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Futures Trading, Spot Price Volatility and Structural Breaks: Evidence from Energy Sector

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ABSTRACT

The present study empirically examines the impact of Stock Futures on India's underlying Energy Sector Stocks by incorporating the Structural breaks in the AR (1)-GARCH (1, 1) model. Although the issues relating to the effect of Derivatives trading on Cash Market Volatility have been empirically discussed in two ways: by evaluating Cash Market Volatilities during the Pre-and Post-Derivatives trading periods and, secondly, by determining the influence of Derivatives trading on the conduct of Cash Markets by comparing it with proxies. Nevertheless, these methodologies cannot isolate the influence of derivatives trading from the effects of other market reforms on the volatility of the underlying Cash Market. The study offers mixed results for the select sample of Energy sector stocks. However, there is evidence of a reduction in unconditional volatility for most energy sector stocks. The study's findings suggest that trading in Stock Futures may not necessarily be associated with the destabilization of the underlying Energy sector Stocks.

Keywords: Stock Futures, Volatility Modelling, ICSS Test, AR (1)-GARCH (1, 1), Structural Breaks, Futures Trading, Energy Sector
JEL Classifications: G11, G14

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.

Issues relating to the effect of Derivatives trading on Cash Market Volatility have been empirically discussed in two ways: by evaluating Cash Market Volatilities during the Pre-and Post-Futures/Options trading periods and, secondly, by determining the influence of Options and Futures trading on the conduct of Cash Markets by comparing it with proxies. Furthermore, most of the 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." (Andreou 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), Brorsen (1991), Lee and Ohk (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). Gulen and Mayhew (2000) analyzed Index Futures' effect on international stock markets' volatility by using the GJR-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 $\varepsilon_t = y_t - u_t$ be the residual series. The squared series ϵ_t^2 is utilized to implement the LM test for checking conditional heteroscedasticity. Under the null hypothesis, we have:

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

Versus

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

In the Linear Regression

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

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 ε_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 > $\chi_\alpha^2(q)$ 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 through 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:

$$x_t = u_t + \sigma_t \in_t, \mathrm{E}\left[\in_t\right] = 0, \mathrm{E}\left[\in_t^2\right] = 1, \in_t \text{ i.i.d...},$$

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

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

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

Table 1: Unit root test (Augmented Dickey-Fuller test)

Stock	Spot		Futures		Stock	Spot		Futures	
	ADF at level	ADF at First Difference	ADF at level	ADF at First Difference		ADF at level	ADF at First Difference	ADF at level	ADF at First Difference
ADANIPOWER	−2.669 (−0.079)	−77.982 (−0.000)	−1.840 (−0.361)	−25.085 (−0.00)	NTPC	−1.903 (−0.330)	−252.62 (−0.000)	−1.840 (−0.361)	−251.08 (−0.000)
BPCL	−3.075 (−0.112)	−14.385 (−0.000)	−3.067 (−0.114)	−14.026 (−0.000)	OIL	−2.843 (−0.052)	−264.13 (−0.000)	−2.696 (−0.074)	−264.04 (−0.000)
GAIL	−2.496 (0.116)	(−240.73) (−0.000)	−420.76 (−0.000)	−420.76 (0.000)	ONGC	−1.793 (−0.389)	−435.00 (−0.000)	−1.887 (−0.333)	−297.51 (−0.000)
HINDPETRO	−1.471 (−0.548)	−305.75 (−0.000)	−1.505 (−0.531)	−189.26 (−0.000)	PETRONET	−1.436 (−0.565)	−169.53 (−0.000)	−1.450 (−0.558)	−218.42 (−0.000)
IGL	−1.476 (−0.546)	−296.19 (−0.000)	−1.189 (−0.681)	−186.67 (−0.000)	POWERGRID	−2.496 (0.116)	−240.73 (−0.000)	−420.76 (−0.000)	−420.76 (0.000)
IOC	−1.903 (−0.330)	−252.62 (−0.000)	−1.840 (−0.361)	−251.08 (−0.000)	TATAPOWER	−1.683 (−0.389)	−435.00 (−0.000)	−1.797 (−0.333)	−298.51 (−0.000)
MGL	−2.843 (−0.052)	−264.13 (−0.000)	−2.696 (−0.074)	−264.04 (−0.000)	TORNTPOWER	−1.803 (−0.320)	−242.62 (−0.000)	−1.740 (−0.351)	−241.08 (−0.000)

Note: ( ) denote *P* value

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.

