AN EMPIRICAL ANALYSIS OF STOCHASTIC BEHAVIUR OF SIR LANKA EXCHANGE RATE CHANGES

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Abstract

The main purpose of this study was to explore the main characteristics of stochastic behaviour of Sri Lankan exchange rate aginst to US dollar,(LKR/US$). This study used daily spot exchange rate time series collected from Central Bank, Sri Lanka web site. The study covers the time period from 2008 to 2010, which represents 722 trading days. The sample period was divided into two. One period was from January 1, 2008 to May 19, 2009 and the other period from May 30, 2009 to December 31, 2010. Graphical techniques, Kernel density function, autocorrelation function, and GARCH models were used to analyse the behaviour of the exchange rate in this study. The results show that basic statistical properties of Sri Lankan exchange rate series was a nonlinear, asymetric shape ,nonstationary series with stochastic trend, I(1). The change in the logarithm of the daily exchange rate (Exchange rate return) series has fatter tails, serial dependence, volatility clustering and ARCH effects in both sample periods. During the period I, the exchange rate was depreciating, distribution was positively skewed , larger volatility (SD=3.4) , non normal and nonstationary. During the period II, exchange rate was appreciating, high persistent and skewed negatively. The changes of log exchange rate behave as normal with an autoregressive conditional heteroscedasticity process for innovations. The characteristics of the exchange rate changes indicates the presence of heterogeneity among market participants as well as changing parameters over time. Standard deviation of this distribution dominates the mean value. variance was also time varying. The results of this study has important implications for exchange rate determination, balance of payments, risk modeling and management, forecasting, market efficiency, statistical inference in empirical work and for the economy, as whole.

*Keywords***:** *Exchange rate return, fatter tails, volatility, confidence coefficient, GARCH*

Introduction

In today's complex and interdependent business world, exchange rate movements have a significant impact on the world's political and economic stability as well as on the welfare of individual countries. Exchange rate data themselves are quite informative. Basic understanding of the statistical properties of stochastic behavior of exchange rates is important because it forms the basis for discussion and analysis of other pertinent issues involving exchange rates. In particular, the empirical behavior of exchange rates is important for various reasons. First, the time series behavior of exchange rates has implications for the questions of market efficiency that has received far more attention in the financial literature. Second, the distributional property of exchange rates in part determines the riskiness of the foreign exchange market and the validity of statistical

inference in empirical work. Third, the statistical behavior of exchange rates provides insight into the nature of the process governing exchange rate determination. Further, exchange rate movements are important factors affecting sales and profit forecasts, capital budgeting plans, and the value of international investments and stock markets. Therefore, knowledge of the statistical properties of the distribution of daily exchange rate changes has important economic applications on international trade, balance of payments and capital flows, mean–variance analysis of international asset portfolios, and the pricing of options on foreign currencies.

Given the small, open and import dependent nature of the Sri Lankan economy, the exchange rate is probably the most important asset price. It has been an important element in the monetary transmission process in Sri Lanka. Movement in this price has a significant effect on consumer prices. Again this background, good understanding of stochastic properties of the behavior of Rupee-US dollar exchange rate changes is important in many aspects. Therefore, an in-depth empirical analysis of exchange rate behavior might also provide useful implications for the direction of future research.

Exchange rates have been the subject of numerous research papers. Several papers have been published dealing with exchange rates mainly focusing on economic aspects, in particular of developed countries. Sri Lankan exchange rate has not received much attention in the finance literature. Very few studies have

attempted to study the exchange rates. However, their focus has been mainly on economic aspects. However, there exists no in-depth technical analysis on statistical properties and stochastic behavior of the Sri Lankan exchange rate changes. This study intends to fill this gap in the finance literature and provide an in-depth analysis. Results of this study provide relevant implications for investors and policy makers. Therefore, a thorough understanding of the stochastic properties of Sri Lankan exchange rate will enable to manage their exchange rate policy.

The main objective of this study is to explore and explain the statistical properties of the stochastic behavior of the changes in logarithms of exchange rates of LKR/US$. Goal of this study is to 'let the data speak for themselves' as much as possible.

The specific objectives are

i. to estimate and describe the stylized facts of exchange rate changes (stochastic properties of exchange rate returns) in order to obtain insights into their dynamic patterns

ii. to introduce the reader to some new insights provided by methods based on new econometric techniques.

iii. to study how conditional expectation and conditional variance of exchange rate evolve over time

iv. to uncover the underlying patterns of exchange rate changes using non-standard techniques

Understanding the statistical properties of the exchange rate behavior has important practical implications. The main contributions of this study are: First, this study accommodates recent theoretical and empirical developments in the analysis that are important to our understanding of the nature of exchange rate behavior. Second, by examining statistical properties of Sri Lankan exchange rate changes, we hope to complement the existing literature on this issue since empirical work on this issue related to Sri Lanka is still lacking. This study differs in several aspects from other studies. This study focuses only Sri Lankan and US Dollar exchange rate. Sample period considered is only from 2008 to 2010. This study captures in a systematic and meaningful fashion the information and properties contained in the daily exchange rate data. These findings may help for further work on appropriate distribution of the exchange rate distribution and estimates of the parameters.

Literature Review:

Mandelbrot (1963), Fama(1965) find that the empirical distribution of price changes of financial asstets is leptokurtic when compared to the normal distribution. Mandelbrot(1967) and Fielitz (1971) provide evidence rejecting the assumptions of homoskedasticity and independence over time.

