1. INTRODUCTION

Energy and Power sector is one of the most critical infrastructure components crucial to nations’ economic growth and well-being. For the sustainable growth of the Indian economy, the presence and construction of adequate infrastructure are essential. Power generation options range from traditional sources such as coal, lignite, natural gas, shale, hydro and nuclear power, to suitable non-conventional sources such as wind, solar, and household and agricultural waste. The country’s energy demand has grown steadily and is expected to grow more in the years to come. A significant addition to the installed generating capacity is expected to satisfy the growing demand for electricity in the region. India ranked fourth out of 25 nations in the Asia Pacific region in May 2018 on an index that assessed their total strength. As of 2018, India was ranked fourth in wind power, seventh in solar power and fifth in installed renewable power capacity. In the list of countries to make significant investments in renewable energy, India placed sixth at US$ 90 billion.

Modelling financial asset volatility has remained one of the essential facets of economic analysis as it advises investors on risk trends found in investment and transaction processes. Trading of derivatives started in the Indian Markets in 2000 by introducing Futures Contracts on the National Stock Exchange (NSE) S&P CNX Nifty Index and BSE Sensex Bombay Stock Exchange (BSE). Trading options began in Indian markets in June 2001. Until then, the F&O market has expanded in terms of the number of contracts exchanged, price, and new product offering. The impact of introducing derivatives on Spot Market volatility and, in turn, its role in stabilizing or destabilizing cash markets have remained an essential subject of analytical and empirical interest.
studies that analyzed the effect of Derivatives on the volatility of the underlying Spot Market used some form of GARCH Model with Dummy Variable Repressors. However, this approach is based on the implied presumption that any adjustments are observed during the time following Derivatives trading’s implementation due solely to Derivatives trading activity. Various factors such as introducing the Rolling Settlement System, Circuit Breakers, and stock exchange regulatory changes can also contribute to market volatility reduction.

Failure to identify structural breaks in variances in the financial series under consideration will lead to a significant upward change in projected GARCH models’ Persistence. Various research studies such as Diebold (1986); Mikosch and Starica (2000); Diebold and Inoue (2001) have reported that neglect of structural disturbances may cause the GARCH model to be spuriously estimated. The presence of structural breaks in the volatility of financial markets has long been assumed. “The primary explanations for these systemic breaks may be due to changes in exchange rate system structures, global financial markets turmoil, or stock market evolution. The shocks caused by such significant economic or political events can cause financial time series behaviour to deviate from its tranquil time.” (Andreu and Ghysels, 2002; Wang and Moore, 2009)

2. LITERATURE REVIEW

The derivatives market’s effect on the underlying spot market remains a topic frequently discussed with arguments both in favour and against. Bae et al. (2004) analyzed the effect of the Listing of Index Futures on the volatility and market efficiency of the underlying KOSPI 200 stocks, using non-KOSPI 200 stocks, and observed a parallel increase in volatility and market efficiency during the post-derived era. Other studies that find substantial rises in index return volatility following the implementation of Futures include Harris (1989), Brousen (1991), Lee and Okt (1992), Antoniou and Holmes (1995), and Yao (2016).

Others argue that the introduction of Futures reduces the Spot Market’s volatility and thereby stabilizes the market. “One of the clarifications for the Destabilizing hypothesis is that a derivative trading destabilizes the underlying Spot Market by providing an additional route for information transmission and reflection in the Spot Market” (Cox and Ross, 1976; Ross, 1989). Gullen and Mayhew (2000) analyzed Index Futures’ effect on international stock markets’ volatility by using the GIR-GARCH and BEKK model to sample 21 European countries and found that Spot Market volatility has declined for most of the countries under study.

Another school of thought suggests that Spot Market Volatility is increasing due to the liquidity provided by speculators. This extra liquidity helps Spot traders to hedge their position, thereby curbing uncertainty due to an order imbalance. Several studies such as Stoll and Whaley (1990); Pilar and Rafael (2002); Bandivadekar and Ghosh (2003); T. Mallikarjunappa (2008); Thenmozhi (2002); Kavussanos (2008); Raju and Karande (2003); Sarangi and Patnaik (2006) reported substantial declines in Indian spot market volatility. Rahman (2001) investigated the impact of Index Futures trading on the volatility of component stocks for the Dow Jones Industrial Average (DJIA) by employing the GARCH (1, 1) model and reported no change in conditional volatility. T. Mallikarjunappa (2008) and Afzal (2008); Thenmozhi (2002); Kavussanos (2008) inferred that the changes in the volatility process are not due to the introduction of Derivatives, but due to many other factors such as better information dissemination and more transparency. Anjana Raju and Shirodkar (2020) stated that “the listing of stock futures may not have any clear effect on the underlying stock’s volatility.”

