



Munich Personal RePEc Archive

## **Testing for weak form market efficiency in Indian foreign exchange market**

Sasikumar, Anoop

University of Hyderabad, India

20 May 2011

Online at <https://mpra.ub.uni-muenchen.de/37071/>  
MPRA Paper No. 37071, posted 03 Mar 2012 19:29 UTC

# Testing for Weak Form of Market Efficiency in Indian Foreign Exchange Market

Anoop S Kumar<sup>\*</sup>

## ABSTRACT

*This paper attempts to examine the weak form of market efficiency in the Indian foreign exchange market using a family of variance ratio tests. Monthly Nominal Effective Exchange Rate (NEER) data from April 1993-June 2010 were used for the analysis. NEER series was considered for the analysis as it is supposed to capture more information compared to the bilateral exchange rates. Three individual variance ratio tests as well as three joint variance ratio tests were used for the purpose of analysis. After analyzing the results from both individual and joint variance ratio test, it was concluded that Indian foreign exchange market does not exhibit weak form of market efficiency.*

## Introduction

The efficient market hypothesis put forwarded by Fama (1965) states that a security price fully reflects all available information. The market is regarded as weak-form efficient if the current price of a security fully reflects all its information contained in its past prices, which means that studying the behaviors of historical prices cannot help in earning abnormal returns. The implication of weak-form efficiency is the random walk hypothesis (RWH), which indicates that successive price changes are random and serially independent.

Among methodologies available to test RWH, variance ratio tests are considered powerful tools. Lo and MacKinlay (1988) proposed the conventional variance ratio test. Richardson and Smith(1991) proposed a joint test with a wald type statistic. Later, Chow and Denning (1993) modified Lo-MacKinlay's test(1988) to form a simple multiple variance ratio test . Choi(1999) proposed a data-driven automatic Variance Ratio test. Wright (2000) proposed a non-parametric ranks and signs based variance ratio tests to address the potential limitation of Lo-MacKinlay's(1988) conventional variance ratio test. Chen and Deo (2006) proposed a test to take care of the small sample distribution problem associated with Variance ratio (VR ) statistic.

---

<sup>\*</sup>Research Scholar, Dept. of Economics, University of Hyderabad, Gachibowli, Hyderabad-500046, India. E-mail: [taichichuaan@gmail.com](mailto:taichichuaan@gmail.com)

The efficiency or inefficiency of a foreign exchange market has policy implications of tremendous importance. If a foreign exchange market is inefficient, developing a model that best predicts exchange rate movements is possible. Therefore, an inefficient foreign exchange market provides opportunities for profitable foreign exchange transactions. Further, in an inefficient foreign exchange market, the government authorities can determine the best way to influence exchange rates, reduce exchange rate volatility and evaluate the consequences of different economic policies. Alternatively, a foreign exchange market that is efficient needs minimal government intervention and its participants cannot make abnormal gains from foreign exchange transactions.

This study seeks to analyze the presence of weak form of market efficiency in the Indian foreign exchange markets using a family of Variance ratio tests. Six tests are employed to analyze the presence of random walk. As a background to the present study, a review of earlier literature is attempted.

### **Literature Review**

Noman and Ahmed (2008), investigated the weak-form efficiency for foreign exchange markets in seven SAARC countries for the period from 1985 to 2005. They employed variance ratio test of Lo and Mackinlay (1988) and Chow-Denning joint variance ratio test (1993). Their study failed to reject the null hypothesis of random walk for all the seven currencies and the conclusion was that foreign exchange markets in South Asian region follow random walk process and, therefore, are weak-form efficient.

Asad (2009) tested the random walk and efficiency hypothesis for 12 Asia-Pacific foreign exchange market using individual as well as panel unit root tests and variance ratio test of Lo and Mackinlay (1988), the non-parametric-based variance ratio test of Wright (2000). The study used both daily and weekly spot exchange rate data from January 1998 to July 2007.

The results of the study do not differ much between the unit root tests and the variance-ratio tests when using daily data but differ significantly when using weekly data. With the daily data, both types of unit root tests identify non-stationarity for all the series and two variance-ratio tests provide the evidence of random walk behavior for majority of the exchange rates tested.

With the weekly data, panel unit root tests identify non-stationarity in the exchange rates and, the unit root tests on a single series basis identify unit root component for 10 foreign exchange markets. However, the variance-ratio tests reject the martingale null hypothesis for the majority of the exchange rates when using weekly data.