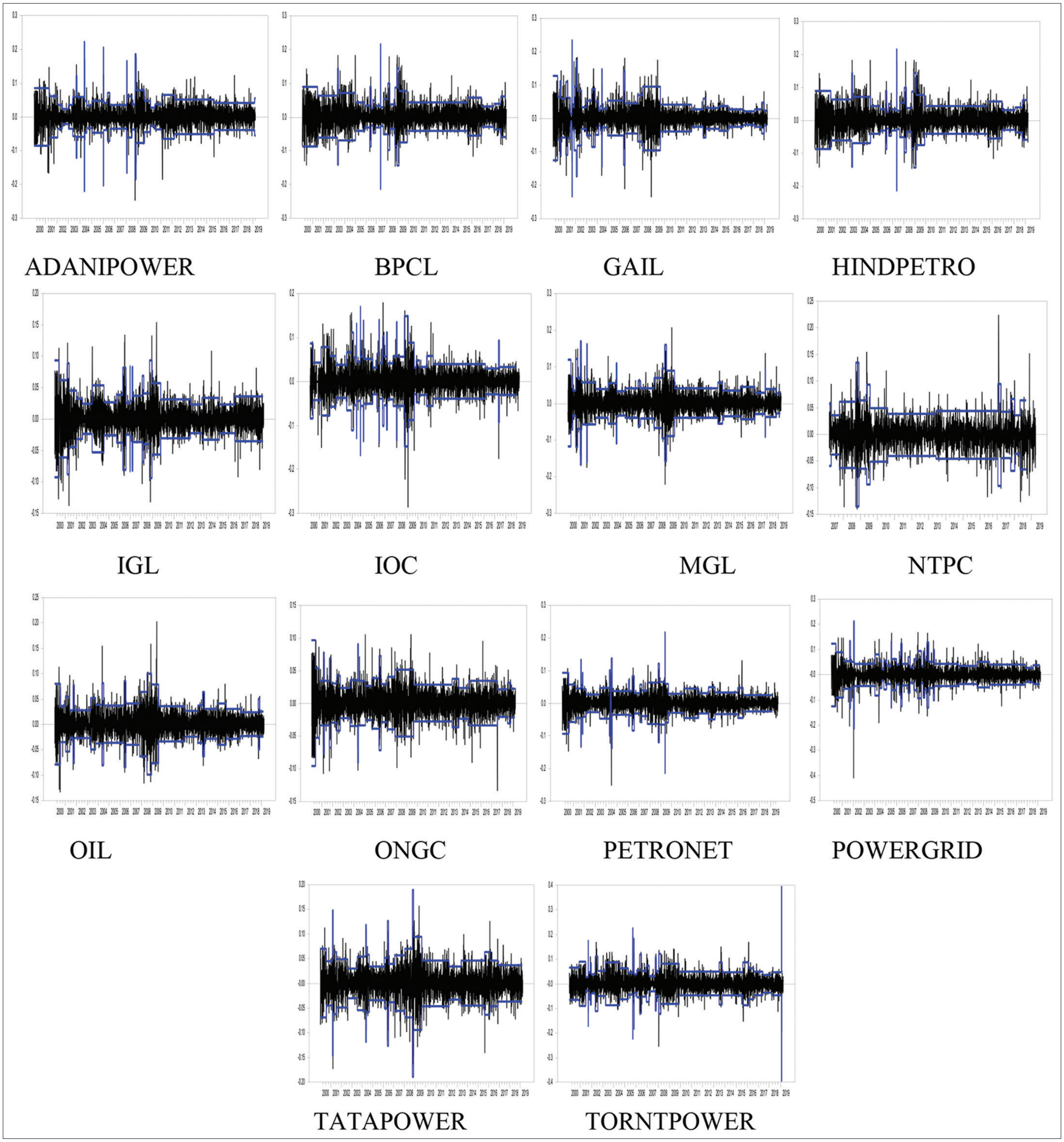
Table 2: Results of ARCH test

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	Impact on the volatility			
	This structural break caused by derivative trading	Direction of impact		
		Persistence	α	Unconditional volatility
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 No=03	Increased=04 Decreased=07	Increased=05 Decreased=06	Increased=03 Decreased=08

Figure 1: Multiple structural breaks (iterated cumulative sums of squares [ICSS]) algorithm of (Inclan and Tiao, 1994)



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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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	−0.019	0.264	0.245	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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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	0.960	8.348
14 March 2007_21 January 2008	0.720	0.038	0.748	0.786	3.368
22 January 2008_06 October 2009	1.128	0.096	0.776	0.872	8.822
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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	5.466
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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	0.713	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-10

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	ω	α	β	Total Persistence: (α+β)	Unconditional volatility: ω/(1−α−β)
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

	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	0.009	−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

	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