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- Bowersox, Donald J., Closs, David J., (1996), "Logistical Management." Tata McGraw, Hill, New Delhi.
- Hunker, H.L. and A.J. Wright (1963), "Factors of Industrial Location in Ohio," Ohio State University.

**Contributions to books**

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

**Journal and other articles**

- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

**Conference papers**

- Chandel K.S. (2009): "Ethics in Commerce Education." Paper presented at the Annual International Conference for the All India Management Association, New Delhi, India, 19–22 June.

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- Kumar S. (2006): "Customer Value: A Comparative Study of Rural and Urban Customers," Thesis, Kurukshetra University, Kurukshetra.

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- Kelkar V. (2009): Towards a New Natural Gas Policy, Economic and Political Weekly, Viewed on February 17, 2011 http://epw.in/epw/user/viewabstract.jsp

# LONG MEMORY MODELLING OF RUPEE-DOLLAR EXCHANGE RATE RETURNS: A ROBUST ANALYSIS

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## ABSTRACT

*Financial time series like exchange rates are highly persistent, i.e., that an unexpected shock to the underlying variable has long lasting effects. The persistence in the volatility of the time series is usually exemplified by a highly persistent fitted GARCH model. Traditional stationary ARMA processes often cannot capture the high degree of persistence in financial time series. In the last few years, more applications have evolved using long memory processes, which lie halfway between traditional stationary I(0) processes and the non-stationary I(1) processes. There is substantial evidence that long memory processes can provide a good description of many highly persistent financial time series. This study starts with an insight into Indian foreign exchange markets, and then last 37 years of continuous log returns of INR-USD exchange rates are analyzed for long memory effect. R/S test statists confirms the presence of long memory effect, parameters are estimated using Whittle's method. Further analysis shows that both long and short memory components makes fractionally integrated FARIMA (0,d,0) more stationary and FARIMA (2,.004,0) explains the variations*

## KEYWORDS
Foreign Exchange markets, Derivative Instruments

## INDIAN FOREIGN EXCHANGE MARKET

The origin of the foreign exchange market in India could be traced to the year 1978 when banks in India were permitted to undertake intra-day trade in foreign exchange. However, it was in the 1990s that the Indian foreign exchange market witnessed far reaching changes along with the shifts in the currency regime in India. The exchange rate of the rupee, that was pegged earlier was floated partially in March 1992 and fully in March 1993 following the recommendations of the Report of the High Level Committee on Balance of Payments (Chairman: Dr.C. Rangarajan). The unification of the exchange rate was instrumental in developing a market-determined exchange rate of the rupee and an important step in the progress towards current account convertibility, which was achieved in August 1994.

A further impetus to the development of the foreign exchange market in India was provided with the setting up of an Expert Group on Foreign Exchange Markets in India (Chairman: Shri O.P.Sodhani), which submitted its report in June 1995. The Group made several recommendations for deepening and widening of the Indian foreign exchange market. Consequently, beginning from January 1996, wide-ranging reforms have been undertaken in the Indian foreign exchange market. After almost a decade, an Internal Technical Group on the Foreign Exchange Market (2005) was constituted to undertake a comprehensive review of the measures initiated by the Reserve Bank and identify areas for further liberalization or relaxation of restrictions in a medium-term framework.

The momentous developments over the past few years are reflected in the enhanced risk-bearing capacity of banks along with rising foreign exchange trading volumes and finer margins. The foreign exchange market has acquired depth (Reddy, 2005). The conditions in the foreign exchange market have also generally remained orderly (Reddy, 2006c). While it is not possible for any country to remain completely unaffected by developments in international markets, India was able to keep the spillover effect of the Asian crisis to a minimum through constant monitoring and timely action, including recourse to strong monetary measures, when necessary, to prevent emergence of self-fulfilling speculative activities (Mohan, 2006a).

## FOREIGN EXCHANGE DERIVATIVE INSTRUMENTS IN INDIA

### FOREIGN EXCHANGE FORWARDS

Authorized Dealers (ADs) (Category-I) are permitted to issue forward contracts to persons resident in India with crystallized foreign currency/foreign interest rate exposure and based on past performance/actual import-export turnover, as permitted by the Reserve Bank and to persons resident outside India with genuine currency exposure to the rupee, as permitted by the Reserve Bank. The residents in India generally hedge crystallized foreign currency/ foreign interest rate exposure or transform exposure from one currency to another permitted currency. Residents outside India enter into such contracts to hedge or transform permitted foreign currency exposure to the rupee, as permitted by the Reserve Bank.