Chiang *et al* (2010) used the traditional variance ratio test of Lo and Mackinlay (1988), the non-parametric variance ratio test of Wright (2000) and the multiple-variance ratio test of Chow and Denning (1993), to examine the validity of the weak form efficient market hypothesis for foreign exchange markets in four foreign exchange markets in Japan, South Korea, Taiwan and the Philippines. The results of the study indicated that the that the

foreign exchange markets of Japan, South Korea and the Philippines are weak form efficient, while the foreign exchange market of Taiwan is inefficient.

The motivation to carry out this study is the reason that an exhaustive study has not been carried out in the Indian context regarding market efficiency in the foreign exchange market.

**Objective of the Study**

The objective of this paper is to analyze whether Indian foreign exchange market exhibit weak form of efficiency.

**Data and Methodology**

Nominal Effective Exchange Rate is the weighted geometric average of the bilateral nominal exchange rates of the home currency in terms of foreign currencies. Specifically,

$$NEER = \prod_{i=1}^n \left( \frac{e}{e_i} \right) w_i$$

Where, e: Exchange rate of Indian rupee against a numeraire, *i.e.*, the IMF’s Special Drawing Rights (SDRs) in indexed form.

$e_i$ = Exchange rate of foreign currency of the  $i^{th}$  country against a numeraire, *i.e.*, the IMF’s Special Drawing Rights (SDRs) in indexed form

$w_i$ =weights attached to foreign currency/country ‘i’ in the index,

$$\prod_{i=1}^n w_i = 1$$

n: Number of countries

Here, Monthly data from April 1993-June 2010 is used for the analysis, taken from the Reserve Bank of India website.

To analyze the presence of random walk, 6 types of variance ratio tests are employed.

**Lo and Mackinlay (1988) Variance Ratio test**

The maintained RWH for a time series  $X_t$  can be given by the following equation:

$$X_t = \mu + X_{t-1} + \varepsilon_t \tag{1}$$

Where  $\mu$  is an arbitrary drift parameter and  $\varepsilon_t$  is the random disturbance term. The underlying assumption is that the disturbance terms  $\varepsilon_t$  are independently and identically distributed normal variables with variance  $\sigma_\varepsilon^2$ . This is the assumption according to the traditional RWH.

Thus,  $H : \varepsilon_t \text{ i.i.d. } N(0, \sigma_\varepsilon^2) \tag{2}$

According to the null hypothesis that the variance ratio should be unity for all levels of aggregation, it can be described as follows;

$$VR(q) = \frac{1}{q} \frac{\sigma_q^2(q)}{\sigma_1^2(q)} = 1 \quad \dots\dots\dots (3)$$

The test statistic that is developed by Lo and Mackinlay for the variance ratio is as follows;

$$Z_1(q) = \sqrt{nq} \bar{M}_r(q) (2(2q-1)(q-1)/3q)^{-1/2} \overset{a}{\approx} N(0,1) \quad \dots\dots\dots (4)$$

Where the variance ratio is,

$$\bar{M}_r(q) \equiv \frac{\bar{\sigma}_c^2(q)}{\bar{\sigma}_a^2} - 1 \quad \dots\dots\dots(5)$$

And where the variance estimators are;

$$\bar{\sigma}_a^2 = \frac{1}{nq-1} \sum_{k=1}^{nq} (X_k - X_{k-1} - \hat{\mu})^2 \quad \dots\dots\dots(6)$$

And,

$$\bar{\sigma}_c^2(q) = \frac{1}{m} \sum_{k=q}^{nq} (X_k - X_{k-q} - q\hat{\mu})^2 \quad \dots\dots\dots(7)$$

Where,

$$m = q(nq - q + 1) \left(1 - \frac{q}{nq}\right) \quad \dots\dots\dots(8)$$

The tests are based on different aggregation levels, signaled by q.

Next to the homoskedastic test statistic, Lo and Mackinlay (1989) also developed a test statistic that is robust to heteroskedasticity. They developed this test statistic with the knowledge that volatilities change over time, and that the error terms of financial time series are often not normally distributed.

Since  $\bar{M}_r(q)$  still approaches zero, therefore we only have to calculate its asymptotic variance, which is defined as  $\theta_q$ .

