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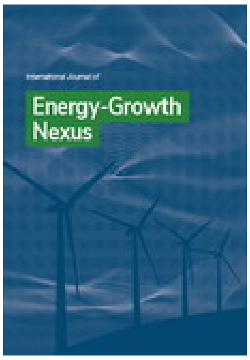

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Natural gas and crude: evidence of nonlinear co-integration from Indian commodities market

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Abstract: The study investigates for India the co-integrating relation between two-energy commodities viz. natural gas and crude for the period 1 April 2017–31 March 2022. The study results from both the models, ARDL (with structural break) and NARDL, revealed that long run co-integration was established only for natural gas while the same was not the case for crude. The elasticity of natural gas with respect to crude was found to be inelastic in short and highly elastic in long run. The long-run asymmetric impact of crude on natural gas was seen only at 10% level with no asymmetry seen in short-run results. Error correction term (ECM) for natural gas was negative and significant reflecting that movement from short run disequilibrium to long run equilibrium was stable, however speed of adjustment was at 3% per period. Model diagnostics were found to be satisfactory.

Keywords: natural gas; crude; ARDL; NARDL; structural break; asymmetry; co-integration.

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1 Introduction

For any economy, crude and natural gas are its prominent energy sources and hence, it becomes important for an economy to understand the price dependencies between the two commodities. Such an exercise would facilitate the evaluation of economy's decision with respect to investment in energy thereby facilitating policy makers in making decisions about the choice of energy fuel say whether to continue with existing fuel or switch over to another alternative fuel. The environmentalists too have keen interests in this area of fuel retention or substitution especially after the Kyoto Protocol of 1997 where targets have been set for reduction of greenhouse gases including CO_2 emissions for every country. Post Kyoto Protocol, more and more countries have now started exploring alternative energy options which are more environment friendly so as to meet the deadlines for emission norms set for each economy. Under this scenario, natural gas, being less CO_2 emitting fuel, becomes the preferred fuel for these nations (Apergis and Payne, 2010).

Natural Gas is especially suitable for developing countries which are not likely to attract enough FDI for some other fuels like the nuclear energy (Shahbaz et al., 2014). The importance of natural gas as an energy fuel can be gauged from the fact that at least 16 of the EU countries import this fuel to meet 90% of their requirements. The biggest plus point of natural gas is that it neither contains any solid particles, inorganic materials or releases harmful SO_2 emissions to the atmosphere and contributes relatively less CO_2 emissions as compared to other renewables and even biofuels. It is also more economical in terms of investment required as compared to other alternatives like nuclear power (Acaravci et al., 2012).

The economic relation between crude and natural gas reveals that the two energy commodities need to be understood not merely as competitors but as both compliments and substitutes to one another. Crude and natural gas are substitutes in consumption and rivals in production. From demand perspective, the two key economy sectors, the industry and power generation which depend upon crude and gas as their main input, display the ability to switch from one fuel to another while from supply's perspective rise in price of crude often exerts pressure to price of natural gas as these are usually produced jointly from same underground reservoirs (Wolfe and Rosenman, 2014). Now, even though the two may be substituted, it is not easy to switch from one fuel to another especially in short run due to infrastructure bottlenecks. The biggest problem associated with natural gas is storing and transportation and in most countries the existing infrastructure is highly saturated and therefore new infrastructure needs to be built which cannot be a quickfix solution but only a long run solution to the problem. For investors, the comparative evaluation of prices and the cross dependencies between crude and natural gas is more important as they view this commodity sector as alternative investment asset class like stocks and bonds. The key announcements in the crude and gas markets which are closely monitored by the investors and those connected with the industry are the weekly inventory reports which are provided by Energy Information Administration (EIA).

The relation between crude and natural gas prices has historically been viewed together by applying simple rules of thumb, the most popular being 10-1 and 6-1 thumb rules. In case of 10-1 rule of thumb, price of crude is ten times the price of natural gas while 6-1 rule is similar in computation but uses the energy content of the two commodities instead of prices (Brown and Yucel, 2008). Another popular set of rules are the burner tip rules where ratio between the two commodities is taken at prices at which the commodity gets consumed. In an interesting study, Barron and Brown (1986) developed a formula for burner tip rule which was based upon residual fuel energy content. This formula given as $P_{HH,t} = -0.25 + 0.1325\ P_{WTI,t}$; considers prices of residual fuel oil, its energy content and transportation cost differential between crude and natural gas to arrive at a slope coefficient figure of 0.1325; (P_{HH} is *the US Henry Hub price of natural gas in \$ per million BTU*, P_{WTI} *is the price of WTI Crude in \$ per barrel, the figure of –0.25 is the transportation cost differential*) (see Brown and Yucel, 2008).

The natural gas prices at Henry Hub US Market, which were once fairly coupled with crude, deviated to a great extend from the year 2000 and this was examined in different studies including Bachmeier and Griffin (2006) and Villar and Joutz (2006). This brings us to an important question? Whether the US Market Henry Hub was the only market of natural gas to decouple or it was the same with entire global gas market. The answer to this question lies in understanding the pricing mechanism for different markets for natural gas over the years. Broadly speaking, we have three major gas markets: US, European and Asian markets. Initially all the three sub-markets used crude as their benchmark for pricing natural gas, however US market switched over to gas based pricing (pricing based upon demand and supply of gas) while other markets continued to follow crude-based pricing. One of the reasons why US markets had to deviate its crude linkages was the discovery of Shale Gas Reserves in US which caused immediate augmentation in supply of natural gas in the region which also impacted the long run relation between crude and natural gas (see Loungani and Matsumoto, 2012; Geng et al., 2016b). Looking at the current scenario, the market for natural gas has undergone a sea change over the past three decades, from being regulated till 1980s, to a completely free market thereby making these markets substantially different from where they were in 1980s (Brown and Yucel, 2008).

Coming to empirical studies, exploring the relation between oil and natural gas, typically the studies report three major findings, first the relation between crude and natural gas is either non-existent or as found in most studies is unstable and time varying, second, the causality reported in most studies shows transmission of information either uni-directionally from crude to natural gas or bidirectional amongst the two commodities and thirdly the asymmetric angle does appear to exist as shown by many studies reflecting different behaviour of positive and negative shocks.

The relation between crude and gas was seen to vary with time in a study by Asche et al. (2012) where they found their relation varied in the short-term but remained in an equilibrium in the long-term. Similarly, again, Brigida (2014) found that although natural gas and crude oil prices exhibited a temporary shift in the early 2000s, their long-term equilibrium relationship was well maintained. In terms of results for causal studies amongst two variables, uni-directional causality from crude to gas was seen in a study by Pindyck (2004), Ji et al. (2014), Brown and Yucel (2008), Nick and Thoenes (2014) and so on, while those reporting bi-directional causality include Tonn et al. (2010), Yorucu and Bahramian (2015) amongst others. Further, bi-directional relation in terms of volatility spillover was reported by Lin and Li (2015) for North American and European markets, but this effect did not exist in the Asian markets. Similar results were notice by Karali and Ramirez (2014) and again by Wolfe and Rosenman (2014) working on high frequency intraday data. On the other hand, the asymmetric impact was seen by Ji et al. (2014) and Perifanis and Dagoumas (2018) where they found asymmetric mechanism existed in these markets with the impact of the decrease in oil prices being relatively stronger.

The relation between crude and natural gas was found to be nonlinear in some of the recent studies like Yaya et al. (2015), Geng et al., (2016a) amongst others. The researchers have also shown that both crude and natural gas do have extreme volatility periods and also jumps in their time series typical of other financial markets Further, this commodity class is also vulnerable to regime changes which take place due to economic events, policy changes or economic circumstances; and hence, makes such markets unpredictable and risky like other asset classes (Fan and Xu, 2011; Geng et al., 2016a, 2016b; Zhang et al., 2008). The short, medium and long-term trends and fluctuations make the dynamic relation between crude and natural gas very complex which again is likely to create increased interest amongst researchers and investors at large. Exploring this dynamic relation, Erdős (2012) showed how the prices of crude and gas were maintained under equilibrium; however, this was in the US and the UK markets before 2009 but after 2009, the US gas prices disconnected, while the UK gas prices remained unchanged with crude prices.

