Asymmetric Response in Foreign Exchange Volatility under Structural Break

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Abstract

This paper considers the embedded dynamics of conditional volatility in five selected exchange rates vis-à-vis Indian Rupee. Specifically, it explores the possible asymmetric response of volatility towards good and bad news and inquires whether it is sensitive to breaks in volatility. Using a suitable GARCH family model no asymmetric response of volatility is found when structural breaks were ignored. However, once the breaks in volatility are incorporated, significant asymmetric volatility response and leverage effects could be detected in all five selected exchange rates. Leverage effects have been strong in the years following the currency crisis of 1997-98, for four out of the five exchange rates. The same phenomenon recurs during the recent recovery after the financial crisis of 2007-08. Thus, during recovery, with the shocks of crisis still in the mind of the investors, bad news tends to exert greater impact on volatility than the good ones.

JEL Classification Code: F31, G15, G01

Key words: Exchange rate dynamics, Structural breaks, asymmetric volatility response,

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I. INTRODUCTION

The embedded dynamics of conditional volatility in the returns of financial assets have long been a topic of discussion in financial economics. The origin of the discussion could be traced back to 1900, when Bachelier (1900) described volatility as "the coefficient of instability" or "nervousness" in his modeling of stock prices. Financial market volatility with its impact on the real economy and possible massive global effect calls for some serious policy prescription particularly for the developing countries.

Foreign exchange markets have turned much volatile since 1970 when majority of the countries shifted to floating exchange rate. This increased volatility is being claimed to have significant bearing on international trade, domestic operation and stock markets thereby affecting the economic stability. While Cushman (1986), Broll (1994) and Wolf (1995) argued that a volatile exchange rate is detrimental to trade, Qian and Varangis (1992) and Feenstra and Kendall (1991) conjectured an antithetical view. Adler and Dumas (1984) found exchange rate volatility to affect the domestic operation at the firm level. These effects, along with the changes in FDI have negative impacts on export, more so for the developing economies (Dooroodian, 1999; Siregar and Rajan, 2002; Arize et al, 2004; Baak, 2004; Égert and Morales-Zumaquero,2005). The link between foreign exchange volatility and stock market has been established by Bahmanee-Oskooee and Sohrabian (1992), Granger (2000), Mishra (2004), and Chakrabarti *et al* (2010). Exchange rate volatility is further shown to have a positive correlation with the degree of central bank's intervention and real domestic interest rate.

This paper, while exploring the issue of foreign exchange volatility in a developing country like India in recent years seeks to analyze its embedded dynamics in a greater detail. Any analysis of dynamics of financial market return should take into account not only the time varying nature of volatility but also the asymmetric response of volatility towards good and bad news. Volatility tends to increase more in response to bad news than the good ones of the same magnitude. In the presence of such leverage effect, foreign exchange market volatility will tend to magnify when there is a fear of financial crisis. It should be further emphasized that such leverage effect might be related to the changing nature of volatility in the foreign exchange market. During a period of high volatility, leverage effect might be stronger compared to that during a relatively stable period. This study thus focusing on Indian foreign exchange market, seeks to address two important questions: firstly, do leverage effects exist? And secondly, whether and how the nature of such leverage effects change with changing volatilities in the Indian foreign exchange market. In other words, are asymmetric responses of volatility sensitive to structural breaks?

II. METHODOLOGY

The study considers movements in Indian Rupee in terms of five other currencies over a period of January 1998 to April 2010. It considers developed country impacts through movements in US dollar and Euro against Indian Rupee. Regional impact on Indian rupee is considered by incorporating Chinese Yuan and Singapore Dollar. Latin American impacts will be captured by Brazilian Real.

The study considers returns for these five exchange rates. Return series are computed as: $R_t = \ln(e_t/e_{t-1})$, where e_t and e_{t-1} are exchange rates at time t and t-1 respectively. The trajectory of the analysis will be as follows:

Firstly the study will consider the whole return series without accounting for the structural breaks in volatility and estimate a suitable model to test for the presence of leverage effect. Secondly the study will look for the presence of structural breaks, if any, in volatility using suitable methods. Finally, once the break dates and sub-periods are identified, the study will inquire whether leverage effects are present in each of these sub-periods and the results will be compared.

II.A. MODEL TO DETECT PRESENCE OF LEVERAGE EFFECT

Any financial time series characterized by time varying nature of higher order moments, autocorrelated returns, volatility persistence, fat tails and non-normality could be best modeled by the Generalized Autoregressive Conditional Heteroscedasticity or GARCH School of models. The GARCH model introduced by Bollerslev (1986) includes past conditional variances in the variance equation.

II.A.1. GARCH MODEL:

The GARCH (*q,p*) model can be specified as -

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \, \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \, \sigma_{t-j}^2 \quad (1)$$

$$\text{or, } \sigma_t^2 = \omega + \alpha(L)\varepsilon_t^2 + \beta(L)\sigma_t^2 \quad (2)$$

Where L is the lag operator, q is the order of autoregressive GARCH terms and p is the order of moving average ARCH terms.

And the restrictions are, $p \geq 0$, $q > 0$; $\omega > 0, \alpha_i \geq 0, i = 1, \dots, q$ and $\beta_j \geq 0, j = 1, \dots, p$.
The conditional variance at period t (σ_t^2) is not only dependent on the squared errors from the previous period, but also on the past conditional variance.