Chen et al. (2014) investigated the impact of structural breaks on the spot–futures oil prices and concluded that existing breakpoint indeed affects the forecast of oil futures volatility. Tabak and Cajueiro (2007) investigated the Brent and WTI crude oil markets’ performance and noticed that oil spot markets had been more competitive over time. Alvarez-Ramirez et al. (2008) have indicated that oil markets have demonstrated inefficiency in the short term, but have been influential in the long term.

However, the literature is inconclusive about whether the introduction of derivatives leads to Spot Market volatility increasing or decreasing. The vast majority of studies in the derivative segment arena focus on Index Futures’ spot market impact. Indian Stock Futures studies concentrate on conceptual specifics or span a short time. The index-focused analysis does not consider the stock’s unique characteristics, which may also play a significant role in volatility creation. This study contributes in two ways to the on-going discussion of the effect derivatives on the underlying stock market volatility. First, this research uses a different methodology based on Aggarwal et al. (1999); Andreou and Ghysels (2002); Malik and Hassan (2004); Kang et al. (2009); Wang-Chen (2007). The analysis attempts to model with Stock Futures the volatility of the underlying Energy Sector Stocks by considering the volatility breaks.

The present study investigates the effect of Stock Futures on the underlying Energy Sector stocks empirically; by defining the structural break, if any, in stock price volatility since the advent of derivatives trading, using Inclan and Tiao’s (1994) ICSS test. The Energy sector or industry comprises those companies involved in the exploration and expansion of Oil or gas reserves, oil and gas drilling, and refining. It also includes integrated power utility companies such as renewable energy and coal. Second, studying the impact of Single Stock Futures would allow us to directly examine a company’s response to Futures trading instead of Index Futures’ market-wide influence.

3. METHODS

The Individual Stock Futures (ISF) has proven to be a principal financial instrument, and the NSE continues to account for most of the total volumes traded worldwide on the ISF. Our study’s resulting sample consists of 14 stocks in the energy sector and their respective future contracts. Data is sourced from the Bloomberg database. The analysis period ranges from 1 January 2000 to 31 March 2019, or the stock listing date (whichever is prior).
3.1. Testing for ARCH Effect
Testing for ARCH involves testing the presence of heteroscedasticity in the time-series model. Engle introduced the Lagrange Multiple (LM) test to check for ARCH disorders. Let $\varepsilon_t = y_t - \mu_t$ be the residual series. The squared series $\varepsilon_t^2$ is utilized to implement the LM test for checking conditional heteroscedasticity. Under the null hypothesis, we have:

$$H_0 : \alpha_i = 0, i = 1, 2, \ldots, q$$

Versus

$$H_1 : \alpha_i \neq 0, \text{ for at least one } i$$

In the Linear Regression

$$\varepsilon_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_q \varepsilon_{t-q}^2 + \epsilon_t = q + 1, \ldots, N,$$

Where q is the length of ARCH lags, and N is the number of observations used in the Regression equation. The test statistic for LM-test is defined by:

$$LM = NR^2$$

In this $R^2$ is the R-squared from the Regression of $\varepsilon_t^2$ in the equation and defined by:

$$R^2 = \frac{\text{Regression sum of squares}}{\text{total sum of squares}}$$

Under the null hypothesis, the test statistics $NR^2$ is distributed as a Chi-squared distribution with q degrees of freedom. $H_0$ is rejected when $LM > \chi^2(q)$ suggests that the ARCH effect exists in the time-series.

3.2. Testing for Multiple Structural Breaks (Iterated Cumulative Sums of Squares [ICSS]) Algorithm of Inclan and Tiao (1994)
The Inclan and Tiao (1994) proposed Iterative Cumulative Sum of Squares (ICSS) algorithm enables identifying several breakpoints in variance in a time series. The idea behind the ICSS algorithm provided by Inclan and Tiao can be summarized in sequential steps. A time series of interest has an absolute stationary variance over an initial period before a sudden split occurs. The unconditional variance is stationary before the next abrupt shift occurs. This process repeats throughout time, giving a time series of observations with multiple breakpoints in n observations’ unconditional variance.