Again in a study which focused exclusively on US Markets, Perifanis and Dagoumas (2018) found the markets of natural gas and crude to be decoupled where neither of the markets was causing movement in other markets, however some cause effect was seen for short periods. The asymmetric impact from crude to natural gas was however positive or impact of rise in crude on natural gas was faster than equivalent decline in prices of crude. The transmission of volatility was however found to be bidirectional. On the other hand, Lin and Li (2015) studied the relation between crude and natural gas in all the three regional markets and their main findings was that crude and natural gas prices were decoupled only in the US markets due to reasons like liberalisation of gas prices, Shale Gas Supply and limited capacity in the US to store and export gas to other nations. Further, in all three regional markets, there was indication of movement of prices from crude to gas but not vice-versa. Also, asymmetry was noticed in all the three markets and bi-directional volatility spillover was seen in two of the three markets excluding the Japanese market. Thus, according to their analysis the regional segmentation coupled with different mechanism of prices, each regional market is expected to behave differently when it comes to spillover effects. On the other hand, Geng et al. (2017) working on causal relation, found long run unidirectional linear Granger causality from crude to gas markets of Europe and North America, while medium term relation was found to exhibit nonlinear characteristics with bidirectional causality. The spillover was however not seen in the results. On the other hand, Batten et al. (2017) in their study using prices from NYMEX found unilateral causality from natural gas to crude and hence concluded that lagged prices of natural gas, could be easily used for prediction of price of crude, however the relation between natural gas and crude was not found to be stable during different periods with somewhat independence in price movement seen after 2007.

Asymmetric co-integration dynamics between natural gas and crude have been reviewed by Kumar et al. (2021) where they found co-integration to exist when natural gas was taken as dependent with short run asymmetric impact existing from crude to natural gas while impact was symmetric but positive in the long run. Obadi et al. (2013) on the other hand, investigated for the presence of a co-integrating relation between natural gas and crude and found long run co-integration with short run price adjustment. The adjustment process could reveal a 5.9% disequilibrium correction in prices of natural gas, while the same figure for crude was much faster, i.e., 22.5% disequilibrium was corrected in one period. Their results also showed that the two variables had a stable relationship with few periods of decoupling. Further, while crude prices were influencing natural gas prices, impact of natural gas on crude was negligible. Their findings showed that demand for natural gas rose at the expense of crude oil and hence natural gas was playing the role of stabiliser of crude prices.

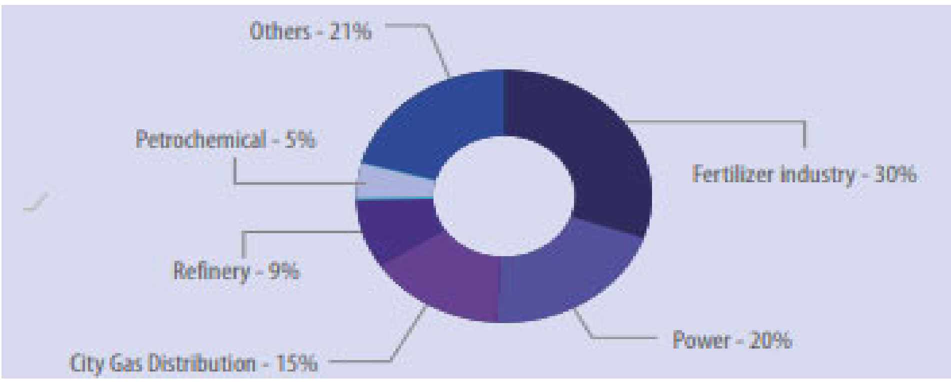
Further, impact of inventory announcement on crude was undertaken by Wolfe and Rosenman (2014) where they worked on high frequency intraday data on crude and natural gas futures from NYMEX which was collected before and after the announcement of inventory. The study gave four interesting results: first, the crude surprizes had an asymmetric impact while the same was symmetric for natural gas; second, although there was an impact on volatility of both crude and natural gas prior and after the announcement of the inventory levels, the impact of gas inventory announcements on crude price volatility far exceeded the crude inventory announcement's impact on gas price volatility; third, both the commodities exhibited time-varying volatility and last, with respect to causality, directional between crude and natural gas was noticed.

The crude-gas price relation is important for any country where bulk of the energy requirement is met through imports and India is no exception. If we take the example of natural gas consumption by industry for India's market, fertiliser and power industries were the biggest consumer of natural gas in 2021–2022. (Figure 1) (http://www.mcxindia.com). According to a report by US Energy Information Administration (2020), updated November 2022 India has been the 4th largest importer of natural gas (in liquified form) since 2011. Whereas the domestic production in India has declined over the years (1.1 trillion cubic feet in 2021), its consumption was 2.3 trillion cubic feet in 2021. In order to cover this huge gap between consumption and domestic production, the country had to import more than 50% of its requirement of natural gas, i.e., 1.2 trillion feet which was approx. 7% of world trade in natural gas. These imports are mainly as LNG and not in pipeline form as the borders of the country do not have smooth terrain. Further, natural gas constituted only 6% of India's primary energy requirement in 2021, however, the country has fixed an ambitious target of bringing this to 15% by 2030.

Coming to natural gases prices in Indian Sub-continent, both futures and options contracts are traded on MCX Exchange of India and as seen in Figure 2, the futures price of natural gas has a very high correlation with its price traded at Henry Hub US Markets (http://www.mcxindia.com). On the other hand, the crude oil production in India was 29.7 million metric tonnes (MMT) while the consumption of petroleum products was 204 MMT in 2021–2022 thus making the import content 3/4th of the total annual requirement.

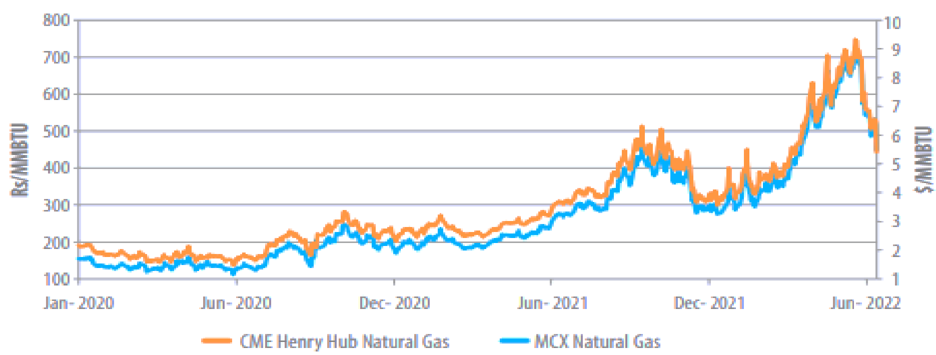
According to an estimate, a rise in $1 in crude prices raises India's import bill by 2,900 crores rupees. Similarly, a rupee fall in India's currency against dollar has almost the same impact on the crude import bill. Further in terms of subsidies, total subsidies to both crude and gas for the year 2019 were whopping INR 67,000 crores and according to a projection, in the absence of this subsidy, the gas based power plants would become highly uncompetitive (Kumar et al., 2021).