### FOREIGN CURRENCY RUPEE SWAP

A person resident in India who has a long-term foreign currency or rupee liability is permitted to enter into such a swap transaction with ADs (Category-I) to hedge or transform exposure in foreign currency/foreign interest rate to rupee/rupee interest rate.

### FOREIGN CURRENCY RUPEE OPTIONS

ADs (Category-I) approved by the Reserve Bank and Ads (Category-I) who are not market makers are allowed to sell foreign currency rupee options to their customers on a back-to-back basis, provided they have a capital to risk weighted assets ratio (CRAR) of 9 per cent or above. These options are used by customers who have genuine foreign currency exposures, as permitted by the Reserve Bank and by ADs (Category-I) for the purpose of hedging trading books and balance sheet exposures.

### CROSS CURRENCY OPTIONS

ADs (Category-I) are permitted to issue cross-currency options to a person resident in India with crystallized foreign currency exposure, as permitted by the Reserve Bank. The clients use this instrument to hedge or transform foreign currency exposure arising out of current account transactions. ADs use this instrument to cover the risks arising out of market-making in foreign currency rupee options as well as cross currency options, as permitted by the Reserve Bank.

### CROSS CURRENCY SWAPS

Entities with borrowings in foreign currency under external commercial borrowing (ECB) are permitted to use cross currency swaps for transformation of and/or hedging foreign currency and interest rate risks. Use of this product in a structured product not conforming to the specific purposes is not permitted. [1] Reserve Bank of India. 2006. *Comprehensive Guidelines on Derivatives Market.*

## FOREIGN EXCHANGE MARKET: AN ASSESSMENT

As per the Triennial Central Bank Survey by the Bank for International Settlements (BIS) on "Foreign Exchange and Derivatives Market Activity", global foreign exchange market activity rose markedly between 2001 and 2004 the strong growth in turnover may be attributed to two related factors. First, the presence of clear trends and higher volatility in foreign exchange markets between 2001 and 2004 led to trading momentum, where investors took large positions in currencies that followed persistent appreciating trends. Second, positive interest rate differentials encouraged the so-called "carry trading", *i.e.,* investments in high interest rate currencies financed by positions in low interest rate currencies. The growth in outright forwards between 2001 and 2004 reflects heightened interest in hedging. Within the EM countries, traditional foreign exchange trading in Asian currencies generally recorded much faster growth than the global total between 2001 and 2004. Growth rates in turnover for Chinese renminbi, Indian rupee, Indonesian rupiah, Korean won and new Taiwanese dollar exceeded

100 per cent between April 2001 and April 2004. Despite significant growth in the foreign exchange market turnover, the share of most of the EMEs in total global turnover, however, continued to remain low.

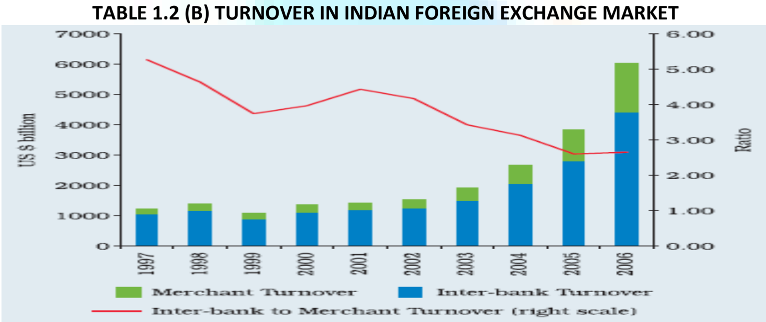
The Indian foreign exchange market has grown manifold over the last several years. The daily average turnover impressed a substantial pick up from about US $ 5 billion during 1997-98 to US $ 18 billion during 2005-06. The turnover has risen considerably to US $ 23 billion during 2006-07 (up to February 2007) with the daily turnover crossing US $ 35 billion on certain days during October and November 2006. The inter-bank to merchant turnover ratio has halved from 5.2 during 1997-98 to 2.6 during 2005-06, reflecting the growing participation in the merchant segment of the foreign exchange Mumbai alone accounts for almost 80 per cent of the foreign exchange turnover.