The variance ratio estimate as defined before, is asymptotically equivalent to a weighted sum of serial autocorrelation coefficient estimates, such that;

$$\bar{M}_r(q) = \sum_{j=1}^{q-1} \frac{2(q-j)}{q} \hat{\rho}(j) \quad \dots\dots\dots(9)$$

Where  $\hat{\rho}(j)$  is the estimator of the  $j^{\text{th}}$  autocorrelation factor.

Here, the asymptotic distribution of  $\bar{M}_r(q)$  under the null hypothesis is defined as follows;

$$\sqrt{nq} \bar{M}_r(q) \overset{a}{\approx} N(0, V(q)), \quad \dots\dots\dots(10)$$

Where  $V(q)$  is the asymptotic variance of  $\bar{M}_r(q)$  and can be calculated as

$$V(q) = \sum_{j=1}^{q-1} (2(q-j)/q)^2 \bar{\delta}(j), \quad \dots\dots\dots(11)$$

Where

$$\bar{\delta}(j) = \frac{(nq) \sum_{k=j+1}^{nq} (X_k - X_{k-1} - \bar{X})^2 (X_{k-j} - X_{k-j-1} - \bar{X})^2}{\left[ \sum_{k=1}^{nq} (X_k - X_{k-1} - \bar{X})^2 \right]^2} \quad \dots\dots\dots(12)$$

And  $\bar{\delta}(j)$  is the estimator for the weighted sum of the variances of  $\hat{\rho}(j)$ .

The standard normal Z-statistic under heteroskedasticity is computed as:

$$Z_2(q) = \sqrt{nq} \bar{M}_r(q) [V(q)]^{-1/2} \overset{a}{\approx} N(0,1). \quad \dots\dots\dots(13)$$

**Wald Test of Richardson and Smith (1991)**

Richardson and Smith (1991) suggested a joint test based on the following Wald statistic:

$$RS(k) = T(VR - 1_k)' \phi^{-1} (VR - 1_k) \dots\dots\dots(14)$$

where **VR** is the  $(k \times 1)$  vector of sample  $k$  VRs,  $1_k$  is the  $(k \times 1)$  unit vector and  $\phi$  is the covariance matrix of **VR**. The joint  $RS(k)$  statistic follows a  $\chi^2$  distribution with  $k$  degrees of freedom. The usefulness of this test relies on the fact that, whenever the VR tests are computed over long lags with overlapping observations, the distribution of the VR test is non-normal; then, neither the Lo–MacKinlay(1988) test nor Chow–Denning(1993) procedure is valid for drawing inference.

**Chow and Denning (1993) multiple variance ratio test**

The test developed by Lo and Mackinlay (1988) uses the property of the RWH to test individual variance ratios for different values of the aggregation factor  $q$ . Chow and Denning (1993) recognized that the test lacks the ability to test whether all the variance ratios of the different observation intervals are equal to 1, simultaneously. This is a requirement of the RWH, and since Lo and Mackinlay(1988) overlooked this requirement, they used the standard normal tables to test the variance ratios on significance. Failing to control for the overall test size, leads to a large probability of a Type 1 error .

To circumvent this problem, Chow and Denning developed a test that controls for the joint test size, and also provides a multiple comparison of variance ratios. They used the Studentized Maximum Modulus (SMM) critical values to control for the overall test size and to create a confidence interval for the Variance Ratio estimates. They used the same test statistic of the Lo and MacKinlay (1988) Variance Ratio test. Only now they are simply compared to the SMM critical values, instead of the standard normal critical values to look for significance.

Since Chow and Denning(1993) consider multiple comparisons of the variance ratio estimates, and all variance ratio estimates should be above the SMM critical value, they use the following largest absolute value of the two test statistics as defined before in the Lo and MacKinlay(1988) procedure

$$Z_1^* (K) = \text{Max}_{1 \leq i \leq K} |Z_1(q_i)| \dots\dots\dots (15)$$

$$Z_2^* (K) = \text{Max}_{1 \leq i \leq K} |Z_2(q_i)| \dots\dots\dots (16)$$

$Z_1(q)$  and  $Z_2(q)$  is calculated same as above

In which  $(q_i)$  are the different aggregation intervals for  $\{q_i | i = 1, 2, \dots, m\}$ . The decision about whether to reject the null hypothesis or not can be based on the maximum absolute value of individual variance ratio test statistics.