3.3. Associating the Volatility Breaks with Derivative Trading
First, the dates of structural breaks in the stocks will be predicted, and later we will seek to correlate those dates with the dates of launch of derivative trading on individual stocks. AR (1)-GARCH (1, 1) is a GARCH family model, in which the mean is modelled by a first-order auto-regressive AR (1), with a GARCH (1, 1) error:

$$x_t = \mu_t + \sigma_t \varepsilon_t, E[\varepsilon_t] = 0, E[\varepsilon_t^2] = 1, \varepsilon_t \text{ i.i.d...}$$

$$\mu_t = \lambda X_{t-1},$$

$$\sigma_t^2 = a_0 + a(X_{t-1} - \mu_{t-1})^2 + b\sigma_{t-1}^2$$

Once all structural breakpoints have been identified, dummy variables are created for each break detected. Each dummy variable is denoted with a value ‘1’ from the location identified to the end of the data series and ‘0’ elsewhere.

4. RESULTS AND DISCUSSION
Augmented Dickey-Fuller test results are shown in Table 1. All variables are non-stationary at the level since the P-value is more than 0.05%. The Unit Root test is, therefore performed in the first difference for all variables. All the series are stationary at a 1% level of significance at the first difference. The results of the ADF test indicate that all variables are integrated in the same order.

Table 2 depicts the ARCH test results for all the fourteen Stocks traded at the Cash segment of NSE. The standard diagnostic test
of the Residuals from the model confirms the presence of ARCH effect. The absence of the ARCH effect hypothesis is false in the closing return series of all the variables.

Following the detection of structural breaks in the return series of 14 Energy Sector stocks, an attempt has been made to relate these dates to the launch of Derivatives trading on the individual stocks as shown in Figure 1. After incorporating the detected structural breaks into the AR (1)-GARCH (1, 1) Model, detailed analysis is presented in the appendix.

If a structural break is observed within 6 months following the introduction of Derivative trading, it has been attributed as possible to Derivative trading. Following this structural break date, the change in volatility persistence, the unconditional volatility and the rate of adjustment of the volatility to the new information are observed and reported in Table 3. In the case of BPCL, GAIL, and HINDPETRO, the Persistence of the volatility have increased; while, the adjustment coefficient and unconditional volatility declined for the period after this break.

On the contrary, IOC, NTPC, and OIL demonstrated a decline in the Persistence of volatility, unconditional volatility, and rate of volatility adjustment to new information. We noticed a rise in the adjustment coefficient, Persistence of volatility and the unconditional volatility of ONGC and PETRONET for the period following the introduction of Derivative Trading. For MGL and TATAPOWER, the adjustment coefficient and unconditional volatility are reduced. Still, the persistence rate of adjustment volatility has increased during the observed volatility structural break. However, no structural break is found in proximity to the introduction of Derivatives trading for ADANIPOWER, IGL and POWERGRID.

The results of this study show a mixed picture. Out of the fourteen stocks, no structural break has been observed in three stocks within the 6 months following Derivative Trading’s introduction. Out of the remaining eleven stocks, which show a structural break during the vicinity of Derivative trading, the unconditional volatility of Eight Stocks declined. The study’s findings show that, following the Futures contracts’ implementation, the unconditional volatility of most stocks declined. Volatility persistence increased in four stocks and decreased in seven stocks. The rate of adjustment of volatility to new information increased in five stocks, while it decreased in six stocks.

Table 2: Results of ARCH test

| Stock    | P-value | Result | Stock    | P-value | Result |
|----------|---------|--------|----------|---------|--------|
| ADANIPOWER | 0.000   | Present | NTPC     | 0.000   | Present |
| BPCL      | 0.000   | Present | OIL      | 0.000   | Present |
| GAIL      | 0.000   | Present | ONGC     | 0.000   | Present |
| HINDPETRO | 0.000   | Present | PETRONET | 0.000   | Present |
| IGL       | 0.000   | Present | POWERGRID| 0.000   | Present |
| IOC       | 0.000   | Present | TATAPOWER| 0.000   | Present |
| MGL       | 0.000   | Present | TORNTPOWER| 0.000  | Present |