GARCH models however have some limitations (Nelson, 1991). These models cannot capture leverage effects. Moreover, the non-negativity restriction of ω^* and ϕ_k rule out any random oscillatory movement restricting the dynamics of the conditional variance process. Further, the GARCH model cannot properly explain the volatility persistence, especially in the cases where a shock in the time series persists for a long time. For all these reasons, this study uses an asymmetric GARCH model.

II.A.2. ASYMMETRIC GARCH MODELS: EGARCH

Nelson (1991) first proposed an Exponential GARCH model that meets these limitations. The EGARCH(1,1) model can be specified as:

$$\log(\sigma_t^2) = \omega + \alpha\big(|z_{t-1}| - E(|z_{t-1}|)\big) + \gamma z_{t-1} + \beta \log(\sigma_{t-1}^2) \tag{3}$$

$$\text{where } \varepsilon_t = \sigma_{t-1} z_t \tag{4}$$

From (2.3) and (2.4), an EGARCH(q,p) model can be expressed as -

$$\log(\sigma_t^2) = \omega + \sum_{j=1}^{p} \beta_j \log\left(\sigma_{t-j}^2\right) + \sum_{i=1}^{q} \alpha_i \left|\frac{\varepsilon_{t-i}}{\sigma_{t-i}} - E\left(\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right)\right| + \sum_{k=1}^{r} \gamma_k \frac{\varepsilon_{t-k}}{\sigma_{t-k}} \tag{5}$$

The dependent variable is no longer the conditional variance. It is now the log of conditional variance. The EGARCH model overcomes the most important limitation of the GARCH model by incorporating the leverage effect. If $\alpha > 0$ and $\gamma = 0$, the innovation in $\log(\sigma_t^2)$ is positive (negative) when z_{t-1} is larger (smaller) than its expected value. And if $\alpha = 0$ and $\gamma < 0$, the innovation in $\log(\sigma_t^2)$ is positive (negative) when z_{t-1} is negative (positive). Moreover, the EGARCH process is that it contains no inequality constraint, and by parameterizing the

$\log(\sigma_t^2)$ can take negative value so there are fewer restrictions on the model. Lastly, the EGARCH process can capture volatility persistence quite effectively. $\log(\sigma_t^2)$ can easily be checked for volatility persistence by looking at the stationarity and ergodicity conditions.

II.A.3. ASYMMETRIC GARCH MODELS: TARCH

An alternative process for modeling the leverage effect was proposed independently by Glosten, Jagannathan and Runkle (1993) and Zakoian (1994). The Threshold ARCH or TARCH (also known as GJR-GARCH) is a modification of GARCH process with a threshold term included. The model is of the following form -

$$\sigma_t^2 = \omega + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{k=1}^{r} \gamma_k \varepsilon_{t-k}^2 I_{t-k} \qquad (6)$$

Where $$I_{t-k} = \begin{cases} 1 & if\ \varepsilon_{t-i} < 0 \\ 0 & if\ \varepsilon_{t-i} \geq 0 \end{cases}$$ I is the indicator function (7)

i.e. good news ($\varepsilon_{t-i} > 0$) and bad news ($\varepsilon_{t-i} < 0$) have asymmetric effect on the conditional variance. For a good news, i.e $\varepsilon_{t-i} > 0$, the impact on σ_t^2 is of magnitude $\alpha_i \varepsilon_{t-i}^2$. And for a bad news, i.e. $\varepsilon_{t-i} < 0$, the impact is of magnitude $(\alpha_i + \gamma_i)\varepsilon_{t-i}^2$. So for a positive γ_i, a bad news increases volatility and a leverage effect is said to exist. For $\gamma_i \neq 0$, the news impact is asymmetric.

Presence of leverage effects in the chosen return series will be tested by using a properly ordered model. The best fit model order will be chosen on the basis of the selection criteria available in the literature.

II.A.4. INFORMATION CRITERIA

Three information criterion, Akaike Information criteria or AIC (Akaike, 1973), Schwartz (Bayesian) Information Criterion or SIC (Schwartz, 1978) and Hannan-Quinn Criterion or HQC (Hannan-Quinn, 1979) are widely used to determine the appropriate order of the models and for selecting the proper model.

$$\text{AIC} = -2\left(\frac{l}{T}\right) + 2\left(\frac{k}{T}\right) \qquad (8)$$

$$\text{SIC} = -2\left(\frac{l}{T}\right) + k\frac{log(T)}{T} \qquad (9)$$

$$\text{HQC} = -2\left(\frac{l}{T}\right) + 2klog(\log(T))/T \qquad (10)$$

HQC is chosen for large samples (sample size > 500) and SIC for smaller samples (sample size < 500). This is based on the findings by Shittu and Asemota (2008) who showed that HQC performs better than SIC for large samples.

The residuals will be tested for the possible presence of remaining ARCH effects to judge the efficacy of the fitted model in capturing conditional heteroscedasticity properly. To test for ARCH-LM effect in the residual, an LM test is used where the squared residuals are regressed on a constant and lagged squared residuals upto lag q.

$$e_t^2 = \beta_0 + \left(\sum_{s=1}^{q} \beta_s e_{t-s}^2\right) + v_t \tag{11}$$

Under the null hypothesis of no additional ARCH effect, the LM test statistic $LM = TR^2$ asymptotically follows a $\chi^2(q)$distribution. T being the sample size and $R^2$is calculated from the regression.