**Non-Parametric Variance Ratio Tests Using Ranks and Signs by Wright (2000)**

As already noted, the Lo–MacKinlay (1988) tests, which are asymptotic tests whose sampling distribution is approximated based on its limiting distribution, are biased and right-skewed in finite samples. In this respect, Wright (2000) proposed a non-parametric alternative to conventional asymptotic VR tests using signs and ranks. Wright’s (2000) tests have two advantages over the Lo–MacKinlay(1988) test when sample size is relatively small: (1) as the rank ( $R1$  and  $R2$ ) and sign ( $S1$  and  $S2$ ) tests have an exact sampling distribution, there is no need to resort to asymptotic distribution approximation, and (2) the tests may be more powerful than the conventional VR tests against a wide range of models displaying serial correlation, including fractionally integrated alternatives.

The tests based on ranks are exact under the i.i.d. assumption, whereas the tests based on signs are exact even under conditional heteroskedasticity. Wright(2000), defined the  $R1$  and  $R2$  statistics as follows

$$R_1(k) = \left( \frac{(Tk)^{-1} \sum_{t=k}^T (r_{1,t} + \dots + r_{1,t-k+1})^2}{T^{-1} \sum_{t=k}^T r_{1,t}^2} - 1 \right) X\phi(k)^{-1/2} \dots\dots\dots(17)$$

$$R_2(k) = \left( \frac{(Tk)^{-1} \sum_{t=k}^T (r_{2,t} + \dots + r_{2,t-k+1})^2}{T^{-1} \sum_{t=k}^T r_{2,t}^2} - 1 \right) X\phi(k)^{-1/2} \dots\dots\dots(18)$$

Given a variable in first differences  $\{x_t\}_{t=1}^T$ , let  $r(x)$  be the rank of  $x_t$  among  $(x_1, \dots, x_T)$ . Under the null hypothesis that  $x_t$  is generated from an i.i.d. sequence,  $r(x_t)$  is a random permutation of the numbers of  $1, \dots, T$  with equal probability, giving the distribution of the test statistics as stated in proposition 1.

Proposition 1: Under the assumption of iid returns,  $R1$  and  $R2$  have the same distribution as

$$\left( \frac{(Tk)^{-1} \sum_{t=k}^T (r_{1,t}^* + \dots + r_{1,t-k+1}^*)^2}{T^{-1} \sum_{t=k}^T r_{1,t}^{*2}} - 1 \right) X\phi(k)^{-1/2} \text{ and}$$

$$\left( \frac{(Tk)^{-1} \sum_{t=k}^T (r_{2,t}^* + \dots + r_{2,t-k+1}^*)^2}{T^{-1} \sum_{t=k}^T r_{2,t}^{*2}} - 1 \right) X\phi(k)^{-1/2}$$

where the standardized ranks  $r_{1,t}^*$  and  $r_{2,t}^*$  are given by

$$r_{1,t}^* = \frac{r^*(x_t) - \frac{T+1}{2}}{\sqrt{\frac{(T-1)(T+1)}{12}}} \dots\dots\dots(19)$$



$$r^*_{2,t} = \frac{\phi^{-1}r^*(x_t)}{T+1} \dots\dots\dots(20)$$

Where,

$$\phi(k) = \frac{2(2k-1)(k-1)}{3kT}$$

$\phi^{-1}(k)$  is the inverse of the standard normal cumulative distribution function, and  $\{r^*(x_t)\}_{t=1}^T$  is any permutation of 1, 2,..., T each with equal probability. So, the exact sampling distribution of R1 and R2 may be simulated to an arbitrary degree of accuracy.

Because this distribution is free of nuisance parameters, it could be used to construct an exact test. Wright (2000) reports the 2.5 and 97.5 percentiles of the null distribution of R1 and R2 for some values of T and k, which could be used to construct a two-sided equal-tailed exact test. If  $x_t$  is a martingale difference sequence, but is not iid, then  $r(x_t)$  is not just a random permutation of the integers from 1 to T in which each permutation has equal probability. Therefore, Proposition 1 does not apply and the proposed tests are not exact under conditional heteroscedasticity. Wright (2000) showed that the size distortions of these tests under conditional heteroscedasticity are small.