**TABLE 1.2 (A) TRADITIONAL FOREIGN EXCHANGE MARKET TURNOVER IN EM CURRENCIES - APRIL 2004 (DAILY AVERAGES, IN MILLIONS OF US DOLLARS)**

| | Spot | Forward | Swap | Total | Growth since 2001 (%) |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Chinese renminbi | 992 | 811 | 9 | 1,812 | 530 |
| Hong Kong dollar | 6,827 | 2,221 | 24,133 | 33,181 | 21 |
| Indian rupee | 2,877 | 1,531 | 1,658 | 6,066 | 114 |
| Indonesian rupiah | 760 | 267 | 1,025 | 2,051 | 283 |
| Korean won | 10,510 | 6,048 | 4,592 | 21,151 | 117 |
| Malaysian ringgit | 351 | 237 | 399 | 987 | 7 |
| Philippine peso | 345 | 232 | 188 | 765 | 52 |
| Singapore dollar | 5,177 | 1,242 | 10,591 | 17,010 | 32 |
| New Taiwan dollar | 3,607 | 2,798 | 856 | 7,261 | 129 |
| Thai baht | 1,333 | 490 | 1,669 | 3,492 | 88 |
| *Memo:* | | | | | |
| US dollar | 528,639 | 170,357 | 874,083 | 1,573,080 | 48 |
| Euro | 272,887 | 88,243 | 298,231 | 659,361 | 49 |
| Pound sterling | 82,839 | 31,338 | 185,241 | 299,417 | 93 |
| Japanese yen | 130,382 | 47,135 | 181,715 | 359,231 | 35 |

**Source :** BIS Quarterly Review, March 2005.

**TABLE 1.2 (B) TURNOVER IN INDIAN FOREIGN EXCHANGE MARKET**




## RUPEE-DOLLAR MARKET

The spread in the Indian foreign exchange market has declined overtime and is very low at present. In India, the normal spot market quote has a spread of 0.25 of paisa to1 paisa, while swap quotes are available at 1 to 2 paisa spread. A closer look at the bid-ask spread in the rupee-US dollar spot market reveals that during the initial phase of market development (*i.e.*, till the mid-1990s), the spread was high and volatile due to a thin market with unidirectional behavior of market participants. In the subsequent period, with relatively deep and liquid markets, the bid-ask spread declined sharply and has remained low and stable, reflecting efficiency gains.

It was empirically observed that expected volatility of the rupee-dollar exchange rates could impact the spread which increases with the increase in volatility. However, the trading volume has negligible impact on the exchange rate spread. The intercept of the estimated equation is highly significant showing the flatness of the spread in the Indian foreign exchange market. The flat and low spread can be attributed to lower volatility in the foreign exchange market.

An important aspect of functioning of the foreign exchange market relates to the behaviour of forward premia in terms of its linkages with economic fundamentals such as interest rates and its ability to predict future spot rates. An analysis of forward premia essentially reflects whether a currency is at a premium/discount with respect to other reserve currencies. Forward premia is particularly important for importers and exporters who need to hedge their risks to foreign currency. The forward market in India is active up to six months where two-way quotes are available. In recent years, however, the segment up to one year maturity has also gained liquidity. The link between the forward premia and interest rate differential seems to work largely through leads and lags. The integration between the domestic market and the overseas market is more often through the forward market. The integration has been facilitated by allowing ADs to borrow from their overseas offices or correspondents and invest funds in overseas money market. The forward segment is also influenced by a number of other factors: (i) importers and exporters availing or extending credit to overseas parties (importers can move between sight payment and 180 days usance depending on the global interest rate, domestic interest rate and expectations on future spot rate); (ii) importers switching between rupee credit and foreign currency credit; (iii) the decision to hedge or not to hedge the exposure, depending on expectations and forward premia; (iv) exporters delaying payments or advance receivables, subject to conditions on repatriation and surrender, depending upon the interest on rupee credit, the premia and interest rate overseas; and (v) availing of pre/post-shipment credit in foreign exchange and switching between rupee and foreign currency credit.

