We have calculated the returns of the variables by taking the first difference of their natural logarithm and then multiplying by 100. Net foreign portfolio investment data are adjusted for negative values before taking log difference as per the standard practice, i.e., by adding a constant positive number which makes the minimum number (negative) in the whole series to a small positive number. For all variables except VIX and India VIX return, the data are in natural logarithm form.

The descriptive statistics of the data as per the required transformation of the data as discussed above are given. The average of daily returns of all the variables is positive (negative for MSCI emerging market return), small as compared to standard deviation and close to zero showing the absence of any type of trend in the data.

It is evident that the stock price return in India is higher as compared to the global stock price return in the US, the UK, and emerging markets. The volatility of these variables as represented by standard deviation shows that the exchange rate has lower variability as compared to return on stock and commodities prices. Oil price returns and stock indices returns, as mentioned in the literature, are some of the most volatile variables among all commodity prices. The skewness statistics of exchange rate return and net portfolio flows are positive and skewed to the right (more positive return than negative return), while it is negatively skewed for all other return variables.

The kurtosis value for each variable is significantly higher than normal distribution indicating that the series is highly peaked and thus leptokurtic. This implies that returns have larger, thicker tails than the normal distribution which reveals the occurrence of extreme returns more frequently. The Jarque–Bera test statistics show that not all the variables are normally distributed.

All the variables are tested for stationarity at the level and if they are not stationary when the first difference (log difference) is taken. All the variables except net FPI, VIX and India-

VIX are found to be I(1). Net FPI, VIX and India-VIX are I(0). Since VIX and India-VIX are volatility indices, the analysis is done by taking the log transformation of these two series. As we are examining the pair-wise causality between two financial time series, we have used the return of net FPI even though it is stationary at the level.

The dynamic behaviour of these variables are shown in ows that all the commodity prices, stock prices and exchange rates have shown an upward trend in general. During the periods 2003-2008 and 2009-2011, the exchange rate recorded appreciation (downward movement) as a result of huge capital inflows in India. However, the exchange rate recorded a sharp depreciation during the periods of global uncertainties - the global financial crisis (2007-2009); post-announcement effects of quantitative easing programmes by the US Federal Reserve from May 23, 2013 to September 4, 2013 (Fed taper tantrum); and the recent COVID-19 pandemic (February 27, 2020 to May 29, 2020). shows that most of the series exhibit strong clustering behaviour and sharp movements during the heightened global uncertainties. We have used both international oil prices, Brent crude and WTI oil price in our study as Brent is the benchmark price in India while WTI is the international oil price. The stock indices of the US and the UK are taken as both the countries have significant cross-border transactions in terms of trade and foreign investments with India. Both BSE and NSE indices are used due to their varied compositions.

We check for the existence of nonlinearity in the relationship between exchange rate return with the selected variables in the study by applying the BDS test developed by Brock, Dechert and Scheinkman (1996). The test is exercised on each residual of VAR(1) model of exchange rate return with selected variables and on the residuals obtained from the AR(1) model of exchange rate return. presents the results of the BDS test which indicate rejection of the null hypothesis at various embedding dimensions (m). This proves statistically that there is a non-linear relationship between the exchange rate return and each selected variable. The results of linear Granger causality indicate all variables except MSCI return, net FPI and India VIX, significantly cause exchange rate However, any inference based on linear Granger causality results may lead to mis-specification errors as there exist non-linear relationships among the variables.

We conduct the Bai and Perron (2003) test and find multiple structural breaks (the VAR(1) model of exchange rate return with selected variables and the residuals obtained from AR(1) model of exchange rate return). The Bai and Perron test is based on a dynamic

programming algorithm which optimises the exhaustive computational procedure for testing multiple breakpoints of global minimiser of squared residuals (SSR). This approach can allow for autocorrelation and heteroskedasticity in the time series. In the test, we employ quadratic spectral kernel-based HAC (heteroskedasticity-autocorrelation-consistent (HAC) correction) covariance estimation using pre-whitened residuals.

The results detect two structural breaks in NSE and S&P 500 returns on September 11, 2008 and April 3, 2014, respectively. There is no break observed in the VAR(1) model of exchange rate return incorporating BSE return, Net FPI, India VIX and VIX. There are three structural breaks in the VAR(1) model with WTI and two breaks with Brent crude oil price. Most of the break dates are during the global financial crisis and the ensuing quantitative easing programmes by the Federal Reserve. The presence of non-linearity and structural breaks in the selected variables support the use of a nonparametric causality-in-quantile approach, as this test is robust to such mis-specifications.

3.2 Methodology

We use the methodology developed by Balcilar et al. (2017a) for uncovering nonlinear causality through a hybrid approach using the methodology of Nishiyama et al. (2011) and Jeong et al. (2012). We represent the dependent variable exchange rate returns as y_t and the independent variables (selected variables) as x_t.