The tests based on the signs of first differences are given by

$$S_1(k) = \left( \frac{(Tk)^{-1} \sum_{t=k}^T (s_t + \dots + s_{t-k+1})^2}{T^{-1} \sum_{t=k}^T s_t^2} - 1 \right) X\phi(k)^{-1/2} \dots\dots\dots(21)$$

$$S_2(k) = \left( \frac{(Tk)^{-1} \sum_{t=k}^T (s_t(\bar{\mu}) + \dots + s_{t-k+1}(\bar{\mu}))^2}{T^{-1} \sum_{t=k}^T s_t(\bar{\mu})^2} - 1 \right) X\phi(k)^{-1/2} \dots\dots\dots(22)$$

Where  $\phi(k)$  is defined as above,  $s_t = 2u(x_t, 0)$ ,  $s_t(\bar{\mu}) = 2u(x_t, \mu)$  and  $(x_t, q) = \{ 0.5 \text{ if } x_t > q$

-0.5 otherwise

Similar to R1 and R2 tests, the critical values of the S1 and S2 tests can be obtained by simulating their exact sampling distribution. Note that S1 assumes a zero drift value.

### Joint Variance Ratio Test of Chen and Deo(2006)

Chen and Deo (2006) suggested a simple power transformation of the VR statistic that, when  $k$  is not too large, provides a better approximation to the normal distribution in finite samples and is able to solve the well-known right-skewness problem. They showed that the transformed VR statistic leads to significant gains in power against mean reverting alternatives. Furthermore, the distribution of the transformed VR statistic is shown, both theoretically and through simulations, to be robust to conditional heteroscedasticity. They defined the VR statistic based on the periodogram as

$$VR_p(k) = \frac{1}{1-k/T} \frac{4\pi}{T\hat{\sigma}^2} \sum_{j=1}^{[0.5(T-1)]} W_k(\lambda_j) I_y(\lambda_j) \dots\dots\dots(23)$$

Where,

$$I_y(\lambda_j) = (2\pi T)^{-1} \left| \sum_{t=1}^T (Y_t - \hat{\mu}) \exp(-i\lambda_j t) \right|^2 \dots\dots\dots(24)$$

$$\hat{\sigma}^2 = (T-1)^{-1} \sum_{t=1}^T (Y_t - \hat{\mu})^2 \dots\dots\dots(25)$$

and  $\lambda_j = 2\pi j/T$ ; while  $W_k(\lambda) = k^{-1} \{\sin(0.5k\lambda)/\sin(0.5\lambda)\}^2$  is a weighting function. Chen and Deo (2006) found that the power-transformed statistic  $VR_p^{\beta_k}(k)$  gives a better approximation to a normal distribution than  $VR_p(k)$ , where

$$\beta_k = 1 - \frac{2 \sum_{j=1}^{[0.5(T-1)]} W_k(\lambda_j) \left( \sum_{j=1}^{[0.5(T-1)]} W_k^3(\lambda_j) \right)}{3 \left( \sum_{j=1}^{[0.5(T-1)]} W_k^2(\lambda_j) \right)^2} \dots\dots\dots(26)$$

Let  $(k_1, \dots, k_l)$  be a vector of holding periods satisfying the conditions given in Theorem 5 of Chen and Deo (2006). Conditions (A1) to (A6) in Chen and Deo(2006) allow the innovations  $\varepsilon_t$  to be a martingale difference sequence with conditional heteroskedasticity. They are explained below.

A1)  $\{\varepsilon_t\}$  is ergodic and  $E(\varepsilon_t/\vartheta_{t-1})=0$  for all  $t$ , where  $\vartheta_t$  is a sigma field,  $\varepsilon_t$  is  $\vartheta_t$  measurable And  $\vartheta_{t-1} \subset \vartheta_t$  for all  $t$ .

(A2)  $E(\varepsilon_t^2) = \sigma^2 < \infty$

(A3) For any integer  $q$ ,  $2 \leq q \leq 8$  and for  $q$  non negative integers  $s_i$ ,  $E(\prod_{i=1}^q \varepsilon_{t_i}^{s_i})=0$  when at least one  $s_i$  is exactly one and  $\sum_{i=1}^q s_i \leq 8$

(A4) For any integer  $r$ ,  $2 \leq r \leq 4$  and for  $r$  non negative integers  $s_i$ ,  $E(\prod_{i=1}^r \varepsilon_{t_i}^{s_i}/\vartheta_t)=0$  when at least one  $s_i$  is exactly one and  $\sum_{i=1}^r s_i \leq 4$

$$(A5) \lim_{n \rightarrow \infty} \text{Var}[E(\varepsilon_{t+n}^2 \varepsilon_{t+n+j}^2 | \mathcal{D}_t)] = 0 \text{ uniformly in } j \text{ for every } j > 0$$

$$(A6) \lim_{n \rightarrow \infty} E(\varepsilon_t^2 \varepsilon_{t-n}^2) = \sigma^4$$