Baillie and Bollerslev (1989) find that short run exchange rate changes of major European currencies behave as Martingale process with leptokurtic distributions and conditionally heteroskedasticitic errors. Bollerslev (1987),

Hsieh (1988) and Akgiray and Booth (1900), among others, report similar findings for other major currencies. Boothe Paul and D.Glassman (1987) have shown that changes in logarithms of exchange rates have non-normal distributions for daily, weekly and possible monthly data. The scale mixtures of distributions best describe the daily data. The issue of time varying parameters were not examined.

Methodology

The data set consists of daily nominal spot exchange rates between the US dollar and Sri Lankan rupee, LKR/US $ exchange rate. Let ER_t be the spot exchange rate, expressed in domestic currency price of one unit of a foreign currency at time, t (hence forth referred to as the level form). An increase in ER_t means a depreciation of the domestic currency. Let $e_t = \ln(R_t)$. The raw exchange rates were transformed into log returns, r_t, which can be interpreted as a series of continuously compounded daily returns (Brook et al, 1991). Log return=$r_t = e_t - e_{t-1}$. The change in the logarithm of the daily exchange rate is called return of exchange rate. This is a unit free measure. The main reason for using returns rather than prices (exchange rates) is that returns have more suitable statistical properties than prices. Exchange rate return is a measure investors frequently use for evaluating the behavior of an exchange rate over time. The use of logarithmic changes is common in the speculative market literature.

The sample covers the period from January 1, 2008 to November 30, 2010 which gives a total

of 722 observations. The sample period was divided *into two; period I as January 1, 2008 - May 19, 2009(PI) and period II May 21, 2009 – November* 30, 2010 (**PII**) in order to investigate and compare the variability characteristics of exchange rate behavior during the war period and post war period in Sri Lanka. The data was obtained from Central Bank of Sri Lanka web site.

Numerical descriptive statistics and graphical techniques - Line graphs, Histograms, and correlograms, Box-Plots, kernel density estimate, confidence ellipse, Q-Q plots - are used to explore the behavior of exchange rate changes. Further, Auto regressive conditional heteroscedasticity (ARCH) model, Generalized autoregressive conditional heteroscedasticity (GARCH) model are also used along with a variety of parametric specifications to explore the stochastic behaviour of exchange rate changes of Sri Lanka. Persistence is measured by the sum of the AR coefficients.

Empirical Findings

This study tries to highlight the stylized facts of exchange rate changes during the study periods. Empirical findings that are so consistent across time periods are termed as stylized facts (Sewell, 2006). A stylized fact is a simplified presentation of an empirical finding. They are a means to represent complicated statistical findings in an easy way.

The exchange rate time series are presented in levels and in first differences of the logarithms for the two periods as ER1 and ER2 as r_1 and r_2 respectively.

In this analysis, prominent data features of the exchange rate (LKR) are first, varying trend behaviour. One can observe the changing trend which implies a changing mean in the exchange rates. Time varying mean contains information on the trending of the exchange rate levels. Figure 1 shows the movements of the LKR against USA dollar for the sample period. The line graph shows considerable randomness. One can clearly see two main trend patterns from the time plots, upward movement and downward movement. The time plot of the nominal exchange rate, Figure 1, over the sample period, shows that Sri Lankan exchange rate has behaved with two remarkable trend characteristics: First, it has an upward movement (exponential trend with fluctuations) which indicates a depreciation of the rupee, that is the cost of obtaining a unit of dollar has increased. Second, since 2009 May, a downward movement that indicates an appreciation of the rupee against the US dollar.

Figure-1 shows that Sri Lankan exchange rate has depreciated before 2009 may, and appreciated since May 2009 during the sampleperiod. Since 2009 may, LKR is appreciated during the sample period. High inflow of capital flow and the increase in reserve, remittances, IMF grants, foreign loan may have caused the appreciation of the rupee. According to the histogram, ER has behaved differently during the war period and post war periods. The dissimilar monetary policies in war and postwar periods are implied by positive and negative skewness measures.
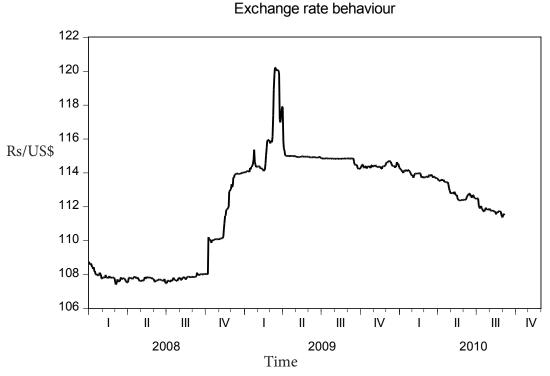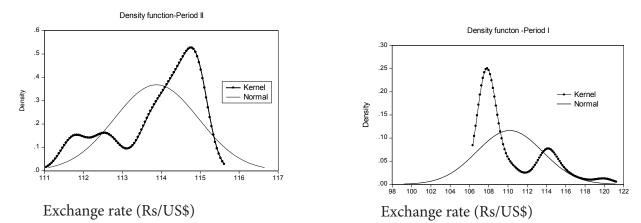
Exchange rate behaviour

Figure 1: Exchange rate behavior in level form

Figure 2 indicates the density distribution of the exchange rate in level form. The Kernel estimates of the ER density distributions indicate that density distributions of exchange rate in level form are not normal. ER1 is positively skewed and ER2 is negatively skewed. The histogram, and the JB statistics also indicate they are non-normal distributions. Summary statistics for the exchange rate (in level form) are given below,

The distribution of exchange rate return show that it was much volatile during the period of May 2009. There were large positive and large negative returns observed in 2009 first quarter and 2010. The figure-3 shows that variances of r_t appear to change over time and means are lower than standard deviation in both periods. Friedman and Vandersteel (1982) also showed

Distribution of exchange rate level form:

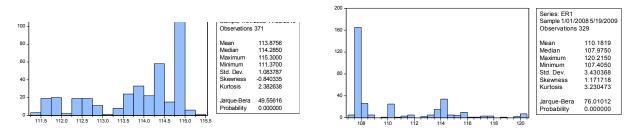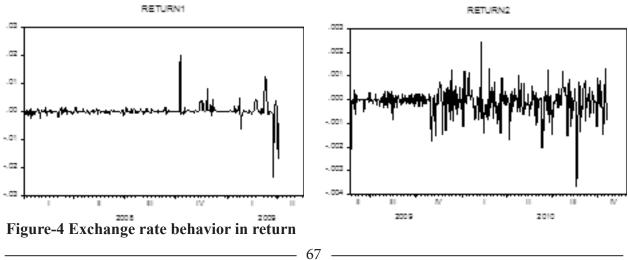**Figure- 2 Density function of exchange rates, ER1 and ER2**

Figure-3 Summary statistics of exchange rate distributions

that the means and variances of r_t appear to change over time.

The Moments of the Empirical Distribution of the Exchange Rate Changes

Measures of the various sample moments provide a preliminary description of the properties of the distribution of changes in daily exchange rate for Sri Lanka. The empirical density function of exchange rate return is estimated by Kernel density estimator, $\hat{f}(y) = \frac{1}{h}\sum_{i=1}^{\ddot{}} k\left(\frac{y_t - y}{h}\right)$ where k(z) is a function which satisfies $\int k(z)d = 1$ and h is the band width. The Kernal density function of the LKR return data was estimated with normal distribution imposed. The unconditional distribution of daily returns has fatter tails than normal distribution. The sample mean, variance, skewness, and kurtosis were calculated for two sample periods. Figure 4 shows the basic

descriptive statistics of the logarithmic returns of the Sri Lankan rupee exchange rates against the US$. Summary statistics show that kurtosis of both distributions are much larger than the normal value. Large observations occur more often than one might expect for a normally distributed variable. Thus, both very small and very large observations occur more often compared to normally distributed variable with the same first and second moments. The kurtosis of the exchange rate returns is high in war period than in the post war period. Means, standard deviations, skewness and kurtosisvary between these two periods. Calderon-Rossell and Ben Horim (1982) found that mean, skewness and variance of the distribution vary over time.

The Figure -4 displays the frequency distributions of return series in a histogram for period I and period II. The histogram divides

Empirical Distribution of the Exchange Rate Changes

The exchange rate return behavior during the study periods are given in the figure- 3 below.

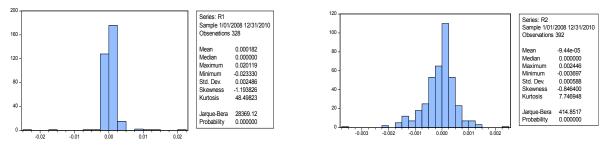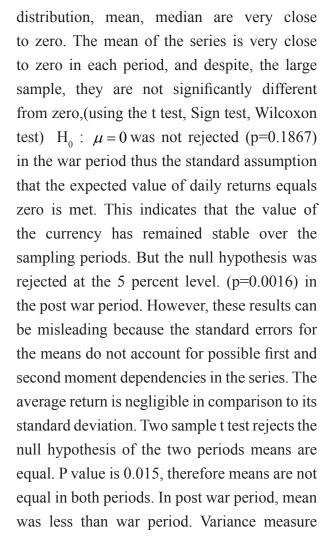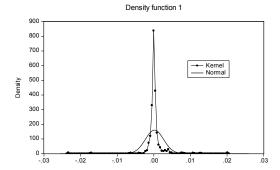**Figure-4 Exchange rate behavior in return**

Figure 4 Descriptive Statistics of Return Distributions

the series range into a number of equal length intervals (bin) and displays a count of the number of observations that fall into each bin. Descriptive statistics are also shown in this fugure4.   In previous studies in the literature, the consensus is that the distribution of these changes is unimodal and has fatter tails than thenormal distribution. These distributions show clearly more peaked and have fatter tails than their corresponding normal distribution. [

Figure 5 shows the empirical density functions have longer and fatter tails than that of the corresponding normal distribution, excess peakedness at the mean. The distributions are approximately symmetric and leptokurtic(heavy tailed). The plots indicate that the normality assumptions is questionable for these return series. There primary differences between these densities are in their means, variances, skewness and kurtosis.

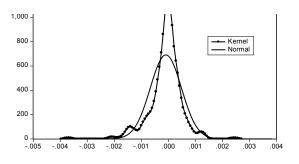Measures of central tendency of the return

distribution, mean, median are very close to zero. The mean of the series is very close to zero in each period, and despite, the large sample, they are not significantly different from zero,(using the t test, Sign test, Wilcoxon test) H_0 : $\mu = 0$ was not rejected (p=0.1867) in the war period thus the standard assumption that the expected value of daily returns equals zero is met. This indicates that the value of the currency has remained stable over the sampling periods. But the null hypothesis was rejected at the 5 percent level. (p=0.0016) in the post war period. However, these results can be misleading because the standard errors for the means do not account for possible first and second moment dependencies in the series. The average return is negligible in comparison to its standard deviation. Two sample t test rejects the null hypothesis of the two periods means are equal. P value is 0.015, therefore means are not equal in both periods. In post war period, mean was less than war period. Variance measure

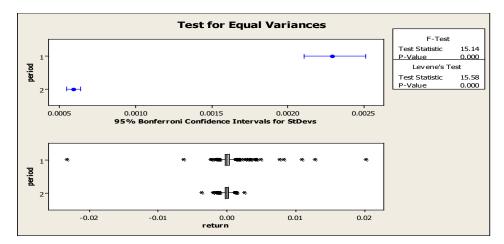**Figure 5 Comparison of Empirical Return (kernel) Density Functions**