II.B. DETECTION OF STRUCTURAL BREAK

Structural breaks or the persistent and pronounced macroeconomic shifts in the data generating process are one of the most common properties of an economic time series. Longer the period under consideration, higher is the probability of observing structural breaks. Let us consider a simple AR(1) process.

$$y_t = \alpha + \rho y_{t-1} + \varepsilon_t \tag{12}$$

$$E\varepsilon_t^2 = \sigma^2 \tag{13}$$

where ε_t is a time series of serially uncorrelated shocks. For a stationary series, the parameters α, ρ and σ^2 are time invariant. A structural break occurs if at least one of the parameters changes permanently at some point (Hansen, 2001). The date the parameter changes value is known as the "break date" and the breaks are irreversible in nature (Brooks, 2002). The reasons behind occurrence of structural breaks' are manifold. Economic policies, for example change in exchange rate sub-period, change in interest rate, monetary policy shifts or trade policies may cause structural breaks to occur. These are one-off shifts, as opposed to shifts caused by business cycles. Economic events like bursting of asset price bubble, development in the stock market and even shifts in required risk premium also lead up to structural breaks. There may also be some unidentifiable reasons that cause breaks in return or volatility (Valentinyi- Endrész ; 2004). Ignoring the presence of structural breaks in the data set when there are some may lead to imperfect forecast, spurious non-rejection of the unit root (Perron,1989; Rappoport and Reichlin, 1989; Nelson and Plosser, 1982; and Zivot and Andrews, 1992), exaggeration of volatility persistence in ARCH and GARCH models (Diebold,1986; Lamoureux and Lastrapes, 1990; Pesaran and Timmerman 1999; Hwang and Pereira, 2008; and Hwang and Chu, 2004) and mimicry of long memory while there is actually none (Lobato and Savin, 1998; Mikosch and Stărică, 2004 ; Granger and Hyung, 2004; and Diebold and Inoue, 2001).

Now the study will test for the presence of structural break in the Indian foreign exchange market over the chosen period and the breakpoints, if any will be identified. Finally the data will be modeled around those breaks. The best way to do that is to perform the tests to the subsamples where regression parameters are constant (Kim and Maddala, 1991). As the study focuses on the conditional variance or volatility in the foreign exchange market, it will solely consider breaks or shifts in volatility. Shifts in mean although is widely discussed in a number of studies is left out as it lies outside the scope of this work.

II.B.1. IDENTIFICATION OF MULTIPLE STRUCTURAL BREAKS IN VARIANCE: THE ICSS TEST

The Iterative Cumulative Sum of Squares or simply the ICSS algorithm by Inclan and Tiao (1994) is used to detect sudden and multiple shifts in unconditional variance for a stochastic process. The algorithm is based on the premise that the time series displays a stationary variance over an initial period which is changed due to a shock to the system and again continues to be stationary till it experiences another shock in the future. This process is repeated over time till all the breakpoints are identified. The ICSS test is built to capture the breakpoint.

II.B.1.1. THE ORIGINAL MODEL BY INCLAN AND TIAO: BREAKS IN UNCONDITIONAL VARIANCE

Let $C_k = \sum_{t=1}^{k} a_t^2$, k = 1,2, …T, be the cumulative sum of squares for a series of independent observations $\{a_t\}$, with $a_t \sim iidN(0,\sigma^2)$ and t=1,2,…,T and $\sigma^2$is the unconditional variance.

$$\sigma^2 = \begin{cases} \tau_0, \ 1 < t < \kappa_1 \\ \tau_1, \ \kappa_1 < t < \kappa_2 \\ \dots \\ \tau_{N_T}, \ \kappa_{N_T} < t < T \end{cases} \tag{14}$$

Where $1 < \kappa_1 < \kappa_2 <\ldots< \kappa_{N_T} < T$ are the points where the breaks in variances occur, i.e. the breakpoints. And N_T is the total number of such changes for T observations. Within each interval, the variance is $\tau_j^2,\ \ j = 0,1,\ldots,N_T$

And let the centralized or normalized cumulative sum of squares be D_k

$$D_k \text{ is defined as } D_k = \frac{C_k}{C_T} - \frac{k}{T} \qquad D_0 = D_T = 0 \tag{15}$$

where C_T is the sum of squared residuals for the whole sample period. If the variance doesn't change within the sample period, i.e. with no volatility shift, D_k will oscillate around zero, i.e., if D_k is plotted against k, it will be a straight line. It will drift upward or downward when there is a change in the variance and it will exhibit a pattern going out of some specified boundaries (provided by a critical value based on the distribution of D_k) with high probability. If at some k, say k*, the maximum absolute value of D_k , given by $\max_k\left|\sqrt{T/2D_k}\right|$ exceeds the critical value, the null hypothesis of constant variance is rejected and k* will be regarded as an estimate of the change point. Under variance homogeneity, $\sqrt{T/2D_k}$ behaves like a Brownian bridge asymptotically.

For multiple breakpoints however, the usefulness of the D_k function is questionable due to "masking effect". To avoid this, Inclan and Tiao designed the following iterative algorithm that uses successive application of the D_k function at different points in the time series to look for possible shift in volatility.