Figure 1 Industry wise consumption of natural gas during 2021–2022 (see online version for colours)



Source: http://www.mcindia.com

Figure 2 Correlation of natural gas future prices as traded on MCX and Henry Hub Natural Gas Markets (Jan 2020–June 2022) (see online version for colours)



Source: MCX and Bloomberg

Going ahead, the present study makes an attempt to empirically investigate the interlinkages between crude and natural gas by taking daily future prices of the two commodities from the India's Multi Commodity Exchange (http://www.mcxindia.com). The prime focus of the study would be to establish dynamic linkages between the two energy commodities by establishing a linear and nonlinear ARDL co-integrating relation by taking prices of two commodities as traded in India. The study would further test whether crude has an asymmetric impact on the price of natural gas and vice versa. The need for the current study stems from the desire to investigate in a comprehensive manner, the crude-natural gas price linkages during the five-year period: April 1, 2017–March 31, 2022 for an emerging market like India, to understand whether or not a stable co-integrating relation exists. The study assumes importance because of two reasons: first most of the existing studies on natural gas and crude focus on two major gas markets of US and Europe with negligible studies on other markets including India. Hence, a study on a sub market like India with prices being taken from Indian Commodities Market is actually a need of the hour and second, after taking clues from existing research studies that the relation between crude and natural gas is unstable and time varying, the present study would make an attempt to test the same on Indian Markets. Further, the study would also attempt to apply the appropriate co-integration methodology to see if the two variables are co-integrated.

Many reasons have been identified for the unstable relation between the two and these include limited ability of an economy to undertake short run substitution of the two energy commodities due to infrastructure bottlenecks, different pricing norms followed for natural gas in different markets, discovery of new natural gas reserves and its impact of the US markets on gas pricing in regional markets especially in the US markets and so on. The outcome of this paper which can be either strong, weak or no co-integrating relation amongst the energy commodities and also results pertaining to speed of adjustment towards equilibrium would immensely benefit the policy holders in taking the decision of future investments in two commodities considering the fact that crude and natural gas are substitutes in consumption and rivals in production.

The rest of the paper is structured as follows: Section 2 gives the descriptive statistics of our return distribution, Section 3 explains the methodology employed, Section 4 provides empirical results and finally, we have Section 5 as conclusion, limitations of study and policy implications. The paper ends with references as Section 6.

2 Descriptive statistics of return distribution

2.1 Statistical description of returns

The statistical description of daily returns of crude and natural gas (in decimals) for the five year period April 1, 2017–March 31, 2022 (1,271 data points) is given in Table 1. The table shows that out of the two commodities, crude generates slightly higher average return of 0.1339% on daily basis (48% in annualised terms) while natural gas gives a return of 0.1256% daily or 45.8% on annualised basis. Thus in terms of average returns, the two commodities are fairly close to each other and on positive side none of these two have given negative average daily returns during the five-year study period which is an important consideration for commodity investors and hedgers.

On the other hand, natural gas has higher standard deviation of returns, a popular proxy for risk which is again only slightly higher than crude. Thus, analysis of both risk (σ) and return (μ) reveals that both the energy commodities are very close to each other with respect to their computed values showing that an investor could hold any one of these two assets, or in other words reaping the benefits of diversification by distributing funds in both the assets may not work in case of these two assets.

Further, in spite of the closeness of the two assets with respect to above characteristics, it would be interesting to determine which of the two is a better performer when both risk and return concepts are taken together and to achieve this we have applied a simple tool called coefficient of variation; (CV) = σ / μ, which balances risk with return and this provides a yardstick of measurement which is nothing but a risk adjusted return. The results of CV reveal that crude has a lower risk adjusted return out of the two indicating this asset to be a better commodity from investment perspective.

Table 1 Statistical description of returns of crude and natural gas for the period April 1, 2017–March 31, 2022

Parameter	*Natural gas*	*Crude*
Mean (μ)	0.001256	0.001339
Std. dev. (σ)	0.037999	0.034661
Skewness (S)	2.557976	–0.053210
Kurtosis (K)	42.29913	50.87532
Coefficient of variation (CV) = σ / μ	30.25	25.88
JB Statistics = $\frac{n}{2}\left\{S^2 + \frac{1}{4}(K-3)^2\right\}$	83,176.05	121,383.6
Probability (JB)	0.00	0.00
Observations (n)	1,271	1,271

On the other hand, if we consider the shape of the distribution of two commodities, the two appear to be very different from each other. We find that the distribution of natural gas is positively skewed while crude has a negatively skewed distribution. Further, in most research studies, an easy way to take care of a distribution skewness is to convert the raw data to natural log terms and we also would be following the same approach in our study. On the other hand, kurtosis of both the distributions is far more than '3'; which is the kurtosis for a normal distribution signifying that the two distributions have fatter tails, higher and sharper peaks and are a profusion of outliers. We also tested for normality of variables by applying JB test, however, both the distributions reject the null that the distribution is normal (both have 'p' statistics lower than 0.05) revealing that neither of the two variables is normally distributed.

2.2 graphic representation of return of crude and natural gas

This section provides a graphic representation of the returns of crude and natural gas for the period April 1, 2017–March 31, 2022 (Figures 3–4).

A close look at Figures 3–4 reveals that crude (Figure 3) had a very high volatility period between observations 740 and 806. Also during this period, it reached a peak of 0.41% daily return (observation 774) and achieved a lowest return of –0.43% which was just two days before, observation: 772 showing a sharp movement in a gap of two days. On the other hand, the return on natural gas has been more volatile with frequent volatility clustering. It is interesting to note that the highs and lows for return on natural gas too were also seen during the two subsequent days ; the low being on 1,229 (–0.26% per day) while high being arrived at 1,228 observation (0.56). Further, although in case of both the commodities the structural breaks have been identified as two separate dates, i.e., observation no. 1191 (6 December 2021) for crude and observation no. 1063 (7 June 2021) for natural gas, neither of these two dates are a part of highest or lowest return dates as seen above. This clearly reveals that even extremely highs and lows return and volatilities need not trigger a structural break especially for energy commodities. One likely reason for the structural breaks not being a part of highs and lows is that we have identified the breaks for prices or a break is detected for an unexpected change in prices (and not returns) during the study period.

Figure 3 Daily return on natural gas (April 1, 2017–March 31, 2022) (see online version for colours)

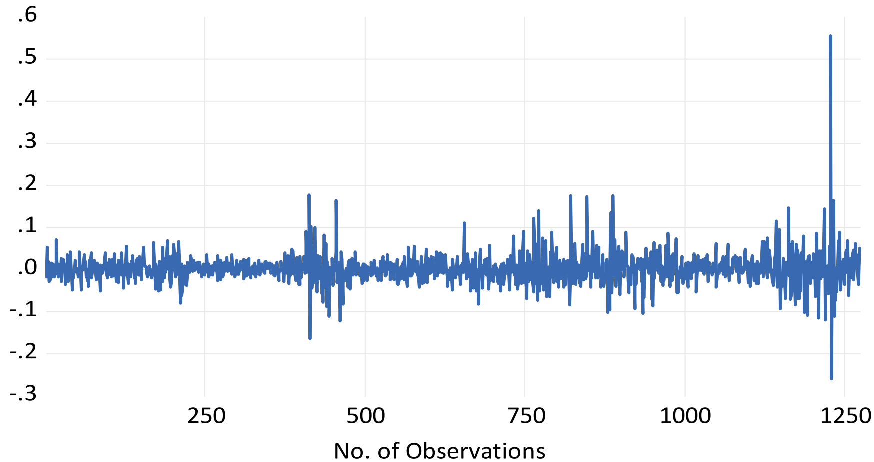
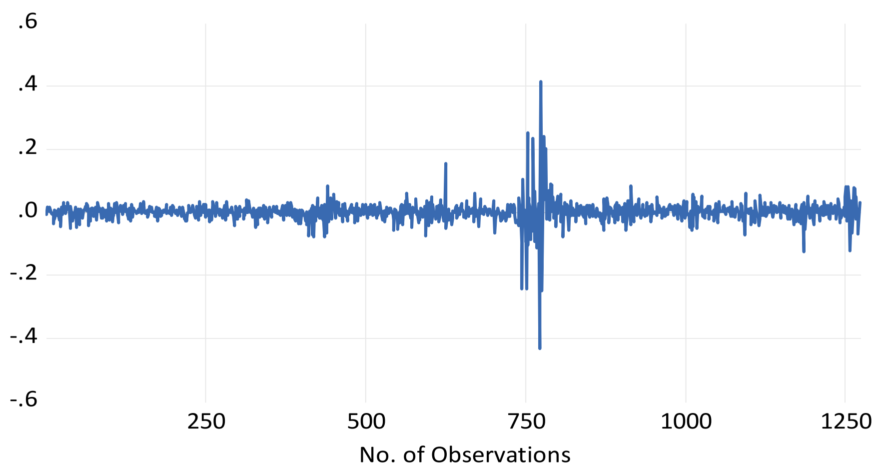