Figure 6 Variability of the Distributions

does not adequately describe the exchange rate return distribution. Standard deviation of the return series is lower in post war period compared to war period. The variability of the returns are higher in the period I (SD=0.24) than in period II (SD=0.06). Variance test - Levene's test shows that variances are not equal statistically in both sample periods

The return series become much more volatile in war period than in post war period

Table 1 : Variability of the exchange rate return series

	P1	**P2**
SD	0.00248	0.000588
mean	0.000182	-0.0000944
(SD/mean)	13.62	6.23

The coefficient of variation in the war period 13.62 while in the post war period is 6.23. The sample variance of the rupee dollar return is higher in war period. The standard deviation of the returns completely dominates the mean of the returns. The non-Gaussian character of the distribution makes it necessary to use other measures of dispersion than the standard deviation in order to capture the variability of returns. One can consider higher order moments or cumulants as measures of dispersion and variability. Unconditional variance understates

the actual degree of uncertainty.

The skewness statistics indicate that the distribution of the exchange rate return series is slightly negatively skewed in both periods. The negative skewness implies that large negative returns tend to occur more often than the large positive ones. Negative skewness indicates fat tails on the left hand side of the distribution. Although return series is negatively skewed in both periods, the negative magnitude of skewness is high in the war period.

Kurtosis

Kurtosis measures peakedness of the distribution and the fatness of the tails of the distribution. It is defined to be the fourth moment about the mean divided by the square of the second moment about the mean. The property is related to the concept of leptokurtosis. A distribution is said to be leptokurtic if the ratio of the fourth central moment (β_2) to the square of the variance, is greater than 3. It can be shown that leptokurtosis can be caused by excessive mass compared with the normal distribution, both at centre of the distribution and in the tails.

The excess kurtosis statistics indicate that the distribution of the exchange rate return series

is highly leptokurtic relative to the normal distribution in both sample periods. It indicates that there is large excess kurtosis. However, excess kurtosis was high in war period(k=48) compared to the post war period.(k=7.7). These values indicate that return distributions are not normal. Leptokurtosis is a very strong and robust statistical property of short run price dynamics in speculative markets. Additivity and volatility clustering are connected with the fat tail property.

Table 2 Measure of Kurtosis

	P1	P2
kurtosis	48.49	7.74
N	328	392

Mandelbrot(1963) pointed out the insufficiency of the normal distribution for modeling the marginal distribution of asset returns and their heavy tailed character. Conditional heavy tails- even after correcting returns for volatility clustering e.g. via GARCH type models, the residual time series still exhibit heavy tails. However, the tails are less heavy than in the unconditional distribution of returns. The distribution tends to be non-Gaussian, sharped peaked and heavy tailed, these properties are more pronounced during the war period.

One of the important characteristics of the exchange rate return series is their high variability. As revealed by the heavy tailed distributions of their changes and the non-negligible probability of occurrence of violent market movements. These large market movements, far from being discardable as simple outliers,

Martingale Property

Testing for the martingale property in exchange

rates is important because it provides a benchmark for evaluating the performance of alternative models of exchange rate determination. Under the random walk version of the martingale hypothesis, r_t should be serially uncorrelated at all leads and lags. The results of Variance–Ratio methodology of Lo and MacKinlay (1997) shows that the p values larger than 0.05, indicating that the martingale hypothesis cannot be rejected at 5 percent level in the war period. This indicates that Sri Lankan exchange rate return, r_{ts}, is found to follow a martingale sequence in war period. On the basis of the individual and Joint tests, it can be seen that the martingale hypothesis is rejected in the post war period. (p=0.000). Empirical results provide evidence that exchange rate market is efficient in war period, in the sense that the exchange rate, RS/US are non predictable as the exchange rate follow martingale sequences.

The Random Nature of Exchange Rate:

It is often said that asset prices, such as stock prices, or exchange rates, follow a random walk; that is they are non-stationary. A random walk is a process with two properties. (i) a unit root and (ii) white noise error term. For any random walk series, the disturbances, ε_t, are serially uncorrelated, or the innovations are unforecastable from the past innovations. However, the literature has concluded that a series follows a random walk because the null hypothesis of a unit root is not rejected, or because error term is white noise.

Unit Root Property and Stationarity

A stochastic process is said to be

Figure 7 ACF of Exchange Rate Series

covariance stationary if $E[R(t)] = \mu$ for all t, $\operatorname{Var}\operatorname{Var}[R(t)] < \infty$, for all t, and $\operatorname{Cov}[R(t)R(t+j)] = \gamma_j$ for all t, and j. It has finite mean, variance and covariance that do not depend on the time, and the covariance depends only on the interval j.

ER series display random walk–type behavior (see Campbell, Lo and MacKinlay, 1997). To investigate the random walk nature (issue of unit roots) of empirical exchange rate behavior, (LKR), the augmented Dickey- Fuller and the Phillips- Perron tests were implemented on logarithm of the spot exchange rate series,. The ADF test method involves estimating the model $\Delta e_t = \alpha_0 + \alpha_1 t + \alpha_2 e_{t-1} + \sum_{j=1} \Delta e_{t-j} + \varepsilon_t$,and testing the null hypothesis $H_0 : \alpha_2 = 0,$ vs $H_1 : \alpha_2 < 0$. t is a time trend. The Phillips-Perron test involves estimating the model $r_t = \beta_0 + \beta_1(t - T/2) + \beta_2 r_{t-1} + v_t$

and testing the null hypothesis $H_0 : \beta_2 = 1$ vs $H_1 : \beta_2 < 1$. Where T is the sample size. For each model, the null hypothesis is that the series is unit root, I(1). The ordinary least squares method is used to obtain estimates and standard errors for the parameters of the both models.

