always move in tandem with prices of metals on London Metals Exchange; the world"s leading centre of trade in Industrial Metals.

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APPENDICES

Appendix I : Statistical Data Description and Model Diagnostics of three base metals during pre and during-covid periods

A . STATISTICAL DESCRIPTION OF DATA

Parameter	PRE COVID			DURING-COVID		
	Return on Aluminium	Return on Copper	Return on Lead	Return on Aluminium	Return on Copper	Return on Lead
Mean	-0.0008	-0.0004	-0.0004	0.0007	0.0011	6.35E-05
Median	-0.0009	-0.0006	0.0002	0.0000	0.0018	0.0003
Maximum	0.02788	0.0278	0.02955	0.02454	0.0308	0.0261
Minimum	-0.0268	-0.0498	-0.0367	-0.0222	-0.0667	-0.0354
Std. Dev.	0.0081	0.0093	0.0092	0.0073	0.0122	0.0090
Skewness	0.0613	-0.3388	-0.3342	0.2591	-1.2587	-0.4193
Kurtosis	4.5170	5.8935	4.1626	3.2968	8.5380	4.6520
Coefficient of Variation (C.V) = σ /μ	-9.078	-21.127	-21.684	10.6337	11.285	142.11
JB Statistics = $\frac{n}{6}\{S^2+\frac{1}{4}(K-3)^2\}$	26.6366	101.5648	20.6830	3.5198	365.4457	33.8977
Probability (JB)	0.000002	0.000000	0.000032	0.172064	0.000000	0.000000
Observations	276	276	276	237	237	237

B. MODEL DIAGNOSTICS

Diagnostic Tool			PRE COVID			DURING-COVID		
			Return on Aluminium	Return on Copper	Return on Lead	Return on Aluminium	Return on Copper	Return on Lead
^DF-GLS Unit root test (Computed 't' values)			-18.4300	-3.1909	-4.2218	-13.8046	-15.9493	-15.2389
@ BPG Hetrosced-asticity test		Obs. R^2	3.51736	1.758695	3.946293	0.913648	2.74325	0.270803
		Prob. Chi Sqr.	0.1835	0.4151	0.1390	0.6333	0.3266	0.8734
Autocorrelation**	Q(1)	Comp. Value	3.21	5.4871	0.0725	2.0516	0.7691	0.1044
		Prob. (p)	0.073	0.019	0.788	0.152	0.380	0.747
	Q(7)	Comp. Value	14.23	7.8283	6.1066	9.3120	3.6177	4.7692
		Prob. (p)	0.047	0.166	0.296	0.097	0.606	0.445
	Q(10)	Comp. Value	16.05	17.760	9.9694	14.261	7.9976	5.9426
		Prob. (p)	0.098	0.059	0.443	0.161	0.629	0.820

(i) ^ $\Delta\ \ddot{Y}_{m,t} = \lambda_{1,m}\ddot{Y}_{(t-1),m} + \sum_{j=1}^{l}\delta_j\ \Delta\ \ddot{Y}_{(t-1),m} + u_{t,m}$ (DF-GLS Unit Root test, Null Hyp : Time Series has a Unit root with Critical Values as : -1.942013 at 5 % and -2.573619 at 1 %:) $\ddot{Y}_{m,t}$ is the de-trended variable for variable „m"= 1,2 & 3 represents each of the three metals viz. aluminium, lead and copper. „t" represents the time period , $\Delta\ \ddot{Y}_{m,t}$ is the change in de-trended variable $\ddot{Y}_t$ in period „t" for variable „m", λ_1 checks for variable stationary. $\Delta\ \ddot{Y}_{(t-j),m}$ is the augmentation taking care of serial correlation for variable „m" and sums up „l" times till serial corr. is removed Finally $u_{t,s}$ is the error term for variable „m".