Table 3: Impact of derivatives trading on volatility of underlying stock

| Stock         | This structural break caused by derivative trading | Impact on the volatility | Direction of impact | Unconditional volatility |
|---------------|-----------------------------------------------------|---------------------------|---------------------|-------------------------|
|               |                                                     | Persistence | α | Decreased | Increased | Decreased | Decreased |
| ADANIPOWER    | No                                                  | -           | - | -         |           | -         |           |
| BPCL          | Yes                                                 | Decreased   | Increased | Decreased |
| GAIL          | Yes                                                 | Decreased   | Increased | Decreased |
| HINDPETRO     | Yes                                                 | Decreased   | Increased | Decreased |
| IGL           | No                                                  | -           | - | -         |           | -         |           |
| IOC           | Yes                                                 | Decreased   | Decreased | Decreased |
| MGL           | Yes                                                 | Increased   | Decreased | Decreased |
| NTPC          | Yes                                                 | Decreased   | Decreased | Decreased |
| OIL           | Yes                                                 | Decreased   | Decreased | Decreased |
| ONGC          | Yes                                                 | Increased   | Increased | Increased |
| PETRONET      | Yes                                                 | Increased   | Increased | Increased |
| POWERGRID     | No                                                  | -           | - | -         |           | -         |           |
| TATAPOWER     | Yes                                                 | Increased   | Decreased | Decreased |
| TORNTPOWER    | Yes                                                 | Decreased   | Decreased | Increased |
| Total=14      | Yes=11                                              | Increased=4 | Increased=5 | Increased=3 |
|               | No=03                                               | Decreased=7 | Decreased=6 | Decreased=8 |
5. CONCLUSION

In this analysis, an attempt was made to model with Stock Futures the volatility of the underlying Energy Sector stocks by considering the breaks in volatility. We used the Iterated Cumulative Sums of Squares (ICSS) algorithm to detect multiple structural breaks for 14 Energy Sector stocks. The results of this study show a mixed picture. Out of the fourteen stocks, no structural break has been observed in three stocks within the 6 months following Derivative Trading’s introduction.

Out of the remaining eleven stocks, which show a structural break within the 6 months of Derivative trading, Eight Stocks’ unconditional volatility declined. The study’s findings show that, following the Futures contracts’ implementation, the unconditional volatility of most stocks declined. Volatility persistence increased in four stocks and decreased in seven stocks. The rate of adjustment...
of volatility to new information increased in five stocks, while it decreased in six stocks. The mixed result may probably be attributed to different stock characteristics which could also play a significant role in volatility development. The study results indicate that Stock Futures trading may not inherently be correlated with the underlying stock destabilization.

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## Volatility Breaks in ADANIPOWER

**Date of commencement of Derivative trading: 30-July-2010**

| Date          | \(\omega\) | \(\alpha\) | \(\beta\) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------|------------|------------|------------|---------------------------------|---------------------------------|
| 05 January 2000_16 November 2001 | 3.256 | 0.310 | 0.540 | 0.850 | 21.713 |
| 17 November 2001_01 January 2003 | 0.142 | 0.266 | 0.784 | 1.051 | -2.803 |
| 02 January 2003_18 November 2004 | 0.172 | 0.096 | 0.888 | 0.984 | 10.853 |
| 19 November 2004_04 May 2006 | 3.323 | 0.085 | 0.411 | 0.497 | 6.601 |
| 05 May 2006_18 January 2008 | 2.728 | 0.259 | 0.453 | 0.712 | 9.478 |
| 19 January 2008_18 August 2009 | 2.281 | 0.079 | 0.815 | 0.894 | 21.560 |
| 19 August 2009_07 June 2012 | 1.175 | 0.146 | 0.558 | 0.704 | 3.962 |
| 08 June 2012_20 November 2014 | 0.056 | 0.039 | 0.940 | 0.979 | 2.657 |
| 21 November 2014_24 September 2015 | 0.840 | 0.032 | 0.703 | 0.735 | 3.169 |
| 25 September 2015_31 January 2017 | 1.287 | 0.079 | 0.815 | 0.894 | 1.705 |
| 01 February 2017_29 March 2019 | 1.037 | 0.276 | 0.123 | 0.400 | 1.726 |