Table 3 Unit Root Test:

War period	ADF test statistics (P value)	PP Test (P Value)
Level (e_t)	-0.3844(0.908)	-0.1401 (0.942)
First difference (r_t)	-14.236(0.000)	-14.3098 (0.000)
Post war period		
Level, (e_t)	0.846 (0.994)	0.846 (0.997)
First difference, (r_t)	-18.156 (0.000)	-18.108(0.000)

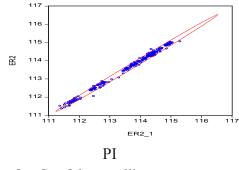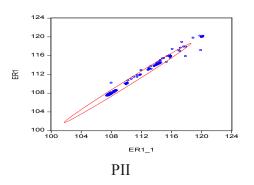Table 4 reports the unit root test results for e_t and
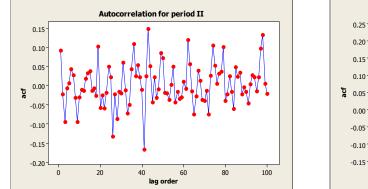
PI

PII

Figure 8: *Confidence ellipse*

their first differences(r_t). The results indicate that the unit root hypothesis cannot be rejected in both periods for the e_t and rejected for the first differences(rt). It indicates that e_t followed random walks and integrated of order I(1) during both sample periods. these results are consistent with the results of Cambell, Lo , and Mackinly(1997), Doukas and Rahman(1987) and Singleton(1982) .

Application of three augmented Dickey-Fuller tests(no trend and no intercept, intercept, and trend plus intercept) and PP test indicated that the series $\{r_t\}$ are integrated of order zero, i.e. stationary, with p- values less than 0.001. the appropriate lag lengths for the tests were selected by minimizing AIC. However, return series cannot be described by a strict –sense stationary stochastic process, since standard deviation of the return series, namely the volatility, is time–dependent in real markets.

Autocorrelation function(ACF) and long memory process

The level of exchange rate of ER_t behave as a random variable which behave as random walk, I(1). The results of Hsieh (1989) supports this finding. The nature of the trend of this variable is stochastic and tends to diverge. The impact of a shock ε_t on ER_t or e_t does not diminish over time. Therefore, the shocks are persistent. The empirical auto-correlation function analysis (corrologram) of the ER series (level) for both periods show that autocorrelation values vary as shown in the figure 7. Empirical autocorrelation function (ACF) and the partial autocorrelation function (PACF) of the exchange rate series (r_t) may help to identify what sort of stochastic process.

Figure 9: Autocorrelation Function of Return Series

Figure 7 indicates that during the period I, ACF decays faster in war period than during the post war period.

Table 4 Autocorrelation Function

	ER1	ER2
ACF (for 1st and 36 lags)	0.993, 0.597	0.991, 0.695

The sample acfs of ER1 and ER2 die off slowly a clear *linear* decline with very large values of first order autocorrelations. Analysis of the sample autocorrelation function of the ER_t for the both periods shows the most striking feature of the correlogram is that the sample autocorrelation coefficients at various lags (Table-4) are very high even up to first 36 lags. The autocorrelation coefficient starts at a very high value (0.993) close to 1 and declines very slowly toward zero as the lag lengthens. ACF provides strong evidence of the presence of serial correlation. Results indicate that ER_t series has a very *long memory, or long term dependence* . This property characterizes the behavior of the series'long-lagged auto co variances. A shock to the series persists for a long time(has long lasting impact) even though it eventually dissipates. Long memory is indicated by the fact that the spectral density becomes unbounded as the frequency approaches zero. It indicates that the ER series in both periods are nonstationary series. The order of the series can be identified by partial autocorrelation function(PACF). Both sample PACF of both series show that first one PACF to be relatively large and all the remaining ones to be notsignificantly different from zero. It indicates that ER1 and ER2 series are ~I(1) stochastic process. The confidence ellipse of the ER series show that ER series in war and post war periods are highly auto-correlated. The following Figure-8 shows the 95% confidence region around the mean and it shows positive autocorrelation. Lagged scatter plot display autocorrelation regardless of the form of the dependence on past values. An organized curvature in the pattern of dots might suggest linear dependence between time separated values.

Autocorrelation of Exchange Rate Return and Correlogram:

Sample autocorrelations for lags one to thirty six were computed for RS/US$ return series. In general, ACF are negligible for return series. However, our empirical results of ACF show that the magnitude of autocorrelation is small and statistically significant (Q statistics) in war period and nonsignificant in the post war period. In this study, the autocorrelation of the exchange rate return series are weak but not independent and identically distributed. (iid). No autocorrelation coefficient exceeds 0.2 implying that there is little serial correlation, which is in agreement with the literature. Sample ACF decays slowly to zero at a *polynomial* rate as the lag increases. This type of process is referred to as long–memory time series. Autocorrelations, auto-covariances are varying over time. it seems to mimic thecorrelation properties of a random walk process. It is seen that the autocorrelations of the return series are very small, even at low lags. $Corr(r_{t+1}, r_{t+1-\tau}) \approx 0$, $\tau = 1,2,3,....$.