II.B.1.2. MODIFIED ICSS TEST: BREAKS IN CONDITIONALVARIANCE

Sansó, Aragó and Carríon (2004) found significant size distortions for the ICSS test when the process is non-mesocartic and conditional heteroscedasticity is present. This leads to spurious results for the unconditional variance hence making the original ICSS test of little use in financial time series which is often characterized by fat tails and conditional heteroscedasticity. To correct this, they incorporated two new tests that explicitly consider the fourth moment properties of the disturbances and the conditional heteroscedasticity.

The first test, also known as the $\kappa_1$test makes the asymptotic distribution free of nuisance parameters for *iid* zero mean random variables.

$$\kappa_1 = \sup_k\left|T^{-1/2}B_k\right|, \qquad k=1,\ldots,T \tag{16}$$

Where $B_k = \frac{C_k - \frac{k}{T}C_T}{\sqrt{\hat{\eta}_4 - \hat{\sigma}^4}}$, while $\hat{\eta}_4 = T^{-1}\sum_{t=1}^{T}\varepsilon_t^4$ and $\hat{\sigma}^4 = T^{-1}C_T$, This statistic is free of any nuisance parameter. And the second test, the κ_2 test is able to address the issues of fat tails and persistent volatility.

$$\kappa_2 = \sup_k \left|T^{-1/2}G_k\right| \tag{17}$$

Where $G_k = \hat{\omega}_4^{-\frac{1}{2}}(C_k - \frac{k}{T}C_T)$, $\hat{\omega}_4$ is a consistent estimator of ω_4. A nonparametric estimator of ω_4 can be expressed as -

$$\hat{\omega}_4 = \frac{1}{T}\sum_{l=1}^{T}(\varepsilon_t^2 - \hat{\sigma}^2)^2 + \frac{2}{T}\sum_{l=1}^{m}\omega(l,m)\sum_{t=1}^{T}(\varepsilon_t^2 - \hat{\sigma}^2)\,(\varepsilon_{t-1}^2 - \hat{\sigma}^2) \tag{18}$$

Where $\omega(l,m)$ is a lag window, such as Bartlett and defined as $\omega(l,m)$ = [1-*l*/(*m*+1)]. The bandwidth *m* is chosen using Newey-West (1994) technique.

As it incorporates the fat tail and conditional variance, the κ_2 test is more powerful than the original Incaln-Tiao test or even the $\kappa_1$test. Kokoszka and Leipus (2000) proposed a similar test but they assume an ARCH(∞) type model. But the κ_2 test employs a more general framework and hence a better suited model for our purpose.

In our study, once the breakpoints are identified, the inquiry for the presence of asymmetric response will be carried out in each of the sub periods individually.

III. RESULTS

III.A. RESULTS WITHOUT CONSIDERING STRUCTURAL BREAK

III.A.1. DESCRIPTIVE STATISTICS FOR THE FOREIGN EXCHANGE MARKET

The descriptive statistics for the five exchange rate return series are given in table 1 below.

[INSERT TABLE 1 HERE]

The measure of skewness shows that four of the five series are negatively skewed, i.e. with longer left tails. All the five series are leptokurtic as it is greater than 3 in all of them. And finally, the Jarque-Bera test statistic suggests that all the nine series are non-normal in nature. Hence, the series could be best modeled by models of the GARCH family.

III.A.2. TESTING FOR THE PRESENCE OF UNIT ROOT:

Table 2 shows the results from the Augmented Dickey-Fuller and the Phillips-Perron tests. No evidence of unit root is found in the daily returns. All return series are stationary.

[INSERT TABLE 2 HERE]

III.A.3. RESULTS FROM APPLYING EGARCH MODEL

The results from applying EGARCH model are summarized in Table 3.

[INSERT TABLE 3 HERE]

Asymmetry and leverage effect do not exist for the five selected exchange rate return series. The coefficient of the asymmetric component is insignificant in the best fit EGARCH model for the Rs-Dollar, Rs-Euro, Rs-Yuan, Rs-Singapore dollar, and Rs-Real series.

The ARCH-LM test is run to check for any possible presence of ARCH effect in the residuals. As the result suggests (table 4), no significant ARCH-LM effect is present in the residual.

[INSERT TABLE 4 HERE]

III.B. IDENTIFICATION OF BREAK DATES

Using the modified ICSS test, the break dates are identified. The dates associated with each break for each exchange rate are provided in table 5. Results from only κ_2 test are considered because of its ability to model conditional volatility and volatility persistence.

[INSERT TABLE 5 HERE]

As it can be seen from the table, each return series is characterized by multiple breaks in volatility. The breakpoints are identified as vertical straight lines in the figures. The Rs/US Dollar and Rs/Singapore Dollar has five breaks each. Rs/Real has four. Rs/Yuan has six breaks while Rs/Euro has eight breaks. Rs/USD, Rs/Yuan and Rs/Singapore$ had a break in volatility in 1998. All but Rs/USD experienced a volatility break in 2003. However, only Rs/Real and Rs/Singapore $ had no break in volatility during 2004. The period from June 2004 to January 2008 was almost free from any break in volatility. The only exception has been Rs/Euro series that showed a break in 2005. All the five return series had breaks during the financial crisis period of 2008-2009. Within this short span of time, Rs/USD, Rs/Real and Rs/Singapore $ had two breaks, while Rs/Euro and Rs/Yuan had three breaks each.

Once the break dates are identified, the sub-periods are constructed between two break dates. The further analysis takes each sub-period individually and explores the presence of asymmetric response of volatility within it.