## Volatility Breaks in BPCL

**Date of commencement of Derivative trading: 02-July-2001**

| Date          | \(\omega\) | \(\alpha\) | \(\beta\) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------|------------|------------|------------|---------------------------------|---------------------------------|
| 05 January 2000_04 October 2000 | 5.439 | 0.159 | 0.458 | 0.617 | 14.200 |
| 05 October 2000_17 September 2001 | 0.006 | -0.021 | 1.017 | 0.996 | 1.761 |
| 18 September 2001_16 July 2004 | 0.793 | 0.060 | 0.815 | 0.875 | 6.353 |
| 17 July 2004_12 September 2005 | 0.480 | 0.033 | 0.692 | 0.725 | 1.749 |
| 13 September 2005_13 March 2007 | 0.331 | 0.224 | 0.736 | 0.784 | 3.368 |
| 14 March 2007_21 January 2008 | 0.720 | 0.038 | 0.748 | 0.786 | 8.822 |
| 22 January 2008_06 October 2009 | 1.128 | 0.096 | 0.776 | 0.872 | 3.162 |
| 07 October 2009_03 July 2012 | 1.592 | 0.241 | 0.100 | 0.341 | 2.415 |
| 04 July 2012_25 July 2013 | 1.019 | 0.167 | 0.085 | 0.252 | 1.362 |
| 26 July 2013_10 March 2015 | 0.166 | 0.087 | 0.861 | 0.947 | 3.148 |
| 11 March 2015_05 August 2016 | 0.354 | 0.104 | 0.623 | 0.728 | 1.299 |
| 06 August 2016_29 March 2019 | 0.513 | 0.022 | 0.807 | 0.829 | 3.004 |

## Volatility Breaks in GAIL

**Date of commencement of Derivative trading: 26-September-2003**

| Date          | \(\omega\) | \(\alpha\) | \(\beta\) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------|------------|------------|------------|---------------------------------|---------------------------------|
| 05 January 2000_05 January 2001 | 1.467 | 0.188 | 0.651 | 0.839 | 9.129 |
| 06 January 2001_09 October 2003 | 0.336 | 0.187 | 0.744 | 0.931 | 4.841 |
| 10 October 2003_11 May 2004 | 0.968 | -0.108 | 0.862 | 0.754 | 3.933 |
| 12 May 2004_18 May 2006 | 0.416 | 0.081 | 0.799 | 0.881 | 3.488 |
| 19 May 2006_27 June 2008 | 0.160 | 0.056 | 0.921 | 0.976 | 6.773 |
| 28 June 2008_22 December 2011 | 0.050 | 0.055 | 0.934 | 0.990 | 4.850 |
| 23 December 2011_06 August 2013 | 0.904 | 0.023 | 0.553 | 0.576 | 2.133 |
| 07 August 2013_06 October 2015 | 0.178 | 0.054 | 0.890 | 0.944 | 3.172 |
| 07 October 2015_29 March 2019 | 0.216 | 0.052 | 0.833 | 0.885 | 1.872 |

## Volatility Breaks in HINDPETRO

**Date of commencement of Derivative trading: 02-July-2001**

| Date          | \(\omega\) | \(\alpha\) | \(\beta\) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------|------------|------------|------------|---------------------------------|---------------------------------|
| 05 January 2000_19 July 2000 | 13.355 | 0.229 | 0.021 | 0.249 | 17.791 |
| 20 July 2000_23 October 2001 | 1.187 | 0.049 | 0.772 | 0.820 | 6.605 |
| 24 October 2001_28 April 2003 | 0.779 | 0.046 | 0.466 | 0.513 | 1.599 |
| 29 April 2003_06 July 2004 | 1.756 | 0.187 | 0.476 | 0.663 | 5.214 |
| 07 July 2004_02 February 2006 | 1.546 | 0.100 | 0.384 | 0.484 | 2.994 |
| 03 February 2006_18 August 2009 | 0.745 | 0.135 | 0.729 | 0.864 | 6.466 |
| 19 August 2009_15 August 2014 | 0.946 | 0.014 | 0.549 | 0.562 | 2.162 |
| 16 August 2014_03 September 2015 | 0.217 | 0.011 | 0.930 | 0.941 | 3.664 |
| 04 September 2015_28 December 2016 | 1.343 | 0.252 | 0.138 | 0.390 | 2.201 |
| 29 December 2016_23 May 2017 | 0.210 | 0.197 | 0.547 | 0.744 | 0.818 |
| 24 May 2017_29 March 2019 | 0.530 | 0.144 | 0.646 | 0.790 | 2.527 |
### Volatility Breaks in MGL
Date of commencement of Derivative trading: 28-April-2017

| Date Range               | $\omega$ | $\alpha$ | $\beta$ | Total Persistence: $(\alpha+\beta)$ | Unconditional volatility: $\omega/(1-\alpha-\beta)$ |
|-------------------------|----------|----------|---------|--------------------------------------|-------------------------------------------------|
| 12 November 2015 - 22 January 2016 | 11.610   | 0.304    | -0.109  | 0.196                               | 14.436                                          |
| 23 January 2016 - 16 February 2016 | 10.775   | -0.123   | 0.663   | 0.540                               | 23.432                                          |
| 17 February 2016 - 19 August 2016 | 2.533    | -0.050   | 0.600   | 0.550                               | 5.632                                           |
| 20 August 2016 - 29 April 2017   | 2.401    | 0.212    | -0.098  | 0.114                               | 2.711                                           |
| 30 April 2017 - 29 March 2019   | 0.977    | 0.024    | 0.828   | 0.852                               | 6.613                                           |