In the post-liberalization phase, the forward premia of the US dollar *vis-à-vis* Indian rupee has generally remained high indicating that rupee was at a discount to the US dollar. In recent times, however, reflecting the build-up of foreign exchange reserves, the strong capital flows and the confidence in the Indian economy, the forward premia has come down sharply from the peak reached in 1995-96. For a short period in 2003-04, the forward premia turned negative defying the traditional theory according to which the currency of a country with higher inflation rate/interest rate should be at a discount *vis-à-vis* other country's currency. This was the period when Indian rupee was gaining strength against the US dollar, which depreciated against most other currencies. The period since 2002 has, in fact, witnessed sharp co-movement of forward premia and exchange rate with the premia exhibiting a decline, whenever rupee appreciated.

Forward premia is also affected by movements in call rates, reflecting the principle of interest-rate parity. Tightening of liquidity in the domestic market immediately pushes up call rates, which in turn, pushes up forward premia. Whenever liquidity in the domestic market is tightened, banks and other market players sell the US dollar in cash or spot market and buy in the forward market pushing forward premia upward. Several studies have analyzed the behavior of forward premia and have attempted to explore the factors that determine it in the Indian foreign exchange market. Forward premia of Indian rupee is driven to a large extent by the interest rate differential in the interbank market of the two economies, FII flows, current account balance as well as changes in exchange rates of US dollar *vis-à-vis* Indian rupee (Sharma and Mitra, 2006). Another study has observed that the forward premia for the period 1997 to 2002 systemically exceeded rupee depreciation, implying that there has been an asymmetric advantage to sellers of dollar forwards (Ranade and Kapur, 2003).

One way of assessing market efficiency is to observe the forward rate behaviour as to whether forward rates are unbiased predictor of future spot rates. For the period April 1993 to January 1998, it was found that forward rates cannot effectively predict the future spot rates and there is no co-integration between forward rates and future spot rates (Joshi and Sagar, 1998). An analysis using the data for the more recent period during January 1995 to December 2006 reveals that the ability of forward rates in correctly predicting the future spot rates has improved over time and that there is some co-integrating relationship between the forward rate and the future spot rate . This could be attributed to the gradual opening up of the Indian economy, particularly in the capital account, together with other reform initiatives undertaken to develop the forward market such as introduction of new instruments, trading platforms and more players.

**TABLE 2 (A) MOVEMENT OF FORWARD PREMIA AND RUPEE-DOLLAR EXCHANGE RATE**


## LONG MEMORY MODELLING

### INTRODUCTION

Macroeconomic and financial time series like nominal and real interest rates, real exchange rates, exchange rate forward premiums, interest rate differentials and volatility measures are very persistent, i.e., that an unexpected shock to the underlying variable has long lasting effects. Persistence can occur in the first or higher order moments of a time series. The persistence in the first moment, or levels, of a time series can be confirmed by applying either unit root tests to the levels, while the persistence in the volatility of the time series is usually exemplified by a highly persistent fitted GARCH model. Although traditional stationary ARMA processes often cannot capture the high degree of persistence in financial time series, the class of non-stationary unit root or I(1) processes have some unappealing properties for financial economists. In the last few years, more applications have evolved using long memory processes, which lie halfway between traditional stationary I(0) processes and the non-stationary I(1) processes. There is substantial evidence that long memory processes can provide a good description of many highly persistent financial time series.

Much of the analysis in financial economics is based on the assumption of efficient market hypothesis (EMH), which in its weak form implies that returns of financial time series (e.g., equity prices, interest rates, exchange rates) are white noise processes consisting of independent, identically distributed random variables. These characteristics imply that the time series at the level follow random walks. A time series that follows a random walk process has two important properties. First, the series has long memory in the sense that the effects of distant shocks are strongly felt at the present. Second, the first difference of the series is a white noise, short memory process Engle and Garner (1991). A random walk model, however, is incapable of explaining a precipitous drop in many financial time series. For example, a major price change in the stock prices such as the fall of the New York markets in October 1987 can not be explained by a random walk process. For a Gaussian process, the autocorrelation function or the spectral density describes the memory properties of the series Lo (1991). If a series exhibits long memory, there is persistent temporal dependence between distant observations. Such series are characterized by distinct but non-periodic cyclical patterns. In the time domain, this is characterized by autocorrelation function that decays hyperbolically. In the frequency domain, this is characterized by high power at low frequencies, especially near the origin. A broader definition of the long memory processes requires that the autocovariances are not hummable or that the spectral density is unbounded.