III.C. VOLATILITY BREAKS AND ASYMMETRIC RESPONSE OF VOLATILITY

III.C.1. RS/US DOLLAR EXCHANGE RATE

All the sub-periods except the third, shows presence of asymmetric response of volatility in the system. Of these five sub-periods EGARCH is the best-fit for sub-periods 1, 2 and 5, while for sub-period 4, TARCH is the suitable model. Leverage effect exists, however, for the first, second and the fourth sub-period. Figure 1 depicts the conditional variance of the return series with the corresponding breaks.

[INSERT FIGURE 1 HERE] [INSERT TABLE 6 HERE]

The first sub-period ranging from January 1998 to August 24, 1998 is characterized by a low, falling conditional variance. The second sub-period ranging from August 25, 1998 to March 22, 2004 is characterized by very low volatility. The third sub-period from March 23, 2004 to September 8, 2008 showed slightly more volatility. However, conditional volatility increased significantly during the fourth sub-period ranging from September 9, 2008 to May 19, 2009. Volatility has fallen over the fifth sub-period that commenced from May 20, 2009. Hence, the periods of sharper volatility and low volatility are characterized by asymmetric response of volatility towards good and bad news.

III.C.2. RS/EURO EXCHANGE RATE

Figure 2 depicts the conditional variance in Rs/Euro exchange rate return series.

[INSERT FIGURE 2 HERE] [INSERT TABLE 7 HERE]

Over the first sub-period that ended on January 27, 2000 volatility increased. The second sub-period that ranged from January 28, 2000 to April 28, 2001 was characterized by relatively higher and increasing volatility. During the period of April 29, 2001 to May 6, 2003 volatility decreased in the first half. The next three sub-periods were characterized by a falling conditional variance. Volatility increased sharply in the eighth sub-period. Asymmetry is present in sub-periods 1, 3, 4, 5, 6 and 8 where conditional volatilities are relatively lower. Of these sub-periods, sub-period 1 is explained by TARCH while for the other sub-periods, EGARCH is the best fit. Leverage effect is present in sub-periods 3, 4, 5, and 6.

III.C.3. RS/REAL EXCHANGE RATE

Figure 3 shows the conditional variance in Rs/Real exchange rate return series. Sub-periods 1, 2, 3 and 5 show discernible level of asymmetry and leverage effect. EGARCH is the best fit model for sub-periods 1, 2 and 5 while TARCH is the best fit for sub-period 3. Asymmetric responses are present at phases of sharp as well as lower volatility.

[INSERT FIGURE 3 HERE] [INSERT TABLE 8 HERE]

III.C.4. RS/YUAN EXCHANGE RATE

Sub-periods 1, 2, 5, 6 and 7 shows significant asymmetry, all of these five sub-periods are explained by EGARCH model, of which sub-periods 1 and 5 show discernible amount of leverage effect (in sub-period 1, leverage effect is present only in the second asymmetric order). Where as sub-periods 1 and 2 show relatively lower volatility, sub-periods 5, 6 and 7 are characterized by sharper volatility. Like the Rs/USD exchange rate returns, Rs/Yuan exchange rate return series show asymmetric response to volatility at sharper and lower volatility levels.

[INSERT FIGURE 4 HERE] [INSERT TABLE 9 HERE]

III.C.5. RS/SINGAPORE DOLLAR EXCHANGE RATE

Sub-periods 1 and 5 are characterized by sharper volatility. Sub-periods 2, 3, 4 and 6 shows significant asymmetry. For sub-periods 2, 3 and 6 EGARCH is the best fit model while for sub-period 4, TARCH is the best fit. Leverage effect is present in sub-periods 2, 3 and 4. Asymmetric response is present at relatively lower levels of volatility.

[INSERT FIGURE 5 HERE]   [INSERT TABLE 10 HERE]

IV. CONCLUSION

From the analysis, a couple of interesting characteristics of the series can be drawn attention to. Firstly, when the exchange rate series as a whole were considered ignoring the structural breaks, the study found no trace of asymmetry in the five exchange rate return series. The results, however, change significantly once the breaks in volatility are introduced. The study period covers the aftermath of the currency crisis of 1997-98, the financial crisis of 2007-08 and the recent recovery. Once these considerations are brought into account, all the series show presence of significant asymmetric response of volatility towards good and bad news. Moreover, asymmetric responses exist at relatively lower levels of volatility for the Rs/Euro and Rs/Singapore Dollar exchange rate series. For the remaining three, asymmetric responses are found at sharper as well as lower levels of volatility. Hence, the extreme volatility situations are characterized by asymmetric responses. Moreover, leverage effects have been strong during 1998-99, the period following the crisis of 1997-98. This is particularly true for the Rs/Real, Rs/Yuan, Rs/USD and Rs/Singapore dollar exchange rates. The same phenomenon is found to recur at least for the first three rates during the recent years, in the aftermath of the financial crisis of 2007-08. Thus, leverage effect exists particularly after a financial crisis. With the shocks of crisis still in the mind of the investors, bad news tends to have relatively greater impact on volatility than the good ones. However, quite surprisingly, leverage effect does not exist for the Rs/Euro exchange rate in the recent post-crisis years.