Figure 3 Daily return on crude (April 1, 2017–March 31, 2022) (see online version for colours)



3 Research methodology

3.1 ARDL/NARDL model development

Under this section, we would first be developing a linear ARDL model (Pesaran and Shin, et al., 1999; Pesaran et al., 2001) after incorporating one structural break followed by nonlinear ARDL (Shin et al., 2014). The need for both ARDL (with a single structural break) and NARDL model was felt when the nonlinearity was detected in both time series of crude and natural gas using BDS test statistic as given by Brock et al. (1987). We have applied BDS on raw data and specified '*m*' as embedded dimension ('*m*' histories and '*n*' > '*m*') We further roll over the histories in the following manner

$y_1^m = y_1, y_2, y_3 ......y_m, y_2^m = y_3, y_4, y_5 ......y_{m+2}$ and so on.

We define our null hypothesis under BDS as:

H0 The data are independently and identically distributed (IID).

H1 The data is not IID; implying that the time series is nonlinear.

Since the results obtained under BDS proved that both variables crude and natural gas had a nonlinear time series (see Table 2 under results; Section 4), we introduced a break in our ARDL model to tackle the nonlinearity. The complete ARDL models has five parts; the first part (covered under Sections 3.1.1 and 3.1.2) discusses the main ARDL model representative equation; a single equation which includes both short and long run variables, the second part (Section 3.2) discusses the model decision w.r.t long run co-integration relation amongst the variables, the third part and fourth part (Sections 3.3 and 3.4) discuss the long run and short run relation amongst the variables and provides for error correction towards equilibrium. The fifth and the final part (Section 3.5) tests for asymmetric impact in both short as well as long run.

3.1.1 Model representation (ARDL)

$$\begin{aligned}\Delta \ln .NG_t = \beta_1 + \beta_{1,BD_1}{}^{\#} D_{1,t} + \beta_2 \ln .NG_{t-1} + \beta_3 \ln .Crude_{t-1} \\ + \sum\nolimits_{i=1}^{r_1} \left(\beta_{4,i} \Delta \ln .NG_{t-i}\right) + \sum\nolimits_{i=0}^{n_1} \left(\beta_{5,i} \Delta \ln .Crude_{t-i}\right) + e_{1,t}\end{aligned} \tag{1}$$

$$\begin{aligned}\Delta \ln .Crude_t = \alpha_1 + \alpha_{1,BD_2}{}^{\#} D_{2,t} + \alpha_2 \ln .Crude_{t-1} + \alpha_3 \ln .NG_{t-1} \\ + \sum\nolimits_{i=1}^{r_2} \left(\alpha_{4,i} \Delta \ln .Crude_{t-i}\right) + \sum\nolimits_{i=0}^{n_2} \left(\alpha_{5,i} \Delta \ln .NG_{t-i}\right) + e_{2,t}\end{aligned} \tag{2}$$

For equation (1); $\Delta\ln.NG_t$ is the logarithms change in natural gas in period 't' (natural gas being the dependent variable and crude being independent variable), 'β_1' is the intercept while '$\beta_1^{\#}$' is the slope coefficient of intercept dummy (D_1) reflecting a single break (BD_1) denotes the break date in intercept of the dependent variable, natural gas). To identify the break we have applied and the test compares the result with asymptotic one sided 'p' values. The dummy variable (D_1) takes the following values $D_{1,t} = \begin{cases} 1 & \text{if } t \geq BD_1 \\ 0 & \text{if } t < BD_1 \end{cases}$, i.e., dummy shall be '0' if time period (t) is before the break date (BD_1) and shall be '1' if time period is after the break, including break date. The next term; 'β_2' is the slope coefficient of first lag of dependent variable natural gas which is of the nature of AR (1) representation. Parameter β_3 is the slope coefficient of first lag of independent variable ; crude and represents the long run relation with the dependent variable; natural gas. The next term; $\sum\nolimits_{i=1}^{r_1} \left(\beta_{4,i} \Delta \ln .NG_{t-i}\right)$ is the log change in dependent variable; natural gas and has been included as a regressor, with 'r' being the number of lags determined by lag selection criteria AIC. Coefficients of $\beta_{4,i}$; $i = 1, 2, \ldots, r_1$ are summed up till maximum number of lags 'r_1' has been reached. Similarly, $\sum\nolimits_{i=0}^{n_1} \left(\beta_{5,i} \Delta \ln .Crude_{t-i}\right)$ reflect the logarithm change in the independent variable crude with 'n_1' being the number of lags for the variable again determined by

AIC lag determination criteria. All the two terms; $\sum_{i=1}^{r}\left(\beta_{4,i}\Delta \ln .NG_{t-i}\right)$ and $\sum_{i=0}^{n_1}\left(\beta_{5,i}\Delta \ln .Crude_{t-i}\right)$ collectively make up the short run relation with the dependent variable. Finally the equation has $e_{1,t}$ as stochastic error term. Using similar methodology we have developed equation (2) by taking crude as dependent and natural gas as independent variable.

3.1.2 Model representation (NARDL)

The second model discussed in our paper is the nonlinear ARDL (NARDL). This model was introduced in our paper as the outcome of the BDS test revealed nonlinearity in both the variables included in our study. NARDL is simply an asymmetric expansion of linear ARDL where a variable is decomposed into positive and negative values. It would not be incorrect to say that the failure of ARDL to capture the asymmetric effect lead to the development of nonlinear ARDL (Shin et al., 2014). Under NARDL model representation we would be decomposing the independent variable {crude or natural gas} as either crude (+) and crude (–); see equation (3) or NG (+) or NG (–); see equation (4) to obtain both short as well as long run parameters.

The equation after decomposition of variable crude, natural gas as a function of crude is given as equation (3) below:

$$\begin{aligned} \ln .NG_t &= \lambda_1 + \lambda_{1,BD_1}{}^{\#}D_{1,t} + \lambda_2 \ln .NG_{t-1} + \lambda_3^{+} \ln .Crude_{t-1} \\ &+\lambda_3^{-} \ln .Crude_{t-1}\sum_{i=1}^{n}\left(\lambda_{4,i}\Delta \ln .NG_{t-i}\right) \\ &+\sum_{i=0}^{n_1(A)}\left(\lambda_{5,i}^{+}\Delta \ln .Crude_{t-i}\right)+\sum_{i=0}^{n_1(B)}\left(\lambda_{5,i}^{-}\Delta \ln .Crude_{t-i}\right)+e_{3,t} \end{aligned} \tag{3}$$

where

$$\lambda_3^{+} = \begin{cases} \lambda_3 & \text{if } Ret\ \lambda_3 > 0 \\ 0 & \text{if } Ret\ \lambda_3 \le 0 \end{cases} \text{and } \lambda_3^{-} = \begin{cases} \lambda_3 & \text{if } Ret\ \lambda_3 < 0 \\ 0 & \text{if } Ret\ \lambda_3 \ge 0 \end{cases}$$

$$\lambda_5^{+} = \begin{cases} \lambda_5 & \text{if } Ret\ \lambda_5 > 0 \\ 0 & \text{if } Ret\ \lambda_5 \le 0 \end{cases} \text{and } \lambda_5^{-} = \begin{cases} \lambda_5 & \text{if } Ret\ \lambda_5 < 0 \\ 0 & \text{if } Ret\ \lambda_5 \ge 0 \end{cases}$$