Under the assumption that given time series  $Y_t$  follows a conditionally heteroskedastic martingale difference sequence Chen and Deo Showed that

$$V_{p,\beta} \equiv (VR_p^{\beta_1}(k_1), \dots, VR_p^{\beta_l}(k_l))' \dots\dots\dots(27)$$

approximately follows  $N(\mu_\beta, \Sigma_\beta)$ . The details of  $\mu_\beta$  and  $\Sigma_\beta$  are given in Chen and Deo(2006). Based on this, Chen and Deo (2006) proposed a joint test statistic of the form

$$QP = (V_{p,\beta} - \mu_\beta)' \Sigma_\beta^{-1} (V_{p,\beta} - \mu_\beta) \dots\dots\dots(28)$$

It approximately follows a chi-squared distribution with  $l$  degrees of freedom under  $H_0$ :  $V(k_1) = \dots = V(k_l) = 1$  against  $H_1$ :  $V(k_i) \neq 1$  for some  $i$ .

**Automatic variance ratio test under conditional heteroskedasticity of Choi (1999)**

While implementing the VR tests, the choice of holding period  $k$  is important. However, this choice is usually rather arbitrary and *ad hoc*. To overcome this issue, Choi (1999) proposed a data-dependent procedure to determine the optimal value of  $k$ . Choi (1999) suggested a VR test based on frequency domain since Cochrane (1988) showed that the estimator of  $V(k)$ , which uses the usual consistent estimators of variance, is asymptotically equivalent to  $2\pi$  times the normalized spectral density estimator at the zero frequency, which uses the Bartlett kernel.

However, Choi (1999) employed instead the quadratic spectral (QS) kernel because this kernel is optimal in estimating the spectral density at the zero frequency (Andrews, 1991). The VR estimator is defined as

$$VR(k) = 1 + 2 \sum_{i=1}^{T-1} h(i/k) \hat{\rho}(i) \dots\dots\dots (29)$$

Where  $R(i)$  is the autocorrelation function, and  $h(x)$  is the QS window defined as

$$h(x) = \frac{25}{12\pi^2 x^2} \left[ \frac{\sin(\frac{6\pi x}{5})}{6\pi x/5} - \cos(\frac{6\pi x}{5}) \right] \dots\dots\dots(30)$$

The standardized statistic is

$$VR_f = \frac{VR(k)-1}{\frac{1}{(2)^2(T/k)^{-1/2}}}$$
 .....(31)

Under the null hypothesis the test statistic  $VR_f$  follows the standard normal distribution asymptotically. Note that it is assumed that  $T \rightarrow \infty$ ,  $k \rightarrow \infty$  and  $T/k \rightarrow \infty$ . Choi (1999) employed the Andrews (1991) methods to select the truncation point optimally and compute the VR test. Note that the small sample properties of this automatic VR test under heteroskedasticity are unknown and have not been investigated properly.

### ANALYSIS

Summary statistics of the NEER series are given below:

Sample: 1 - 207 (207 observations)

Min: 80.75 Max: 101.87

Mean: 90.315

Std. Deviation: 4.5956

Results of the individual and joint variance ratio tests are reported in table 1 & 2 respectively

Table 1: Result of individual variance ratio tests

TEST NAME	STATISTICS	HOLDING PERIODS	TEST STATISTIC
Lo-Mackinlay	Z <sub>1</sub>	2	13.3766 [0.0000]*
		5	22.8400 [0.0000]
		10	29.5595 [0.0000]
	Z <sub>2</sub>	2	8.0299 [0.0000]*
		5	13.8851 [0.0000]
		10	18.4103 [0.0000]
Wright's	R <sub>1</sub>	2	12.86899***
		5	12.77689***
		10	14.24848***
	R <sub>2</sub>	2	20.76994***
		5	21.01259 ***
		10	25.63336 ***
	S <sub>1</sub>	2	24.85739 ***
		5	25.74409 ***
		10	36.49817 ***
Choi	AVR(K)	2,5,10	49.964***

\*\*\* - Significance at 1% Level

[]\* -P-values in the Parenthesis

Table 2: Result of joint variance ratio tests

TEST NAME	STATISTICS	HOLDING PERIODS	TEST STATISTIC
Chen-Deo	$QP_k$	2,5,10	37.9305***
Chow-Denning	$CD_1$	2,5,10	13.10832***
	$CD_2$	2,5,10	7.862992***
Wald	RS	2,5,10	719.2783***

\*\*\* - Significance at 1% Level

The holding periods ( $k$ ) considered are (2, 5, 10) as advocated by Deo and Richardson (2003).