In the globally integrated economies of today, the behaviors of foreign exchange rates are of great importance to international investors as the volatility of the exchange rates is an important determinant of the degree of risks associated with the investment opportunities. Moreover, the exchange rates play a prominent role in international trade.

In a long memory process, the effects of shocks tend to persist. For example, establishing that shocks to an exchange rate persist, may give the Central Bank's authorities additional incentives to intervene in the currency markets. These interventions would aim at steering the nominal exchange rate toward its long-run equilibrium path, for the cost of inaction on the part of the monetary authorities is further divergence of the nominal exchange rate from its long-run equilibrium value. Alternatively, if the monetary authorities believe that the prevailing nominal exchange rate is in the proximity of its long-run equilibrium, and that lack of intervention in the currency markets would cause divergence of nominal rate from its equilibrium rate, with possible dire consequences, then regular and frequent interventions in the currency markets would be justifiable.

For another example, consider gross domestic product (GDP). Persistence of shocks in the GDP series would require corrective monetary and fiscal policies to force the nominal GDP towards its long-run equilibrium path (see Robinson (1997) for a detailed discussion of testing for persistence of shocks and unit root in macroeconomic time series). In cases where shocks do not persist, policy activism is not required, since the series will automatically and eventually move towards its long-run equilibrium path.

Notwithstanding the di±culties associated with inference based on statistics estimated using a long-memory time series, slowly decaying correlations allow for more accurate predictions of the series. This is due to stronger dependency among the observations in a series (Beran (1994) chapter 4).

## LITERATURE REVIEW

A number of empirical studies (e.g. Booth, Kaen and Koveos, 1982; Cheung, 1993; Batten and Ellis 1996) employ the rescaled range statistical procedure, originally developed by Hurst (1951), to identify long-term return anomalies in currency markets. However, Fama (1998) argues that this type of anomaly may be sensitive to the method employed and will tend to disappear when alternative approaches are used. That is, they are "methodological illusions". Given the scale of the spot Re/USD trading and the high level of information efficiency in foreign exchange markets one may be predisposed to favour the Fama (1998) view. One approach to the problem is to apply similar statistical methods but determine whether the return anomaly persists over different sample periods, or is specific to one or more sub periods.

Many authors have tested for long memory in asset returns, including both stocks and exchange rate returns. Lo (1991) proposed robustifying the rescaled range statistics of Hurst (1951) against short run dependence and tested for US stock indices. Jacobsen (1996) tested for long memory in US, Japanese and some West European stock index returns. Cheung (1993a) tested for long memory in exchange rate returns, while Hiemstra and Jones (1997) considered long memory in US individual stock returns. Crato (1994) and Cheung and Lai (1995) both tested for long memory in stock return indices for a number of developed markets. Greene and Fielitz and Aydogan and Booth (1988) both tested for long memory using rescaled range statistics. Barkoulas and Baum (1997) tested long memory of stock