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TABLES:

Table 1: Descriptive statistics for exchange rate return series (without structural breaks)

	RS/USD	RS/EURO	RS/REAL	RS/YUAN	RS/SING. $
Mean	0.000	0.000	0.000	0.000	0.000
Std. Dev.	0.001	0.002	0.005	0.001	0.002
Skewness	-0.165	0.055	-0.728	-0.082	-0.060
Kurtosis	22.813	5.854	18.565	22.438	15.364
Jarque-Bera	73659.4	1411.9	45845.7	70878.6	28676.2
Probability	0.000	0.000	0.000	0.000	0.000

Table 2: Unit root tests for exchange rate return series (without structural breaks)

	RS/USD	RS/Euro	RS/Real	RS/Yuan	RS/Sing. $
ADF test	-32.20*	-30.16*	-33.74*	-32.09*	-32.57*
Phillips Perron	-64.13*	-30.16*	-33.74*	-32.09*	-32.57*

* denotes significance at 1% level

Table 3. EGARCH result (Without Structural breaks)

EXCHANGE RATE	Variable	Coeff.	Prob.
RS/USD	C(6)	0.028	0.365
RS/REAL	C(8)	-0.022	0.139
RS/YUAN	C(7)	0.018	0.471
RS/SINGAPORE $	C(12)	0.000	0.999
RS/EURO	C(4)	-0.015	0.274

Table 4: Results of ARCH-LM Tests for Exchange Rate Return Series (Without Structural Breaks)

		Rs/USD	Rs/Euro	Rs/Sing $	Rs/Yuan	Rs/Real
Lag 1	F-statistic	0.000	0.281	0.374	1.541	0.002
	Obs*R^2	0.000	0.281	0.374	1.542	0.002
Lag 2	F-statistic	0.101	0.436	2.281	1.238	2.163

	Obs*R^2	0.203	0.872	4.560	2.475	4.324
Lag 3	F-statistic	0.087	0.408	1.661	0.827	1.443
	Obs*R^2	0.261	1.223	4.980	2.482	4.327
Lag 4	F-statistic	0.330	1.017	1.247	0.718	1.146
	Obs*R^2	1.321	4.069	4.990	2.872	4.583
Lag 5	F-statistic	0.270	1.481	1.511	0.649	0.919
	Obs*R^2	1.350	7.400	7.552	3.247	4.595

* (**) denotes significance at 1 (5) % level

Table 5: Break dates for the exchange rate return series

Year	RS/USD	RS/EURO	RS/REAL	RS/YUAN	RS/SING.$
1998	24/08/98			24/08/98	26/06/98
					10/12/1998
1999				16/07/99	
2000		27/01/00			
2001		28/04/01	6/11/2001		
2002					
2003		6/5/2003	31/05/03		12/3/2003
2004	22/03/04	25/06/04		22/03/04	
2005		11/11/2005			
2006					
2007					
2008	8/9/2008	19/02/08	17/09/08	20/09/08	23/07/08
		12/9/2008		14/11/08	
2009	19/05/09	20/05/09	7/1/2009	7/6/2009	20/05/09

Table 6. Result of GARCH/EGARCH/TARCH for the Rs/USD Return Series (with structural breaks)

	Variable	Coeff.	Prob.		Variable	Coeff.	Prob.
	REGIME1				**REGIME 2**		
EGARCH	C(6)	0.195	0.022	***EGARCH***	C(7)	0.08	0
	C(7)	0.817	0		Hannan-Quinn criter.	-12.661	
	Schwarz criterion	-10.5033			**REGIME 4**		
	REGIME 3			***TARCH***	RESID(-1)^2*(RESID(-1)<0)	-0.018	0
GARCH	RESID(-1)^2	0.139	0		Schwarz criterion	-8.253	
	GARCH(-1)	0.314	0.182				
	GARCH(-2)	0.014	0.953				
	GARCH(-3)	0.441	0.018				
	REGIME 5						
EGARCH	C(5)	-0.062	0.002				
	Schwarz criterion	-9.377					

Table 7. Result of GARCH/EGARCH/TARCH for the Rs/Euro Return Series (with structural breaks)

	Variable	Coeff.	Prob.		Variable	Coeff.	Prob.
	REGIME 1				**REGIME 2**		
TARCH	RESID(-1)^2*(RESID(-1)<0)	-0.11	0.004	***GARCH***	RESID(-1)^2	0.139	0.003
	Schwarz criterion	-9.566			RESID(-2)^2	-0.132	0
	REGIME 3				GARCH(-1)	0.435	0
EGARCH	C(8)	-0.047	0.001		**REGIME 4**		
	Hannan-Quinn criter.	-9.613		***EGARCH***	C(10)	-0.168	0
	REGIME 5				Schwarz criterion	-9.158	
EGARCH	C(4)	-0.229	0.001		**REGIME 6**		
	Hannan-Quinn criter.	-9.546		***EGARCH***	C(8)	-0.059	0.002
	REGIME 7				Hannan-Quinn criter.	-10.167	
GARCH	RESID(-1)^2	0.08	0.26		**REGIME 8**		
	GARCH(-1)	-0.113	0.866	***EGARCH***	C(6)	0.244	0
	REGIME 9				Schwarz criterion	-8.102	
GARCH	RESID(-1)^2	0.059	0				

	GARCH(-1)	0.997	0
	GARCH(-2)	-0.924	0

Table 8. Result of GARCH/EGARCH/TARCH for the Rs/Real Return Series (with structural breaks)