We use relatively short holding periods when testing for mean reversion using VR tests. After examining the Individual VR test results, we can see convergence among the various individual variance ratio tests. Here all the individual test statistics are significant at 1% level, and therefore the null hypothesis of random walk is rejected by all the tests.

After examining the joint VR test results, we reach at a similar conclusion. Here too, a convergence among the three tests is observed. All the test statistics are showing significance at 1% level. Hence, the null hypothesis is rejected with the joint tests also. From the above results, it could be concluded that Indian foreign exchange market is not weak form efficient.

### **Conclusion**

This paper attempted to examine the weak form of market efficiency in the Indian foreign exchange market using a family of variance ratio tests. Monthly NEER data from April 1993-June 2010 is used for the analysis. NEER series was considered for the analysis as it is supposed to capture more information compared to the bilateral exchange rates. Three individual variance ratio tests and three joint variance ratio tests were used for the purpose. In particular, the conventional individual and multiple VR tests as well as their improved modifications based on power-transformed statistics, rank and sign tests were presented. After analyzing the results from both individual and joint variance ratio test, it could be concluded that Indian foreign exchange market does not exhibit weak form of efficiency.

### **Acknowledgement**

*The author would like to extend his profound gratitude to Dr. Bandi Kamaiah (Professor, Dept. of Economics, University of Hyderabad) for initiating this work and providing valuable comments and suggestions during all stages of the study.*

\

## REFERENCES

1. Andrews, D.W.K. (1991), "Heteroskedasticity and autocorrelation consistent covariance matrix estimation", *Econometrica*, Vol (58), No. 3, pp.817–858.
2. Asad, A.S.M.S. (2009), "Random walk and efficiency tests in the Asia-Pacific foreign exchange markets: Evidence from the post-Asian currency crisis data", *Research in International Business and Finance*, Vol ( 23), No. 3 pp.322–338.
3. Chen, W.W. and Deo,R.S. (2006), "The variance ratio statistic at large horizons", *Econometric Theory*, Vol(22), No. 2,pp.206–234.
4. Chiang, S.M., Lee, Y.H., Su, H.M., and Tzou, Y.P.(2010), "Efficiency tests of foreign exchange markets for four Asian Countries", *Research in International Business and Finance*, Vol(24), No. 3,pp.284–294.
5. Choi, I. (1999), "Testing the random walk hypothesis for real exchange rates", *Journal of Applied Econometrics* , Vol(14), No. 3, pp.293–308
6. Chow, K.V. and Denning, K.C. (1993), "A simple multiple variance ratio test", *Journal of Econometrics* Vol (58), No .3, pp. 385–401.
7. Cochrane, J.H. (1988), "How big is the random walk in GNP?", *Journal of Political Economy* Vol(96), No .5,pp.893–920.
8. Deo, R.S. and Richardson, M. (2003), "On the asymptotic power of the variance ratio test", *Econometric Theory*, Vol (19), No .2, pp. 231–239.
9. Fama, E.F.(1965), "The behavior of stock market prices", *The Journal of Business*, Vol(38), No .1, pp.34-105.
10. Lo, A.W. and MacKinlay, A.C. (1988), "Stock market prices do not follow random walk: evidence from a simple specification test" *Review of Financial Studies*, Vol( 1), No. 1,pp. 41–66.
11. Lo, A.W. and MacKinlay, A.C. (1989), "The size and power of the variance ratio test in finite samples", *Journal of Econometrics* Vol(40),No .2, pp. 203–238.
12. Noman, A.M .and Ahmed, M.U. (2008), "Efficiency of the foreign exchange markets in South Asian Countries" *AIUB Bus Econ Working Paper Series*, No 2008-18,
13. Richardson, M. and Smith, T. (1991), "Tests of financial models in the presence of overlapping observations", *Review of Financial Studies*, Vol (4), No. 2,pp.227–254.
14. Wright, J.H. (2000), "Alternative variance-ratio tests using ranks and signs", *Journal of Business and Economic Statistics*, Vol (18), No. 1,pp.1–9.

*Reference#24J-2011-08-01-01*