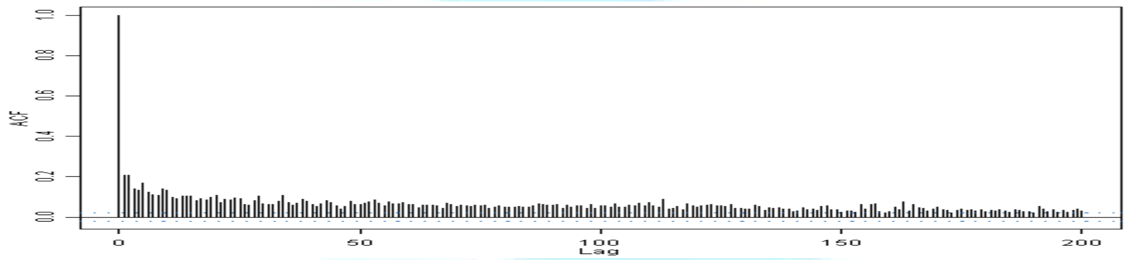
returns and European Deposit Rates. Booth, Kaen, Koveos (1982), Cheung (1993a) Cheung and Lai (1993) Bhar (1994), Feng, Lai and Lai (1994) Barkoulas, Libys and Onochie (1997a) tested long memory for spot and futures currency rates. Other authors have also tested long memory for gold prices, international spot commodity prices and commodity and stock index futures. Wei and Leuthold (2000) tested existence of long memory in agricultural futures prices.
Lo (1991) developed a modified R/S method, which addresses some of the drawbacks of the classical R/S method. Using the variant of R/S analysis, Lo finds no evidence to support the presence of long memory in U.S. stock returns. Applying Lo test, which does not rely on standard regression techniques and is robust to short-term dependence, provides statistical support for the hypothesis that stock market returns follow a random walk (Ambrose, 1993). Using both the modified R/S method and the spectral regression method, Cheung and Lai (1995) find no evidence of persistence in several international stock returns series. Crato (1994) reports similar evidence for the stock returns series of the G-7 countries using exact maximum likelihood estimation.
Fung and Lo's (1993) long memory study analyzed the prices of two interest rate futures markets, Eurodollars and T-bills. The result from the classical R/S analysis and Lo's (1991) modified R/S analysis provide no evidence of the existence of long memory and support for the weak form efficient market hypothesis. Fung et al (1994) examined long memory in stock index futures by using variance ratio, R/S and auroregressive fractally integrated moving average models. All three types of analyses concluded that no long memory exists in the data. Similar tests have been pursued by many academicians but the results are mixed, but all authors agreed the identification of long memory is very important and significant in two senses: (a) the time span and strength of long memory will be an important input for investment decisions regarding investment horizons and composition of portfolios; and (b) prediction of price movements will be improved. It is also noticeable that research methodologies have developed very fast. In the 1980's the classical R/S analysis was the major tool but in 1990's the methods are being diversified with the modified R/S analysis and the AFIMA model as new techniques.

## METODOLOGIES AND MODELLING

### PROPERTIES OF LONG MEMORY TIME SERIES

**1.** For large lags, the sample autocorrelation decays much more slowly than the theoretical autocorrelation. Traditional stationary ARMA processes have short memory in the sense that the autocorrelation function decays exponentially.
2. When the sample autocorrelation decays very slowly, traditional stationary ARMA processes usually result in an excessive number of parameters.
Example: - Consider Time Series under consideration i.e. Log Returns of Rupee-Dollar exchange rate from 02-01-1973 to 30-01-2009

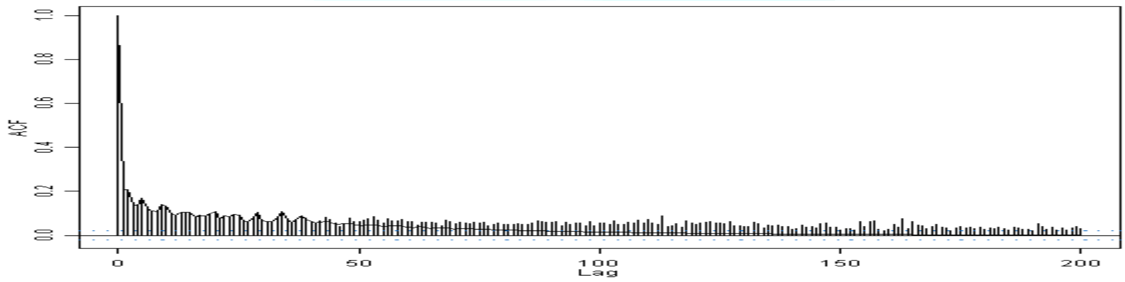
**FIG 4.1 (A) ACF OF CONTINUOUS LOG RETURNS OF RS-USD RATE OVER 37 YEARS**




From fig 4.1 (a) it is concluded that:-

- The autocorrelation of absolute returns is highly persistent and remains very significant at lag 200.
- Moreover simulation proves the best fitting AR process using AIC, which turns out to be an AR (38) model.