(ii) @ **B.P.G = n.R^2_{aux} ~ χ^2_{m-1}.** Where R^2 is computed for auxiliary equation: $u_t^2 = \gamma_1 + \gamma_2 X_{2t} + \gamma_3 X_{3t} + \ldots + \gamma_k X_{kt}$, Null as : No Heteroscedasticity i.e. $\gamma_2 = \gamma_3 = \gamma_4 \ldots = \gamma_k = 0$.

(iii) **Box & Pierce Portmanteau (Q) statistics is given as: $Q_m = n.\sum_{l=1}^{m}\rho_l^2 \sim \chi^2_m$, 'ρ' is estimator of autocorrelation.

Appendix II (a) Transmission & Spill-over amongst base metals : Aluminium & Copper to Lead

	Pre-Covid Period (4 Dec 2018-31 Dec 2019)			During-Covid Period (Jan 1st 2020-Dec 1st 2020)		
MEAN EQUATION	**Beta Coeff.**	**'p' value**	**Transmission / Spill-over**	**Beta Coeff.**	**'p' value**	**Transmission/ Spill-over**
Std Residuals : Aluminium	-0.00048	0.3106	No	-0.000113	0.8674	No
Std Residuals : Copper	0.00025	0.6187	No	-0.000957	0.2591	No
Ln. Return Lead(-1)	-0.14429	0.0231	-	-0.010812	0.8881	
Std Residuals : Aluminium(-1)	-	-	-	-0.000184	0.7565	No
Std Residuals : Copper(-1)	-	-	-	0.000617	0.4523	No
VARIANCE EQUATION						
ARCH term	-0.01558	0.0496	-	0.071768	0.3834	**-**
GARCH term	0.99362	0.0000	**-**	0.247211	0.3333	**-**
Std Residuals SQR : Aluminium	7.91E-07	0.3289	No	5.84E-06	0.2744	No
Std Residuals SQR : Copper	2.15E-06	0.0000	**Yes, Trans-mission**	2.32E-05	0.0006	**Yes, Trans-mission**
Std Residuals SQR : Aluminium(-1)	-	-	**-**	-8.19E-06	0.0452	**Yes, Spillover**
Std Residuals SQR: Copper(-1)	-	-	**-**	4.74E-07	0.9571	No

(i) The standardized residuals have been taken at contemporary level for Pre-Covid (PC) Period and at both contemporary and first lag for During Covid (DC) Period as per the optimal relation established by the VAR Lag Selection Criteria Model.

(ii) The terms transmission have been used when it happens from one metal to another at same level (contemporary) either at return or at return volatility levels and spillover is used when there is change in level i.e. from one metal to another at different levels both in case of return and volatility of returns.

Appendix II(b) Transmission & Spill-over amongst base metals : Aluminium & Lead to Copper

	Pre-Covid Period (4 Dec 2018-31 Dec 2019)			During-Covid Period (Jan 1st 2020-Dec 1st 2020)		
MEAN EQUATION	**Beta Coeff.**	**'p' value**	**Transmission / Spill-over**	**Beta Coeff.**	**'p' value**	**Transmission/ Spill-over**
Std Residuals : Aluminium	0.00310	0.0000	**Yes, Trans-mission**	0.000531	0.4871	No
Std Residuals : Lead	0.010069	0.0000	**Yes, Trans-mission**	0.001040	0.2588	No
Ln. Return Copper(-1)	0.022739	0.2388	-	-0.071325	0.4207	-
Ln. Return Copper(-2)	0.007778	0.3742	-	-	-	-
Residuals(-1)	-0.02098	0.3807		-	-	-
Std Residuals : Aluminium (-1)	-	-	-	0.000775	0.2971	No
Std Residuals : Lead(-1)	-	-	-	0.001759	0.0316	**Yes, Spillover**
VARIANCE EQUATION						
ARCH term	-0.156948	0.0001	**-**	0.141232	0.1750	**-**
GARCH term	0.339367	0.0005	**-**	0.594022	0.0001	**-**
Std Residuals SQR : Aluminium	7.20E-09	0.9600	No	-9.98E-06	0.0028	**Yes, Trans-mission**
Std Residuals SQR : Lead	7.08E-06	0.0000	**Yes, Trans-mission)**	-9.75E-07	0.6873	
Std Residuals SQR : Aluminium(-1)	-	-	-	-6.85E-06	0.0150	**Yes, Spillover**
Std Residuals SQR : Lead(-1)	-	-	-	6.41E-06	0.1915	