Again using similar methodology, we shall be developing our NARDL representative model for crude which is given as equation (4) below:

$$\begin{aligned} \ln .Crude_t &= \theta_1 + \theta_{1,BD_2}{}^{\#}D_{2mt} + \theta_2 \ln .Crude_{t-1} + \theta_3^{+} \ln .NG_{t-1} + \theta_3^{-} \ln .NG_{t-1} \\ &+\sum_{i=1}^{n}\left(\theta_{4,i}\Delta \ln .Crude_{t-i}\right)+\sum_{i=0}^{n_1(A)}\left(\theta_{5,i}^{+}\Delta \ln .NG_{t-i}\right) \\ &+\sum_{i=0}^{n_1(B)}\left(\theta_{5,i}^{-}\Delta \ln .NG_{t-i}\right)+e_{2,t} \end{aligned} \tag{4}$$

where

$$\theta_3^{+} = \begin{cases} \theta_3 & \text{if } Ret\ \theta_3 > 0 \\ 0 & \text{if } Ret\ \theta_3 \le 0 \end{cases} \text{and } \theta_3^{-} = \begin{cases} \theta_3 & \text{if } Ret\ \theta_3 < 0 \\ 0 & \text{if } Ret\ \theta_3 \ge 0 \end{cases}$$

$$\theta_5^+ = \begin{cases} \theta_5 & \text{if } Ret\ \theta_5 > 0 \\ 0 & \text{if } Ret\ \theta_5 \le 0 \end{cases} \text{ and } \theta_5^- = \begin{cases} \theta_5 & \text{if } Ret\ \theta_5 < 0 \\ 0 & \text{if } Ret\ \theta_5 \ge 0 \end{cases}$$

3.2 Test for long-term co-integration: partial 'F' bounds test

The existence of long run co-integration under ARDL is tested using partial 'F' bounds test.

We setup a null hypothesis for co-integration as a 'F' test: H_o: = $\beta_2 = \beta_3 = 0$ [for ARDL NG, equation (1)] and H_o: = $\alpha_2 = \alpha_3 = 0$ [for ARDL crude, equation (2)] and the computed 'F' statistics is compared with critical 'F' bounds as given by Pesaran et al. (2001). The decision on existence of co-integration is based upon following criteria:

- If $\text{'F'}_{\text{computed}}$ < Lower bound critical, result: no co-integration.
- If $\text{'F'}_{\text{computed}}$ > Upper bound critical, co-integration is established.
- If $\text{'F'}_{\text{computed}}$ is between the two bounds, inference is inconclusive and decision is taken using 'tables as given by Banerjee et al. (1986) to confirm the existence of co-integration.

3.3 Long-term relation and long run elasticity

If the results from sub Section 3.2 reveal the presence of co-integration, we establish long run equation under ARDL [equation (5)] followed by long run elasticity [equations 5(a) and 5(b)].

$$\ln .NG_{1,t} = \delta_1 + \delta_{1,BD_1}{}^{\#}D_{1t} + \sum_{i=1}^{g_1}\left(\delta_{2,i} \ln .NG_{t-i}\right) + \sum_{i=0}^{g_2}\left(\beta_{3,i} \ln .Crude_{t-i}\right) + e_{4,t} \qquad (5)$$

We are using g_1, and g_2 as notations for lags of natural gas and crude respectively and these are also determined by AIC. The variables are interpreted as long run elasticities and we consider '*L*' backshift operator, hence, equation (5) takes the following shape 5(a)

$$A(L, g_1)\ln .NG_{1,t} = \delta_1 + \delta_{1,BD_1}{}^{\#}D_{1t} + \beta(L, g_2)\ln .Crude_t + e_{4,t} \qquad (5a)$$

On similar lines, we shall be establishing the equation for of variable crude.

The information obtained from 5(a) is used for computing the long run price elasticity under ARDL of natural gas against variable crude and the same is given as equation 5(b).

$$\frac{A(L, g_1)}{B(L, g_2)} = \frac{1 - \delta_{2,1} - \delta_{2,2} - \ldots\delta_{2,g_1}}{\delta_{3,0} + \delta_{3,1} + \delta_{3,2} + \delta_{3,3} \ldots\ldots \delta_{3,g_2}} \qquad (5b)$$

3.4 Short-term relation and error correction towards equilibrium

The estimated residuals from regression of first lag of long run stationary variables ($Crude_{t-1}$ and $Natural\ Gas_{t-1}$) are used for specifying the short run relation and error correction representation which is given as equation (6) below:

$$\Delta \ln .NG_t = \partial_1 + \partial_{1,BD_1}{}^{\#}D_{1t} + \partial_2 EC_{t-1} + \sum_{i=1}^{r_2}\left(\partial_{3,i}\Delta \ln .NG_{t-1}\right) + \sum_{i=0}^{n_2}\left(\partial_{4,i}\Delta \ln .CRUDE_{t-1}\right) + e_{5,t} \tag{6}$$

We are using r_2, and n_2 as notations for lags of natural gas and crude, respectively. The coefficient $\partial_{4,0}$ shows the short run price transmission elasticity from crude to natural gas. The term EC_{t-1} shows how fast market would adjust to achieve long run equilibrium relation following a shock in the system and the adjustment mechanism is given by ∂_2 and the proportion of shock adjusted after 'n' periods is given as $1 - (1 - \partial_2)^n$.

Moving further to adjustment mechanism towards long run under nonlinear; NARDL, equation (8) has been estimated for the same and is given as under:

$$\Delta \ln .NG_t = \gamma_1 + \gamma_{1,BD_1}{}^{\#}D_{1t} + \gamma_2 EC_{t-1} + \sum_{i=1}^{r_2}\left(\gamma_{3,i}\Delta \ln .NG_{t-1}\right) + \sum_{i=0}^{n_2}\left(\gamma_{4,i}^{+}\Delta \ln .Crude_{t-1}\right) + \sum_{i=0}^{n_{2,B}}\left(\gamma_{4,i}^{-}\Delta \ln .Crude_{t-1}\right) + e_{6,t} \tag{7}$$

3.5 Test for short and long run asymmetry under the NARDL Model

To test for short and long run asymmetry, we use the NARDL model. For long run asymmetry the procedure applied is 'Wald' statistic. We define null hypothesis as $\pi^+ = \pi^-$, where $\pi^+ = \frac{\lambda_3^+}{\lambda_2}$ and $\pi^- = \frac{\lambda_3^-}{\lambda_2}$ [from equation (3)]. For short run symmetry, we define null as $\sum_{i=1}^{n_{2,A}}\left(\gamma_{4,i}^{+}\right) = \sum_{i=1}^{n_{2,B}}\left(\gamma_{4,i}^{-}\right)$ [from equation (7)].

4 Results

Under this section, we would be discussing the results of our study and we begin with BDS test results for linearity of variables. The test of linearity is important as it would help us in deciding the co-integration model to be applied in our study. The results of BDS which are given in Tables 2 and 3 reveal that at all the 'm' dimensions, null hypothesis that the data is IID reflecting linearity is rejected for both the variables under study viz. crude and natural gas.