The Ljung-Box Q (LB) test statistics are used to test for first and second–moment dependencies in the distribution of the r_t series. The LB statistics indicate that percentage changes in

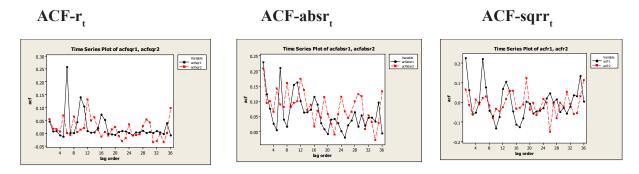ACF-r$_t$ ACF-absr$_t$ ACF-sqrr$_t$

Figure -10 Autocorrelation Function of Return, Absolute Return and Squared Return Series

the LKR with respect to US dollar are serially correlated in war period and not in the post war period at 5 percent level. For the log returns, the Ljung-Box statistics give Q(36)=82.37 which correspond to p value of 0.00 in war period. In Post war period, Q(36)=45 which correspond to p value of 0.14, based on chi-squared distribution with 36 degrees of freedom. The joint test confirms that daily returns have significant serial correlation in war period and no significant serial correlation in post war period.

Autocorrelation function of Absolute return and Squared return and nonlinear dependence

In contrast to the lack of dependence in returns, the autocorrelation for the absolute and squared returns is always positive and significant and decays slowly (see Figure-9). In addition, the autocorrelation in the absolute returns is generally somewhat higher than the autocorrelation in the corresponding squared returns. Sample autocorrelations of exchange rate returns(SACF) are *generally* very small and statistically nonsignificant whereas the sample autocorrelations of the *absolute returns,* $|r_t|$ and *squared* returns r_t^2 are significantly different from zero even for large lags. Manas-Anton (1986) showed that $|r_t|$ and r_t^2 exhibit

substantial autocorrelation. The amplitude of the return is measured by the absolute value of the return or the return square. The autocorrelation function of absolute returns decays slowly as a function of time lag as a *power law.* The absolute or squared return acf shows power correlations with long–range persistence up to several lags. This behavior suggests that there is some kind of *long-range dependence* in the daily exchange rate return.

Variability of sample autocorrelation (for 36 lag order) in war period (0.007) is twice the variance of sample autocorrelation in postwar period (0.003). IQR is 0.09 in the war period and 0.05 in the post war period. This indicates that ACF has higher variability in the war period. The correlogram (ACF plot) shows that the series of return1 is a non-stationary series. They may be non-stationary in mean or variance or both.

Table 5 Serial Correlation Q statistics(LBQ) for ACF

	War period	Post War period
Box-Pierce Q statistics	Q statistic (LBQ) at 36th lags	Q statistic (LBQ) at 36th lag order
Acf	82.37*	41.55^{NS}
Acf absolute	84.80*	125.73*
Acf squared	38.25**	23.13^{NS}

*   significant at 1% level ,

** significant at 1% from lag 6 to lag 25, NS-not significant

Q stat for acf of return 1 series shows that autocorrelation coefficients at various lags are statistically significant at 1 percent level. But the correlation coefficient size is very small (<0.226). The null hypothesis that autocorrelation coefficient is zero is rejected. In war period, Q statistics shows that magnitude of autocorrelations of return1 series are small. However, all coefficients of autocorrelations are statistically significant for 36 lags. This is an exceptional case. This may reflect type II errors or heteroscedasticity. Heteroskedasticity can under estimate the true variance (Hsieh, 1988), Another possible source of bias, leptokurtosis which may create more significant 't' statistics(Friedman and Vandersteel, 1982). For nonlinear, non-Gaussian series, ACFs do not capture adequately the dependence structure of the series under the study. The sample ACF of heavy tailed nonlinear time series can have non-standard statistical properties which invalidate many econometric testing procedures used for measuring dependence. ACF for squared return series1 in the war period, for only some lags, up to 6 and from 25th lag to 36 lags Q stat are significantly different from zero, providing evidence of strong second moment dependencies (conditional heteroskedasticity)
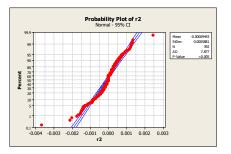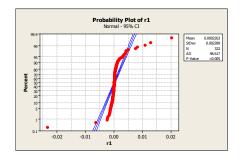
in the distribution of LKR Exchange rate changes in the war period but not in the postwar period..

During post war period, Q statistics for ACF of return series are not statistically significant. Lagged values of the return2 series are uncorrelated. $r_k \cong 0$. This shows that it is asymptotically normally distributed under the assumption of weak stationary. ACF of Absolute return2 are significantly different from zero at up to 36 lags. However, ACF of squared return2 series are not statistically significant at all 36 lags.

Independence and Identical Distribution (IID) of Returns in time.

 The BDS test is a portmanteau test for time based dependence in a series. It can be used for testing whether the series are linear dependence or non-linear dependence or chaos. The results of the BDS test indicate that exchange rate return series cannot be considered as independent and identically distributed (P<0.001) in both sample periods. The autocorrelation function of the return series rapidly decays to zero. The absence of significant linear correlations in return series has been widely documented. It is well known that the absence of serial correlation does not imply the independence of the changes. Independence implies that any

Figure 11- Probability plot of returns

nonlinear function of returns will also have no auto correlation. By assessing the values of the autocorrelation coefficients, partial autocorrelation coefficients and tests of their significance we may come to the conclusion that LKR return may be considered not independent in war time and independent in post war period.

Normality of returns

Normality is a fundamental assumption of many financial models. The empirical results of this study suggest that log return is distributed as a non- normal distribution. Q-Q plots show the non -normality. It shows that there is systematic deviation from the normal distribution with deviation depicted on the graphs by points lying away from the straight line. In period II, deviation was lower from a symmetric distribution. The Jarque–Bera test statistics rejects the null hypothesis of normality of the exchange rate return series for both sample periods. P values for the JB test is 0.0000 for both periods. Rejection of normality can be partially attributed to inter-temporal dependence in the moments of the series.