	Variable	Coeff.	Prob.		Variable	Coeff.	Prob.
	REGIME 1				**REGIME 4**		
EGARCH	C(5)	-0.098	0.002	***GARCH***	RESID(-1)^2	0.206	0.101
	Hannan-Quinn criter.	-8.994			GARCH(-1)	0.715	0
	REGIME 2				**REGIME 5**		
EGARCH	C(8)	-0.068	0.077	***EGARCH***	C(5)	0.029	0.039
	Hannan-Quinn criter.	-8.113			C(6)	-0.14	0
	REGIME 3				Schwarz criterion	-7.893	
TARCH	RESID(-1)^2*(RESID(-1)<0)	0.135	0.021				
	Hannan-Quinn criter.	-9.043					

Table 9. Result of GARCH/EGARCH/TARCH for the Rs/Yuan Return Series (with structural breaks)

	Variable	Coeff.	Prob.		Variable	Coeff.	Prob.
	REGIME 1				**REGIME 2**		
EGARCH	C(6)	0.250	0.000	***EGARCH***	C(5)	0.555	0.000
	C(7)	-0.132	0.000		Schwarz criterion	-12.497	
	Schwarz criterion	-10.453			**REGIME 4**		
	REGIME 3			***GARCH***	RESID(-1)^2	0.199	0.002
GARCH	RESID(-1)^2	0.063	0.002		RESID(-2)^2	-0.001	0.979
	GARCH(-1)	0.002	0.953		RESID(-3)^2	0.031	0.344
	GARCH(-2)	0.909	0.000		GARCH(-1)	0.293	0.001
	REGIME 5				GARCH(-2)	-0.257	0.005
EGARCH	C(3)	-0.343	0.000		GARCH(-3)	0.607	0.000
	Schwarz criterion	-7.551			**REGIME 6**		
	REGIME 7			***EGARCH***	C(6)	0.088	0.050
EGARCH	C(5)	0.069	0.075		Schwarz criterion	-8.531	
	C(6)	0.059	0.059				
	Schwarz criterion	-9.322					

Table 10. Result of GARCH/EGARCH/TARCH for the Rs/Singapore Dollar Return Series (with structural breaks)

	Variable	Coeff.	Prob.		Variable	Coeff.	Prob.
	REGIME 1				**REGIME 2**		
GARCH	RESID(-1)^2	0.528	0.000	***EGARCH***	C(5)	-0.084	0.072
	GARCH(-1)	0.862	0.000		**REGIME 4**		
	GARCH(-2)	-0.646	0.000	***TARCH***	RESID(-1)^2*(RESID(-1)<0)	0.006	0.055
	GARCH(-3)	0.380	0.000		Hannan-Quinn criter.	-10.628	
	REGIME 3				**REGIME 6**		
EGARCH	C(8)	-0.023	0.065	***EGARCH***	C(4)	0.024	0.011
	Hannan-Quinn	-11.168			Schwarz criterion	-9.739	
	REGIME 5						
GARCH	RESID(-1)^2	0.068	0.067				
	RESID(-2)^2	0.024	0.557				
	RESID(-3)^2	0.144	0.000				
	GARCH(-1)	0.541	0.000				
	GARCH(-2)	-0.667	0.000				
	GARCH(-3)	0.749	0.000				