The next set of results pertain to testing long run co-integration amongst the variables for which both ARDL and NARDL models were established and the test employed was partial 'F' bounds test whose results are displayed in Table 4 and Table 5, respectively. The first column of Table 4 which shows the results pertaining to ARDL model testing gives the model specification as model representative equations, i.e., natural gas as a function of crude and crude as a function of natural gas. The second column is the result of the break in time series for each of the two models specified. To identify this break, we have included a dummy variable which uses Perron and Vogelsang (1993) methodology to identify the exact break date of the dependent variable. The presence of a structural break is confirmed by 'p' values as shown in the parenthesis in the second column. Since both the 'p' values are significant it shows that structural break has occurred in both models. Next column in Table 4 is the 'F' bounds computed value which for natural gas is 10.6 and is higher than table value at 1% upper bound critical (given in column 4 of Table 4) showing that co-integration is established. However, the same 'F' bounds value for crude is 3.47 which is lower than 5% lower bound critical showing absence of co-integration.

Table 2 BDS results for our variable crude

Dimension	*BDS statistic*	*Prob.*	*Result*
2	0.193981	0.0000	Null rejected, time series is nonlinear
3	0.329204	0.0000	Null rejected, time series is nonlinear
4	0.422769	0.0000	Null rejected, time series is nonlinear
5	0.487246	0.0000	Null rejected, time series is nonlinear
6	0.531274	0.0000	Null rejected, time series is nonlinear

Note: Table result: null hypothesis of linearity of variables is rejected, time series of crude is nonlinear.

Table 3 BDS results for our variable natural gas

Dimension	*BDS statistic*	*Prob.*	*Result*
2	0.193395	0.0000	Null rejected, time series is nonlinear
3	0.328729	0.0000	Null rejected, time series is nonlinear
4	0.423086	0.0000	Null rejected, time series is nonlinear
5	0.488149	0.0000	Null rejected, time series is nonlinear
6	0.532809	0.0000	Null rejected, time series is nonlinear

Note: Table result: null hypothesis of linearity of variables is rejected, time series of natural gas is nonlinear.

Table 4 Results of the partial bounds test ARDL (with dummy) model

Model specification	*Dummy date with model 'p' value in parenthesis*	*'F' bounds (computed Value)*	*Critical table value at 5%* and 1% ***		*Inference*
			Lower	*Upper*	
			Bound I(0)	*Bound I(1)*	
F : Natural gas as f (crude)	07 June 2021 (0.0031)	10.63357^	8.74* 6.56**	9.63* 7.3**	Co-integration is established at 1% level
F: Crude as f (natural gas)	06 DEC 2021 (0.0011)	3.476992	8.74* 6.56**	9.63* 7.3**	Co-integration is not established

Notes: ^Significant at 1% level (for 'n'=1000 and above; nearest to number of observations) Null Hypothesis for Co-integration; 'F' test: $H_o: = \beta_2 = \beta_3 = 0$ (for NG) and $H_o: = \alpha_2 = \alpha_3 = 0$ (for crude) relevant equations : i and ii respectively. Table result: Co-integration is established only in case of natural gas as a function of crude. Further, the dummy coefficients were significant reflecting presence of the structural break in both the time series.

Our next table (Table 5) gives the results of the partial bounds test using NARDL Model and the table has been constructed in a similar manner as Table 4, however, being a nonlinear model, identification of break through dummy variable has not been considered. The results of this table are like that of earlier Table 4, i.e., 'F' bounds computed value for natural gas is 5.9 which is higher than table value at 1% upper bound critical showing establishment of co-integration while the same is not the case with crude.

Table 5 Results of the partial bounds test NARDL model

Model specification	*'F' bounds (computed value)*	*Critical table value at 5%* and 1% ***		*Inference*
		Lower	*Upper*	
		Bound I(0)	*Bound I(1)*	
F: Natural gas as f (crude)	5.9316^	4.1* 3.1**	5* 3.87**	Co-integration is established at 1% level
F : Crude as f (natural gas)	1.216	4.1* 3.1**	5* 3.87**	Co-integration is not established

Note: Table result: co-integration is established only in case of natural gas as a function of crude with F computed value ^ being significant at 1% level of significance.

Thus, two tables reveal that co-integration was established when natural gas was considered as dependent variable under both ARDL and NARDL Models, which was not seen when crude was considered as dependent variable.

Table 6 gives the results of long run under both ARDL and NARDL models. In the table if we observe the 'p' values for regressor; crude we find that crude contemporaneous and crude lag 1 are significantly impacting natural gas in the long run. On the other hand 'p' values of regressor; natural gas are not significant showing that natural gas does not appear to be impacting crude in the long run. Further, dummy for the regressand was however significant in both the models clearly reflecting the break in time series. On the other hand, 'time' trend variable which was included to capture the 'trend' in time series was not found significant in both the models showing absence of 'time' trend.

The table also gives results for elasticity and the detailed computation for the same are shown as table foot note no. (3). We computed elasticity of natural gas with respect to crude and found this to be highly elastic (+7.25). The elasticity of crude with respect to natural gas was not computed due to insignificant 'p' values of natural gas as stated above. Also, the impact or the response of long run positive and negative changes in crude on natural gas, i.e., asymmetric impact of crude on natural gas as stated under the NARDL model was found to exist but only at 10% level of significance (F-statistic value 2.3104 had the 'p' as 0.099); details of its computation are shown as footnote no. 2 of the table.

Table 7 gives the short run results for our ARDL model together with error correction towards equilibrium. The table reveals that both variables; crude and natural gas were impacting each other in the short run. This was shown by their respective 'p' values of contemporaneous and first lag variables which were found to be significant. The table also provides information about the lagged ECM term which shows the correction mechanism towards long run equilibrium. ECM(–1) term for impact of crude on natural gas has a value of –0.0366 which shows that disequilibrium present in the short run gets corrected and becomes a stable long run equilibrium, the speed of correction towards long run equilibrium was @ 3.66% per period with ECM(–1) term coefficient being negative and statistically significant.

Table 6 Long run results for natural gas and crude under ARDL and NARDL model

	(Natural gas)		*(Crude)*	
Regressors (long run)	*Coeff.*	*p-val.*	*Coeff.*	*p-val.*
$Crude_t$	0.004817	0.0320	-	-
Crude(–1)	0.000340	0.0223	0.98846	0.000
Crude(–2)	–0.004263	0.0875	-	-
Nat Gas_t	-		0.57241	0.0639
Nat gas(–1)	0.751244	0.000	–0.48485	0.1162
Nat gas(–2)	0.212088	0.000	-	-
Dummy for regressand	4.685375	0.0031	53.2657	0.0011
@TREND	–0.000494	0.6273	0.00511	0.6137
$Crude^+(-1)$ (λ_3^+)	0.009456	0.0277	-	-
$Crude^-$ (–1) (λ_3^-)	0.000833	0.0278	-	-
Nat gas (–1) (λ_2)				
Asymmetric impact of crude on natural gas	F-statistic (comp value)			2.3104
$\pi^+ = \pi^- = 0$ (Null: no asymmetry: F Wald see Section 3.5)	F-statistic (‘p’) 0.0996 Null rejected only at 10%, asymmetry exists at 10% level			
Long run elasticity of natural gas with respect to crude; equation 5(b)	Highly elastic			

Notes: (1) Model selection method: AIC, model selected: ARDL(1, 1) for crude and ARDL (2,2) for natural gas, no. of observations 1272.

(2) For asymmetry: $\pi^+ = \left(\frac{\lambda_3^+}{\lambda_2}\right)$ and $\pi^- = \left(\frac{\lambda_3^-}{\lambda_2}\right)$; λ_3^+ and λ_3^- are coefficients from equation (4).

(3) For Long run Elasticity of natural gas with respect to crude the following formula has been applied from equation 5(b): $\frac{A(L, g_1)}{B(L, g_2)} = \frac{1 - \delta_{2,1} - \delta_{2,2,}}{\delta_{3,0} + \delta_{3,1} + \delta_{3,2}} =$

$\frac{1 - 0.751 - 0.212}{0.0048 + 0.0003} = 7.25$ (we have ignored the insig. coeff. in comp. of elasticity).