### Volatility Breaks in NTPC
Date of commencement of Derivative trading: 23-August-2004

| Date Range               | $\omega$ | $\alpha$ | $\beta$ | Total Persistence: $(\alpha+\beta)$ | Unconditional volatility: $\omega/(1-\alpha-\beta)$ |
|-------------------------|----------|----------|---------|--------------------------------------|-------------------------------------------------|
| 27 January 2004 - 26 April 2004 | 0.149    | 0.047    | 0.919   | 0.966                               | 4.339                                           |
| 27 April 2004 - 15 October 2005 | 0.634    | 0.012    | 0.608   | 0.619                               | 1.666                                           |
| 16 October 2005 - 25 July 2006 | 0.463    | 0.169    | 0.709   | 0.878                               | 3.796                                           |
| 26 July 2006 - 06 July 2007   | 1.290    | 0.342    | 0.159   | 0.501                               | 2.588                                           |
| 07 July 2007 - 29 October 2008 | 0.333    | 0.116    | 0.856   | 0.971                               | 11.669                                          |
| 30 October 2008 - 13 August 2009 | 11.142  | 0.241    | -0.171  | 0.070                               | 11.982                                          |
| 14 August 2009 - 05 August 2011 | 1.133    | 0.134    | 0.460   | 0.594                               | 2.794                                           |
| 06 August 2011 - 10 May 2012   | 0.168    | 0.041    | 0.921   | 0.961                               | 4.366                                           |
| 11 May 2012 - 26 June 2013    | 0.021    | -0.041   | 1.030   | 0.988                               | 1.823                                           |
| 27 June 2013 - 20 October 2014 | 0.808    | 0.027    | 0.692   | 0.719                               | 2.873                                           |
| 21 October 2014 - 29 December 2017 | 1.048    | 0.151    | 0.232   | 0.383                               | 1.699                                           |
| 30 December 2017 - 29 March 2019 | 0.363    | 0.047    | 0.799   | 0.846                               | 2.353                                           |

### Volatility Breaks in IGL
Date of commencement of Derivative trading: 30-September-2010

| Date Range               | $\omega$ | $\alpha$ | $\beta$ | Total Persistence: $(\alpha+\beta)$ | Unconditional volatility: $\omega/(1-\alpha-\beta)$ |
|-------------------------|----------|----------|---------|--------------------------------------|-------------------------------------------------|
| 26 July 2013 - 19 September 2013 | 10.009  | 0.113    | -0.079  | 0.034                               | 10.358                                          |
| 20 September 2013 - 02 June 2014 | 1.584    | 0.032    | 0.771   | 0.803                               | 8.039                                           |
| 03 June 2014 - 22 March 2016   | 1.929    | 0.037    | 0.589   | 0.626                               | 5.158                                           |
| 23 March 2016 - 01 November 2018 | 0.271    | 0.086    | 0.855   | 0.942                               | 4.641                                           |
| 02 November 2018 - 29 March 2019 | 3.118    | -0.063   | 0.716   | 0.652                               | 8.969                                           |

### Volatility Breaks in IOC
Date of commencement of Derivative trading: 26-September-2005

| Date Range               | $\omega$ | $\alpha$ | $\beta$ | Total Persistence: $(\alpha+\beta)$ | Unconditional volatility: $\omega/(1-\alpha-\beta)$ |
|-------------------------|----------|----------|---------|--------------------------------------|-------------------------------------------------|
| 05 January 2000 - 27 February 2001 | 0.710    | 0.100    | 0.852   | 0.951                               | 14.612                                          |
| 28 February 2001 - 03 November 2001 | 6.251    | -0.196   | 1.046   | 0.850                               | 41.605                                          |
| 05 November 2001 - 17 May 2004   | 1.033    | 0.108    | 0.778   | 0.886                               | 9.097                                           |
| 18 May 2004 - 28 February 2006   | 0.447    | 0.005    | 0.810   | 0.814                               | 2.408                                           |
| 29 February 2006 - 24 July 2006   | 5.691    | 0.336    | -0.126  | 0.210                               | 7.206                                           |
| 25 July 2006 - 01 May 2009       | 0.053    | 0.061    | 0.931   | 0.992                               | 6.624                                           |
| 02 May 2009 - 12 July 2012      | 0.628    | 0.230    | 0.598   | 0.828                               | 3.650                                           |
| 13 July 2012 - 11 January 2013  | 0.360    | 0.030    | 0.737   | 0.767                               | 1.545                                           |
| 12 January 2013 - 13 March 2014 | 0.560    | 1.277    | 0.205   | 1.482                               | -1.163                                          |
| 14 March 2014 - 18 July 2016    | 0.850    | -0.018   | 0.699   | 0.681                               | 2.661                                           |
| 19 July 2016 - 3/29/2019        | 1.292    | 0.170    | 0.137   | 0.307                               | 1.864                                           |
### Volatility Breaks in ONGC