The results show that distributions of the returns are skewed (sk_1=-1019, sk_2=-0.84) negatively in both periods. This implies that left tail of the distribution is fatter than the right tail. i.e is large negative returns tend to occur more often than large positive ones.

Tails of the distributions of the exchange rate return series are fatter than the tails of the normal distribution. Kurtosis indicates that the density function has longer and fatter tails, excess Peakedness at the mean. Very small and very large observations occur more often compared to a normally distributed variable

with same first and second moments.

The probability plots show that $return_2$ displays the least deviation from the normal distribution since the points, except for some outliers, are found next to the straight line.
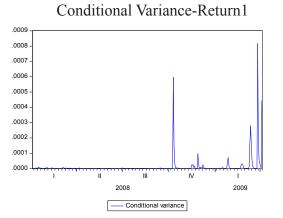
Non-linearity

The absence of autocorrelation does not imply the independence of the increments. Any nonlinear function will also have no autocorrelation. Simple nonlinear functions of returns , such as absolute or squared returns, exhibit significant positive autocorrelation or persistence. Testing for *non linear dependence* is important in terms of model adequacy, market efficiency, and predictability. Evidence of non linearity from figure 3 is shown in the exchange rate return series. Volatility clustering in effect brings non-linear characteristics. Non-linear dependence can be explained by GARCH models. Hsieh(1989a) discovered the evidence of nonlinearity in r_t^2 .

Volatility   Clustering   and   Non-linear Dependence

The term volatility represents a generic measure of the magnitude of market fluctuations. The volatility process is concerned with the evolution of conditional variance of the return over time. Understanding volatility becomes extremely important in studying exchange rate. It is not directly observable. Although it is not directly observable, it has some characteristics that are commonly seen in asset returns. Figure 3 shows that variability of returns vary over time and appear in clusters. There are many quantitative definitions of volatility use in the literature.

Table 7   Kurtosis Measures

Type of variables	P1	P2
Level	3.08	2.29
Return	49.49	7.94
Return square	111.09	109.19

Conditional Variance-Return1

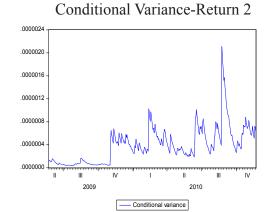Conditional Variance-Return 2

Figure 13- Conditional Variance of Return Series

The negative extreme returns are important in risk management. Positive extreme returns are critical to holding a short position.

Exchange rate volatility tends to be persistent. Volatility clusters are observed as continued periods of high or low volatility. The tendency for volatility in exchange rate returns to appear in bunches. That is large returns (either signs) are expected to follow large returns, and small returns(either signs) to follow small returns. It indicates the strong serial correlation in squared return series. Volatility clusters are observed in LKR/US$ return series during war period than in the postwar period. The implication of volatility clustering is that volatility shocks today will influence the expectation of volatility many periods in the future(long range dependencies). Bollerslev, Engle and
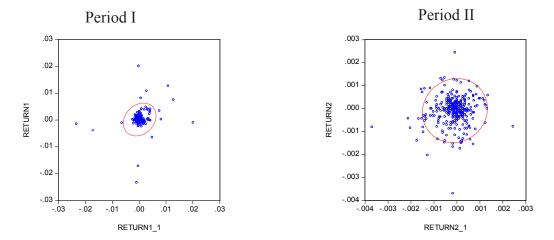
Period I

Period II

Figure 14 Scatter Plot of the Return on day t against the return on day t-1 with Confidence Ellipse

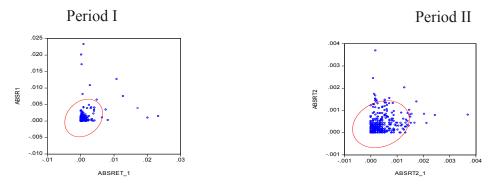Period I   Period II

Figure 15- Scatter plot of the absolute return on day t against the return on day t-1

Nelson (1994) noted that volatility clustering is intimately related to the return series. Figure 3 illustrates this phenomenon on daily exchange rate returns.

Simple nonlinear functions of returns such as absolute or squared returns exhibit significant positive autocorrelation or persistence. This is a quantitative signature of the well-known phenomenon of volatility clustering. A quantity commonly used to measure volatility clustering is the autocorrelation function of the squared returns: Empirical ACF indicates positive values and decays slowly. Volatility clustering is a ARCH effects in the econometric literature.

This slow decay is sometimes interpreted as a sign of long range dependence in volatility. GARCH model is useful for characterizing the persistence in volatility and the fat tails time series of exchange rate returns. GARCH models can be used to study heavy volatile markets .

Figure 13 shows the GARCH characteristics of return series. It indicates that conditional variance varies with time and behave differently in two time periods.

The scatter plots help us to understand the joint distribution of return (r_t) and lag 1return (r_{t-1}). The confidence ellipse enclose areas that would

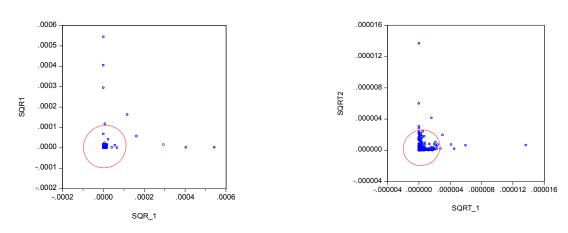Period I   Period II

Figure 15- Scatter plot of the squared return on day t against the return on day t-1

contain 95 percent of the sample

From Figure 14, it appears that large returns tend to occur in clusters. This feature is more apparent when inspecting scatterplots of the return of day t , denoted return1, r_t, against the return of day t-1 denoted by r_{t-1}.