On the other hand, we have not shown any correction term for the impact of natural gas on crude since long run co-integration was not proved under ARDL and therefore such an impact may be considered only as a short run causality (if proved). Speaking of causality, since lagged value of the short run independent variable(s) from crude to natural gas were found to be significant and in the expected direction, short run causality was therefore proved to exist, however results of the formal causality test are given in Table 8 where causality was found to exist moving from crude to natural gas unidirectionally.

Table 7 also gives the results for short run elasticity and short run asymmetry. For short run elasticity, we consider the figures for contemporaneous slope coefficients as these are of the nature of first difference and able figures reveal that we have highly inelastic price transmission from crude to natural gas (0.004263) and fairly inelastic from natural gas to crude (0.572411). As far as short run asymmetry was concerned, this was not detected in the short run results; the applicable formula for the same is given as footnote (2) of the table.

Table 7 Error correction model and short run results

	(D.Nat.Gas)		(D.Crude)	
Regressors	*Coeff.*	*p-val.*	*Coeff.*	*p-val.*
$D(Crude_t)$	0.004263	0.0364	-	-
D(Crude(–1))	0.004817	0.0417	-	-
$D(Nat\ Gas_t)$	-	-	0.572411	0.0425
D(Nat Gas(–1))	–0.212088	0.000		
ECM(–1)	–0.036668	0.0000	-	-
Price transmission (elasticity)		Highly inelastic	Fairly inelastic	
Asymmetry (short run)		Null accepted		

Notes: (1) Model selection method: AIC, model selected: ARDL(1, 1) for crude and ARDL(2,2) for natural gas, no. of observations 1272.
(2) For asymmetry we have applied the formula from equation (3)
$\sum_{i=0}^{n_{1(A)}} \left(\lambda_{5,i}^{+}\right) = \sum_{i=0}^{n_{1(B)}} \left(\lambda_{5,i}^{-}\right).$

Table 8 Causality results

Direction of relation	*Chi square*	*'p' value*	*Null hypothesis (accept/reject)*
Natural gas → Crude	6.664356	0.4646	Accept, no causality exists
Crude → Natural gas	25.07748	0.0007	Reject, causality exists

Notes: (1) Null Hypothesis: No Causality.
(2) Table result: Short run causality moves from crude to natural gas.
(3) No. of lags: 7 (AIC).

Table 9 is the last table under results section which gives results of the model diagnostic tests including stationarity, serial correlation and heteroscedasticity. These table results are given separately for both ARDL and NARDL models. For serial correlation, we have used BG LM test (see Breusch, 1978; Godfrey, 1978) while for heteroscedasticity, the test employed was BPG heteroscedasticity test (Breusch and Pagan, 1979), the methodology employed for the same is shown as a table footnote. The results clearly show that both serial correlation and heteroscedasticity tests were model satisfactory as null hypothesis of no serial correlation and no heteroscedasticity was accepted for both variables; natural gas and crude. This can be seen from the table as all the 'p' values of observed R^2 for both BPG and BGLM tests are higher than the critical 'p' value of 0.05 under both ARDL and NARDL Models. On the other hand, for stationarity test, we had applied ADF Unit root test with single breakpoint and the results reveal both variables as stationary at I(1) levels. The ADF stationary test also identified single break dates which were later included in both ARDL and NARDL Models as breaks in intercepts.

Further to test for the stability of our models, we plotted cumulative sum of the squares (CUSUM) Plots. These plots are shown as Figures 5–8 for all the four models, two ARDL (crude and natural gas) and two NARDL (crude and natural gas) models and since all the plots are within the 5% significance levels, all the models are hence stable.

Table 9 Model diagnostics

Diagnostic tool			*Nat gas*		*Crude*	
			Level	*1st Diff*	*Level*	*1st Diff*
@ stationarity of variables:		1	0.36	<0.01	>0.99	<0.01
ADF Breakpoint unit root test		2	Non-stationary	Stationary	Non-stationary	Stationary
(1	‘p’ values of slope coefficient	3	07/06/21	14/11/18	06/12/21	15/03/22
2	Table result		ARDL nat gas	ARDL crude	NARDL nat gas	NARDL crude
3	‘Break date’)					
* BPG hetroscedasticity test	Obs. R^2		63.64609	6.2093	9.4654	3.9372
	prob. chi sqr. (7)		0.2648	0.7052	0.5731	0.43279
** BG serial correlation LM Test	Obs. R^2		0.414884	0.58326	0.12975	0.161885
	Prob. (p)		0.8678	0.479	0.4118	0.528

Notes: @$\Delta Cr_t = \beta_1 + \beta_1{*}\, D_{C,t} + (\beta_2 - 1)Cr_{t-1} + \sum_{i=1}^{m} \beta_{3i},\ \Delta Cr_{t-i} + \beta_{4,v}t + u_t$ …… is the ADF equation with single break point for variable crude, ΔCr_t is change in crude in period t, β_1, represents the intercept term while $\beta_1{*}\, D_{C,t}$ is the intercept dummy representing a single break in intercept of crude equation. This dummy $\{D_{C,t}\}$ takes the value of ‘1’ if the observation falls after the break date (including the break date) and ‘0’ before the break date. In case the break exists, then the coefficient $\beta_1{*}$ is expected to be statistically significant. The term Cr_{t-1} reveals the stationarity of variable ‘crude’ and has $(\beta_2 - 1)$as its coefficient. The term $\sum_{i=1}^{m} \beta_{3i},\ \Delta Cr_{t-i}$ denotes change in crude in period $t - i$, ‘i’ being the no. of lags and this term represents the ‘augmentation’ for removal of serial correlation. The ADF equation takes care of trend stationarity by including a trend variable ‘t’ with coefficient as β_4. Finally the random error term of this equation is given by u_t. Using similar methodology, we construct the stationary equation for our variable ‘natural gas’.

$*B.P.G. = n.R^2_{aux} \sim \chi^2_{m-1}$. Where R^2 is computed for auxiliary equation: $u_t^2 = \delta_1 + \delta_2 X_{2t} + \delta_3 X_{3t} + \ldots + \delta_k Xk_t$. Null as: no heteroscedasticity, i.e., $\delta_2 = \delta_3 = \delta_4 \ldots = \delta_k = 0$.

**BG-LM serial correlation test is given as under: $u_C = \beta_1 + \beta_2 C_{t-1} + \beta_3 C_{t-2} + \ldots + \beta_p C_{t-p} + \rho_2 u_{c_{t-2}} \ldots + \rho_m u_{c_{t-m}} + e_t$, ‘$p$’ is the no. of lags of the regression and ‘m’ as lags of the error term, BG-LM test assumes ‘p’ > ‘m’). Null: $\rho_1 = \rho_2 = \ldots \rho_m = 0$ (no serial correlation between residuals). If $R^2(n - p)$ of equation (9) $> \chi 2^m$, we reject the null. In the same manner, we test our serial correlation for second variable natural gas.