**Date of commencement of Derivative trading:** 31-January-2003

| Date Range                | \( \omega \) | \( \alpha \) | \( \beta \) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------------------|--------------|--------------|------------|---------------------------------|---------------------------------|
| 05 January 2000 - 15 March 2001 | 0.263        | 0.071        | 0.893      | 0.964                           | 7.290                           |
| 16 March 2001 - 25 April 2003 | 0.427        | 0.266        | 0.707      | 0.973                           | 15.935                          |
| 26 April 2003 - 27 April 2004 | 0.073        | 0.082        | 0.900      | 0.981                           | 3.916                           |
| 28 April 2004 - 26 July 2005 | 0.149        | 0.047        | 0.919      | 0.966                           | 4.339                           |
| 27 July 2005 - 15 May 2006  | 0.767        | 0.074        | 0.639      | 0.973                           | 2.671                           |
| 16 May 2006 - 08 October 2007 | 0.305        | 0.015        | 0.919      | 0.935                           | 4.669                           |
| 09 October 2007 - 31 July 2009 | 0.569    | 0.079        | 0.875      | 0.954                           | 12.340                          |
| 01 August 2009 - 01 August 2011 | 0.271    | 0.060        | 0.861      | 0.921                           | 3.418                           |
| 02 August 2011 - 24 October 2017 | 0.215    | 0.071        | 0.874      | 0.946                           | 3.953                           |
| 25 October 2017 - 08 June 2018 | 0.484    | -0.111       | 0.976      | 0.865                           | 3.582                           |
| 09 June 2018 - 29 March 2019 | 0.179        | 0.081        | 0.869      | 0.950                           | 3.598                           |

### Volatility Breaks in OIL

**Date of commencement of Derivative trading:** 29-October-2010

| Date Range                | \( \omega \) | \( \alpha \) | \( \beta \) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------------------|--------------|--------------|------------|---------------------------------|---------------------------------|
| 05 January 2000 - 15 March 2001 | 2.278        | 0.189        | 0.655      | 0.844                           | 14.638                          |
| 16 March 2001 - 06 February 2002 | 2.859        | 0.356        | 0.041      | 0.397                           | 4.743                           |
| 07 February 2002 - 05 May 2003 | 0.372        | 0.081        | 0.855      | 0.937                           | 5.862                           |
| 06 May 2003 - 07 December 2006 | 1.365        | 0.118        | 0.754      | 0.872                           | 10.630                          |
| 08 December 2006 - 09 March 2007 | 0.969    | -0.211       | 1.177      | 0.966                           | 28.330                          |
| 10 March 2007 - 22 July 2009 | 0.736        | 0.094        | 0.872      | 0.966                           | 21.552                          |
| 23 July 2009 - 02 November 2010 | 3.850    | 0.260        | 0.223      | 0.483                           | 7.450                           |
| 03 November 2010 - 02 April 2012 | 5.351    | 0.184        | -0.181     | 0.002                           | 5.364                           |
| 03 April 2012 - 20 June 2014 | 0.049        | 0.057        | 0.933      | 0.989                           | 4.644                           |
| 21 June 2014 - 16 November 2016 | 0.362    | 0.034        | 0.808      | 0.842                           | 2.292                           |
| 16 November 2016 - 29 March 2019 | 0.127    | 0.101        | 0.833      | 0.935                           | 1.957                           |