Persistence /long run impact / permanent impact

An estimate of the persistence of exchange rate captures the long run effects of a shocks on exchange rate. If the series exhibits a stochastic trend, shocks may have a long run impact. Consider a univariate autoregressive (AR) process for exchange rate such that $e_t = \mu + \sum_{i=1}^{n} \alpha_i e_{t-1} + \varepsilon_t$. Persistence (P) is measured by the sum of the autoregressive coefficients. The results indicate that exchange rate return exhibits high persistence. When P>0.9 the exchange rate is highly persistent.

Table 8   Persistence in the volatility of exchange rate return

	P1	P2
	0.80	0.64
$P = \sum_i \alpha_i$		

Leverage effects /Asymmetric effects

In financial markets, it is a stylized fact that a downward movement is always followed by higher volatility. These characteristics exhibited by percentage changes in exchange rate data is termed as leverage effects. It is the negative correlation between shocks to return (returns) and to volatility (variance). It implies that increase in volatility causes currency to depreciate.

Asymmetries effects are usually induced by increase in uncertainty. Engle and Patton (2001) explained that the asymmetric characteristics of percentage changes induce skewed distributions of price forecasts.

Another measure of nonlinear dependence is the so called leverage effect: the correlation of returns with subsequent squared returns, defined by $L(\tau) = corr(r(t+\tau, \Delta t) |^2, r(t, \Delta t)$, starts from a negative value and decays to zero suggesting that negative returns lead to a rise in volatility. However this effect is asymmetric $L(\tau) \neq L(-\tau)$ and in general $L(\tau)$ is negligible for $\tau < 0$. The existence of such nonlinear dependence, as opposed to absence of autocorrelation in returns themselve, is usually interpreted by stating that there is correlation in volatility of returns but not the returns themselves. These observations motivate a decomposition of the return as a product $r(t, \Delta t) = \sigma(t, \Delta t)\varepsilon(t)$. Correlation between squared returns at a day t and returns at day t-1 is not equal to zero. They are not independent since returns squared are correlated.

Asymmetric effects in the exchange rate returns are statistically significant in the post war period and not significant in the war period.

Model to Explain Volatility Clustering

Various volatility models have been proposed to capture these characteristics (stylized facts) of exchange rate returns. Volatility models may be divided into two classes: the autoregressive conditional heteroskedasticity (ARCH) models and the stochastic volatility (SV) models. The majority of research papers reports that exchange rate changes behave stochastically as GARCH processes and that their distributions have fatter tails (leptokurtic) relative to the

normal distribution.

A number of thick tailed distributions have been suggested for ARCH type models, such as the student t distribution, generalized-error distribution and skewed – t distribution.

Uncertainty is measured by cv. Unconditional variance understates the uncertainty. Therefore conditional variance is considered. The GARCH(p,q) model is an extension of the ARCH class of models allowing both longer memory and a flexible lag structure without having to impose, a priori, any fixed lag pattern. GARCH and ARCH effects measure exchange rate uncertainty.

The Generalized heteroskedastic autoregressive (GARCH) (Engle 1982, and Bollerslev 1986) is used to model the time varying volatility (volatility dynamics) in financial variables. A salient feature of GARCH volatility model relates to the size of the variations in the conditional volatility. This feature is referred as the *amplitude* of the conditional volatility process(see Davidson 2004). The amplitude is given by the sum of the coefficients in the ARCH(∞) representation of GARCH models. As shown in Davidson (2004), for the GARCH(1,1) model amplitude will be given

by $\dfrac{\alpha_1}{(1-\beta_1)}$ and hence GARCH(1,1) model is covariance stationary provided that $\alpha + \beta < 1.$.

Another important and useful feature of GARCH model is the memory of the conditional volatility process (see Baillie et al. 1996, Zaffaroni 2000 and Davidson 2004). The memory of a GARCH model determines how long shocks to the volatility take to dissipate. There are usually two cases discussed in the

literature relating to memory of GARCH, namely the geometric(short) memory and hyperbolic (long)memory. The stationary GARCH models are usually considered to have short memory as shocks have relatively "less" persistent effects or "short –lived effects" on the conditional volatility. Slow hyperbolic rate of decay for the autocorrelations of u_t^2, which is a characteristic of long memory processes. Davidson (2004) discusses memory properties of GARCH model and shows that the length of the memory of the conditional volatility process is a function of the parameters of these models.

GARCH(1,1) model is used to capture ARCH and GARCH effect in exchange rate returns. GARCH(1,1) refers to the presence of a first order GARCH term and a first order ARCH term. ARCH effect and GARCH effects are statistically significant at the 5 percent level. The sum of the ARCH and GARCH coefficients ($\alpha + \beta =$) is very close to one in both periods indicating that shocks to the conditional variance are highly persistent in both periods, in particular, the volatility persistent is higher in period II than in the period I. the values are given in table 9.

Table -9 ARCH and GARCH effects for the two periods

	Period I	Period II
ARCH effect (α)	0.148	0.155
GARCH effect (β)	0.779	0.841
Volatility persistent ($\alpha + \beta$)	0.927	0.996

Unconditional variance understates the actual

degree of uncertainty of exchange rate Rupee-Dollar return.

Summary and Conclusion

The exchange rate market is the most important financial market as it determines all international transactions and in effect influences a country's balance of payment. In this study, statistical properties of the exchange rate series are investigated empirically. These properties play an important role in international economics and international finance-risk management. The major findings of this study are that the expected value of the distribution of exchange rate return series tends to zero. Exchange rate movements are neither independent and identically distributed nor normally distributed. Means and variances of the return appear to change over time. Mean-variance portfolio selection rules and option pricing models are not applicable. Statistical procedure should take into account heteroscedasticity. Researcher should select the correct specification of the model.

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