**FIG 4.1 (B) DOTTED LINE COMPARES ACF OF AR(38) PROCESS WITH THE OBSERVED ACF**




In the above example, the theoretical autocorrelation closely matches the sample autocorrelation at small lags. However, for large lags, the sample autocorrelation decays much more slowly than the theoretical autocorrelation.
When the sample autocorrelation decays very slowly, traditional stationary ARMA processes usually result in an excessive number of parameters. In the above example, 38 autoregressive coefficients were found necessary to capture the dependence in the data.
Based on the above observations, a stationary process Y(t) has long memory, or long range dependence, if its autocorrelation function behaves like:-

$\rho(n) = C_\rho n^{-\alpha}$ as $n \to \infty$ .............. (1)

Where, $C_\rho$ is a positive constant and $\alpha$ is a real number between 0 and 1
The autocorrelation function of a long memory process decays slowly at a hyperbolic rate. it decays so slowly that the autocorrelations are not summable

i.e. $\sum_{n=1}^{\infty} \rho(n) = \infty$ ---------------- (2)

Granger and Joyeux (1980) and Hosking (1981) independently showed that a long memory process Y(t) can also be modeled parametrically by extending an integrated process to a fractionally integrated process. In particular, allow for fractional integration in a time series Y(t) as follows:-

$(1 - L)^d \, (Y(t) - \mu) = u(t)$ ----------- (3)

Where, where L denotes the lag operator, d is the fractional integration or fractional difference parameter, $\mu$ is the expectation of Y(t), and U(t) is a stationary short memory disturbance with zero mean.
In practice, when a time series is highly persistent or appears to be non-stationary, let d = 1 and difference the time series once to achieve stationarity. However, for some highly persistent economic and financial time series, it appears that an integer difference may be too much. To allow for long memory and avoid taking an integer difference of Y(t), allow d to be fractional. The fractional difference filter is defined as follows, for any real d < -1

$$(1-L)^d = \sum_{n=0}^{\infty}\binom{d}{n}(-1)^n L^n$$ ------------------ (4)

When a fractionally integrated series Y(t) has long memory, it can also be shown that

d = H - ½ -------- (5)

Where H is Hurst coefficient (Hurst, 1951)

**DATA**

In all the sections and analysis discussed below continuous log returns of INR-USD exchange rate from 02-01-1973 to 30-11-2009 are used. Given period gives a total of 9241 observations and data are taken from federal reserved website. KPSS stationarity test confirms that selected data is stationary and fit for autoregressive modeling as test statistics value is 0.3846 which is less that the 99% quantile, 0.762 (from standard test table).

**STATICAL TESTS FOR LONG MEMORY**

Given the scaling property of the autocorrelation function, the frequency domain property and the fractionally integrated process representation of a long memory time series, various tests have been proposed to determine the existence of long memory in a time series. For a long memory process, it is not necessary for the autocorrelation to remain significant at large lags as in the previous Rs-USD example as long as the autocorrelation function decays slowly. Beran (1994) gave an example to illustrate this property.

***a) R/S Statistic Test***: - The best-known test for long memory or long range dependence is probably the rescaled range, or range over standard deviation, or simply R/S statistic, which was originally proposed by Hurst (1951), and later refined by Mandelbrot and his coauthors. The R/S statistic is the range of partial sums of deviations of a time series from its mean, rescaled by its standard deviation.

Testing for long memory in INR-USD exchange rates continuous returns using R/S statistics:-

***Test for Long Memory: R/S Test***

***Null Hypothesis: no long-term dependence***

***Test Statistics:***

***VALUE***

***6.8478*****

****: significant at 5% level***

*****: significant at 1% level***

***Total Observ: 9241***

***b) GPH Test***: - Based on the fractionally integrated process representation of a long memory time series, Geweke and Porter-Hudak (1983) proposed a semi-nonparametric approach to testing for long memory.

Outcome of GPH Test on INR-USD observations:-

***Test for Long Memory: GPH Test***

***Null Hypothesis: d = 0***

***Test Statistics:***

***VALUE***

***d 0.4301***

***stat 6.0547*****

****: significant at 5% level***

*****: significant at 1% level***

***Total Observ: 9241***

***Number of Freq: 96***

The estimated value of d from (4) is 0.4301, which suggests long memory, and the gph test statistic is 6.0547. Hence, the null of no long memory is rejected at the 1% significance level.