### Volatility Breaks in PETRONET

**Date of commencement of Derivative trading:** 14-May-2007

| Date Range                | \( \omega \) | \( \alpha \) | \( \beta \) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------------------|--------------|--------------|------------|---------------------------------|---------------------------------|
| 13 March 2007 - 10 April 2007 | 1.942        | -0.050       | 0.589      | 0.540                           | 4.219                           |
| 11 April 2007 - 15 October 2009 | 0.982        | 0.093        | 0.831      | 0.923                           | 12.803                          |
| 16 October 2009 - 06 August 2010 | 0.384        | 0.004        | 0.935      | 0.940                           | 6.357                           |
| 07 August 2010 - 04 June 2013 | 3.145        | 0.198        | 0.007      | 0.205                           | 3.958                           |
| 05 June 2013 - 12 January 2017 | 3.275        | 0.150        | 0.600      | 0.750                           | 13.101                          |
| 13 January 2017 - 29 March 2019 | 7.650        | 0.306        | -0.082     | 0.224                           | 9.861                           |

### Volatility Breaks in POWERGRID

**Date of commencement of Derivative trading:** 05-October-2007

| Date Range                | \( \omega \) | \( \alpha \) | \( \beta \) | Total Persistence: \((\alpha+\beta)\) | Unconditional volatility: \(\omega/(1-\alpha-\beta)\) |
|---------------------------|--------------|--------------|------------|---------------------------------|---------------------------------|
| 05 October 2007 - 29 October 2008 | 0.333        | 0.116        | 0.856      | 0.971                           | 11.669                          |
| 30 October 2008 - 13 August 2009 | 11.142       | 0.241        | -0.171     | 0.070                           | 11.982                          |
| 14 August 2009 - 05 August 2011 | 1.133        | 0.134        | 0.460      | 0.594                           | 2.794                           |
| 06 August 2011 - 10 May 2012 | 0.168        | 0.041        | 0.921      | 0.961                           | 4.366                           |
| 11 May 2012 - 26 June 2013 | 0.021        | -0.041       | 1.030      | 0.988                           | 1.823                           |
| 27 June 2013 - 20 October 2014 | 0.808        | 0.027        | 0.692      | 0.719                           | 2.873                           |
| 21 October 2014 - 29 December 2017 | 1.048        | 0.151        | 0.232      | 0.383                           | 1.699                           |
| 30 December 2017 - 29 March 2019 | 0.363        | 0.047        | 0.799      | 0.846                           | 2.353                           |
### Volatility Breaks in TATAPOWER
Date of commencement of Derivative trading: 02-July-2001

| Date Range                  | ω   | α    | β    | Total Persistence: (α+β) | Unconditional volatility: ω/(1−α−β) |
|----------------------------|-----|------|------|--------------------------|------------------------------------|
| 05 January 2000_05 February 2001 | 0.602 | 0.241 | 0.724 | 0.965 | 17.222 |
| 06 February 2001_16 October 2001 | 1.111 | 0.386 | 0.474 | 0.860 | 7.939 |
| 17 October 2001_22 May 2003   | 0.501 | 0.306 | 0.484 | 0.791 | 2.393 |
| 23 May 2003_14 May 2004       | 1.487 | 0.145 | 0.448 | 0.593 | 3.656 |
| 15 May 2004_30 March 2006     | 0.548 | 0.028 | 0.770 | 0.798 | 2.712 |
| 31 March 2006_28 November 2008 | 0.352 | 0.103 | 0.855 | 0.958 | 8.337 |
| 29 November 2008_08 November 2010 | 0.036 | 0.045 | 0.941 | 0.985 | 2.477 |
| 09 November 2010_04 January 2012 | 3.047 | -0.064 | 0.090 | -0.055 | 2.889 |
| 05 January 2012_03 June 2014  | 0.032 | 0.039 | 0.948 | 0.986 | 2.355 |
| 04 June 2014_07 October 2015  | 0.598 | 0.024 | 0.521 | 0.545 | 1.314 |
| 08 October 2015_29 March 2019 | 0.407 | 0.057 | 0.461 | 0.517 | 0.843 |

### Volatility Breaks in TORNTPOWER
Date of commencement of Derivative trading: 30 December 2015

| Date Range                  | ω   | α    | β    | Total Persistence: (α+β) | Unconditional volatility: ω/(1−α−β) |
|----------------------------|-----|------|------|--------------------------|------------------------------------|
| 28 December 2012_07 June 2013 | 1.175 | 0.146 | 0.558 | 0.704 | 3.962 |
| 08 June 2013_20 November 2014 | 0.056 | 0.039 | 0.940 | 0.979 | 2.657 |
| 21 November 2014_24 January 2016 | 0.840 | 0.032 | 0.703 | 0.735 | 3.169 |
| 25 January 2016_31 January 2017 | 1.287 | -0.019 | 0.264 | 0.245 | 1.705 |
| 01 February 2017_29 March 2019 | 1.037 | 0.276 | 0.123 | 0.400 | 1.726 |