Figure 5 CUSUM plot for crude (ARDL) (see online version for colours)

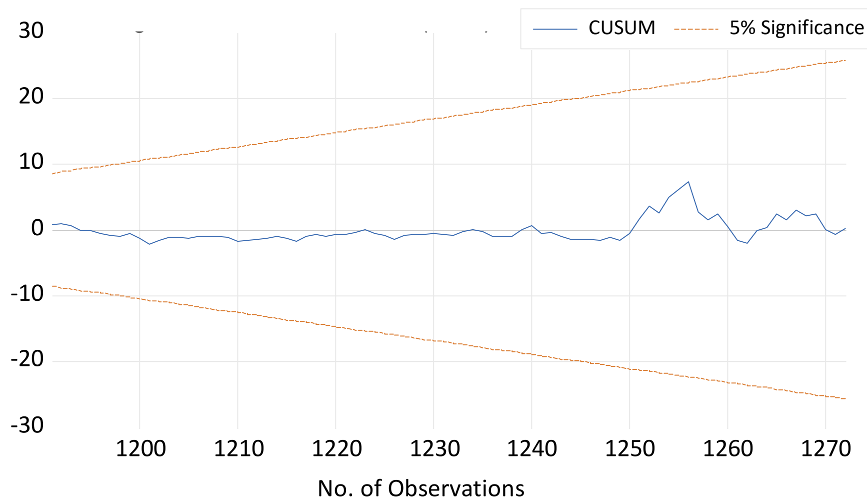


Figure 6 CUSUM for ARDL (natural gas) (see online version for colours)

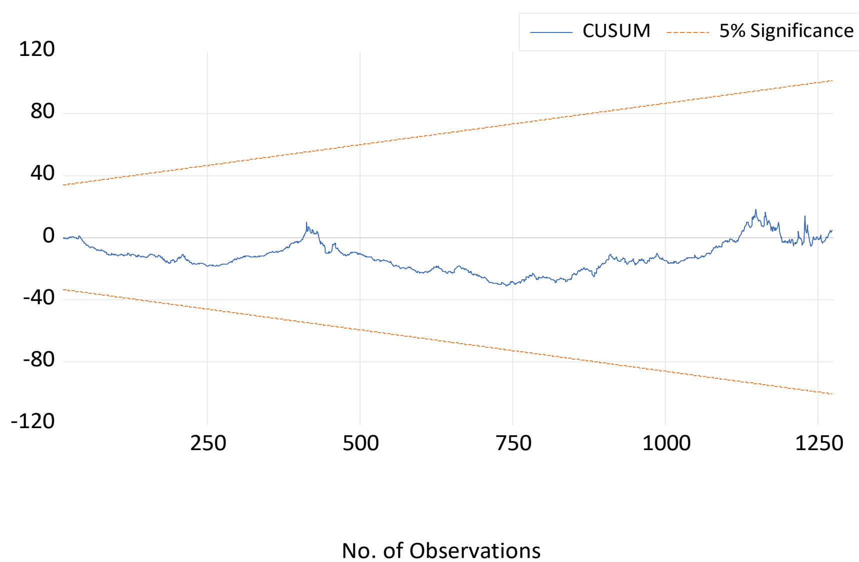


Figure 7 CUSUM for NARDL (crude) (see online version for colours)

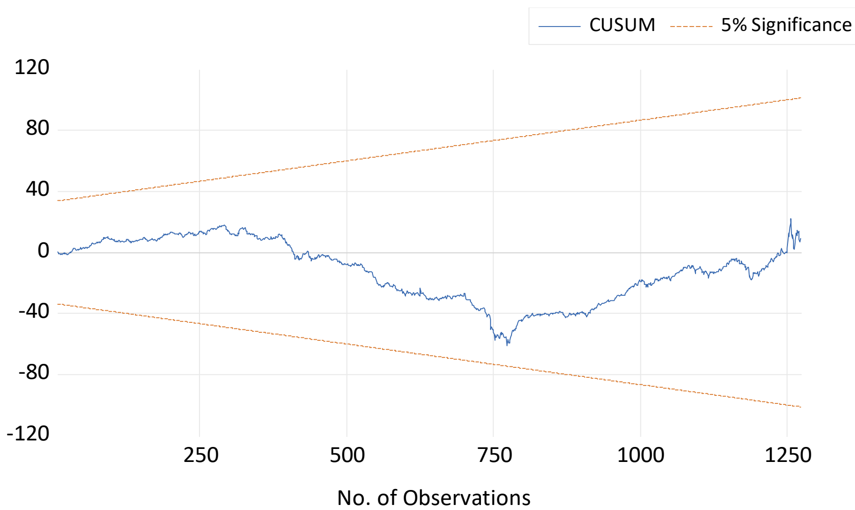
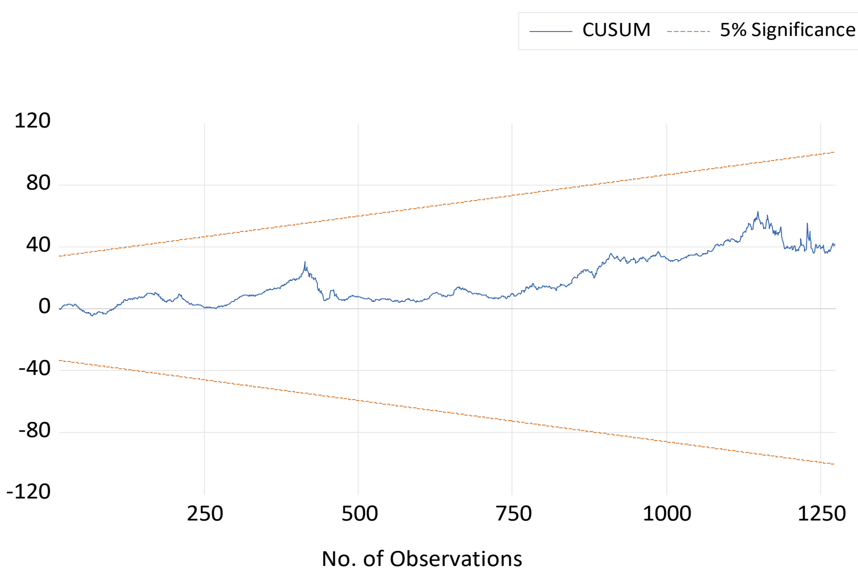


Figure 8 CUSUM for NARDL (natural gas) (see online version for colours)



5 Conclusions and policy recommendations

To conclude, the study made an attempt to investigate the co-integrating relation between two energy commodities viz. natural gas and crude for five year period April 1, 2017–March 31, using linear and nonlinear ARDL co-integrating techniques. The study also tested for asymmetric impact of crude on natural gas. The results from both co-integration techniques; ARDL (with structural break) and NARDL revealed that long run co-integration was established only for natural gas while the same was not the case for crude. The long run elasticity of natural gas with respect to crude was found to be inelastic in short and highly elastic in long run. The asymmetric impact of crude on natural gas was not visible both for short run and long run. The error correction term (ECM) for natural gas was negative and significant reflecting that movement from short run disequilibrium to long run equilibrium was stable. The model diagnostics viz. stationarity, serial correlation, heteroscedasticity and stability were found to be satisfactory.

Since co-integration was proved only for Natural Gas, trading benefits which might exist for this commodity in the short run would eventually evaporate in the long run as natural gas enters a long run co-integrating relationship with crude. Further the adjustment rate for natural gas is quite reasonable considering the speed of adjustment commonly seen for other variables in financial markets when all the short run deviations get corrected and long run stability in prices are achieved. In terms of elasticity, the elasticity of natural gas with respect to crude was found to be inelastic in the short run which became fairly elastic when period became long run. The short run inelasticity could primarily be attributed to factors like infrastructure bottlenecks and poor substitutability, however more flexibility of switching from one fuel to another in the long run was also visible from the results in the form of elasticity of natural gas with respect to crude becoming fairly elastic from being inelastic in the short run.

In view of the above, the study recommends the policy makers from India to make all policy related decisions involving energy fuels only after considering a long run perspective. There is a clear evidence that complete benefit of sustainable development through use of viable energy could be reaped by India only when the focus is long run. However, here India must also decide whether the enormous expenditure in infrastructure on energy fuels is in line with the potential benefits from such an investment. This is important as the difference between the market price of two fuels; crude and natural gas has reduced quite substantially especially after the 2022 Russian War with Ukraine. Another challenge for the decision makers would be that many clean and alternative fuels like solar and wind energy, hydrogen fuel and lithium powered energy sources which are also environment friendly have made rapid progress during the last few years and are also ready to give tough fight to traditional fuels like crude and natural gas.

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