Appendix II(c) Transmission & Spill-over amongst base metals : Lead & Copper to Aluminium							
	Pre-Covid Period (4 Dec 2018-31 Dec 2019)				During-Covid Period (Jan 1st 2020-Dec 1st 2020)		
MEAN EQUATION	**Beta Coeff.**	**'p' value**	**Transmission / Spill-over**		**Beta Coeff.**	**'p' value**	**Transmission / Spill-over**
Std Residuals : Lead	2.74E-05	0.9560	No		-0.000307	0.6204	No
Std Residuals : Copper	-9.81E-05	0.8461	No		-0.001111	0.0707	No
Residuals(-1)	0.126192	0.4993	-				
Ln. Return Aluminium(-1)	-0.033900	0.6207	-		0.068381	0.3355	
Std Residuals : Lead(-1)	-	-	-		-0.000402	0.4527	No
Std Residuals : Copper(-1)	-	-	-		-0.000668	0.2225	No
VARIANCE EQUATION							
ARCH term	-0.016750	0.0076	**-**		0.109417	0.2020	
GARCH term	1.000165	0.0000	**-**		0.529231	0.1258	
Std Residuals SQR : Lead	-1.44E-06	0.0001	**Yes, Trans-mission.**		1.65E-05	0.0130	**Yes, Trans-mission.**
Std Residuals SQR : Copper	2.34E-06	0.0000	**Yes, Trans-mission.**		9.20E-06	0.1217	**No**
Std Residuals SQR : Lead(-1)	-	-	-		-1.09E-05	0.1414	**No**
Std Residuals SQR : Copper(-1)	-	-	-		-3.14E-06	0.6069	**No**

Appendix III (A) VAR LAG LENGTH CRITERIA for Three Metals during the PRE-COVID (PC) Period

Lag	FPE	AIC	SC	HQ
0	**3.69e-13***	**-20.11567***	**-20.07547***	**-20.09953***
1	3.73e-13	-20.10369	-19.94290	-20.03911
2	3.72e-13	-20.10565	-19.82426	-19.99263
3	3.78e-13	-20.09061	-19.68864	-19.92916
4	3.84e-13	-20.07377	-19.55120	-19.86388
5	3.96e-13	-20.04534	-19.40217	-19.78701
6	4.07e-13	-20.01715	-19.25339	-19.71039
7	4.12e-13	-20.00555	-19.12120	-19.65035
8	4.23e-13	-19.97939	-18.97445	-19.57576

* Optimal Lag Model identification by the applicable criteria

Appendix III (B) VAR LAG LENGTH CRITERIA for Three Metals during the COVID (DC) Period

Lag	FPE	AIC	SC	HQ
0	3.25e-13	-20.24062	**-20.19563***	**-20.22247***
1	**3.19e-13***	**-20.26033***	-20.08040	-20.18774
2	3.34e-13	-20.21348	-19.89859	-20.08644
3	3.41e-13	-20.19466	-19.74483	-20.01319
4	3.41e-13	-20.19380	-19.60902	-19.95789
5	3.53e-13	-20.16046	-19.44072	-19.87010
6	3.73e-13	-20.10428	-19.24960	-19.75948
7	3.89e-13	-20.06437	-19.07474	-19.66513
8	3.85e-13	-20.07419	-18.94961	-19.62051

* Optimal Lag Model identification by the applicable criteria