FIGURES

Figure 1: Conditional Variance in Rs/US Dollar with breaks

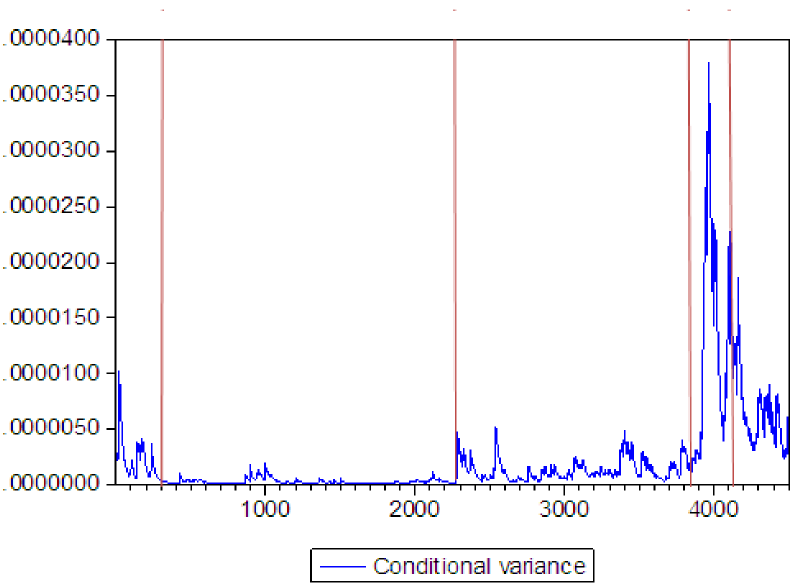

Figure 2: Conditional Variance in Rs/Euro with breaks

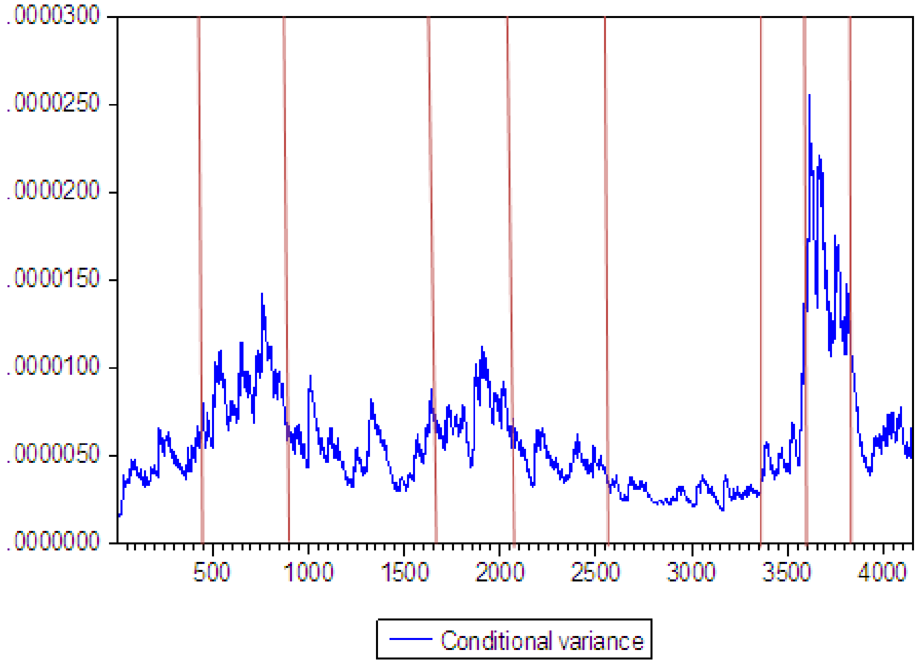

Figure 3: Conditional Variance in Rs/Real exchange rate return with breaks

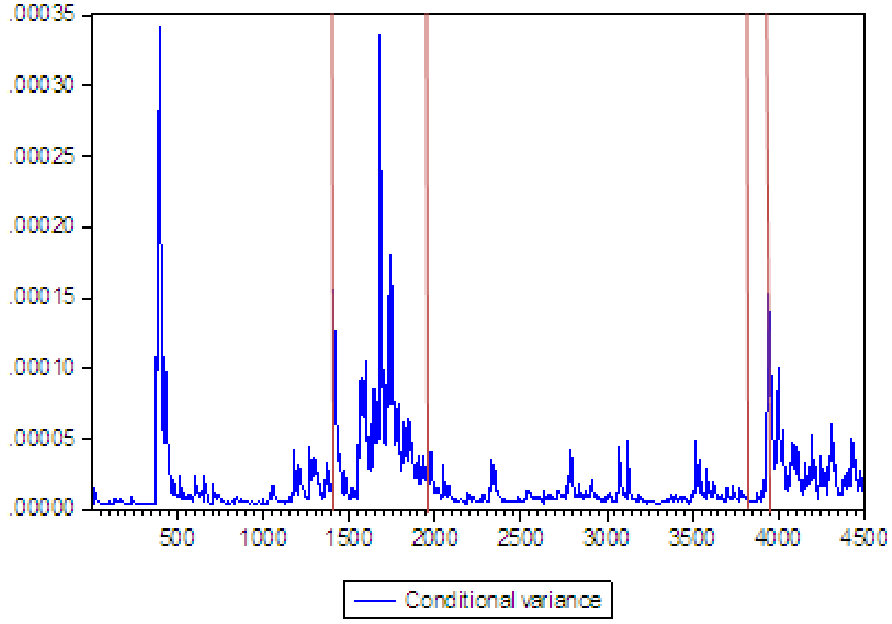

Figure 4: Conditional Variance in Rs/Yuan exchange rate return with breaks

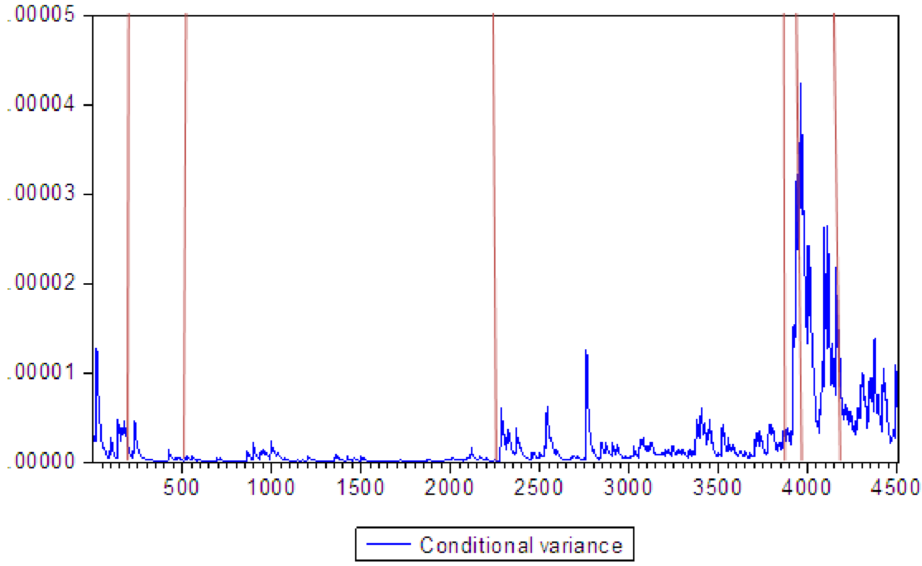

Figure 5: Conditional Variance in Rs/Singapore $ with breaks