**LONG MEMORY PARAMETER ESTIMATION**

***Whittle's Method:*** - Whittle's method for estimating d is based on a frequency domain maximum likelihood estimation of a fractionally integrated process. It can be shown that the unknown parameters can be estimated by minimizing a discretized version of

$$Q(\theta) = \int_{-\pi}^{\pi}\frac{I(\omega)}{f(\theta,\omega)}d(\omega)$$ ........... **(6)**

Where $\theta$ is the vector of unknown parameters including the fractional difference parameter d, $I(\omega)$ is the periodogram of y(t), and $f(\theta,\omega)$ is the theoretical spectral density of y(t). Beran in (1994) derived Whittle's method. It is implemented assuming that u(t) is a standard normal disturbance and thus y(t) follows a FARIMA(0,d,0) process.

For last 37 years continuous returns of INR-USD exchange rates d comes out to be

d = 0.1787747

**ESTIMATION OF _FARIMA_ MODELS**

This section introduces the more flexible fractional ARIMA models, which are capable of modeling both the long memory and short run dynamics in a stationary time series. Many empirical studies have found that there is strong evidence for long memory in financial volatility series, for example, see Lobato and Savin (1998) and Ray and Tsay (2000). Indeed, Andersen, Bollerslev, Diebold and Labys (1999) suggested using FARIMA models to forecast daily volatility based on logarithmic realized volatility.

The traditional approach to modeling an I(0) time series Y(t) is to use the ARIMA model:

$$\Phi(L)(1-L)^d(Y(t)-\mu) = \theta(L)e_t$$ -------- (7)

Where $\Phi(L)$ and $\theta(L)$ are lag polynomials

$$\Phi(L) = 1 - \sum_{i=1}^{p}\Phi_i L^i$$ --------- (8)

$$\theta(L) = 1 - \sum_{i=1}^{p}\theta_i L^i$$ --------- (9)

With roots outside the unit circle, and $e_t$ is assumed to be an normal random variable with zero mean and variance $\rho^2$. This is usually referred to as the ARIMA (p,d,q) model. By allowing d to be a real number instead of a positive integer, the ARIMA model becomes the autoregressive fractionally integrated moving average (ARFIMA) model, or simply, fractional ARIMA (FARIMA) model.

For a stationary FARIMA model with -1/2 < d < 1/2, Sowell (1992) described how to compute the exact maximum likelihood estimate (MLE).

However, for many economic and financial time series, the data usually seem to lie on the borderline separating stationarity from non-stationarity. As a result, one usually needs to decide whether or not to difference the original time series before estimating a stationary FARIMA model, and the inference of unknown

FARIMA model parameters ignores this aspect of uncertainty in d. Beran (1995) extended the estimation of FARIMA models for any d> -1/2 by considering the following variation the FARIMA model:

$\Phi(L)\,(1-L)^{a}[(1-L)^{b}Y(t)-\mu = \theta(L)e_t$ --------- (10)

Where -1/2 < a < ½ and integer b is number of times Y(t) is differenced to achieve stationarity thus d = a + b. the standard errors of unknown parameters are computed using the asymptotic distribution derived by Beran (1995), which takes into account that b is also determined by data rather than by a prior decision.

**MODEL IMPLEMNTATION AND OBSERVATIONS**

1. FARIMA (0, d, 0)

**TABLE 5.1: FARIMA (0,D,0) IMPLEMENTATION STATISTICS**

| Model | Value | Std. Error | t-value | Pr(>\|t\|) | log-likelihood | BIC | Residual scale estimate |
|---|---|---|---|---|---|---|---|
| FARIMA(0,d,0) | d = -0.0509 | 0.0082 | -6.2408 | 0.0000 | 36130.92 | -72252.71 | 0.0048 |

Total residual
Degree of freedom: 9240 9238

d < 0 suggests that above model doesn't appear stationary for the data under consideration i.e. INR-USD 37 years exchange rate returns.

To allow for long memory and short memory at the same time, use FARIMA (p,d,q) model with p ≠ 0 or q ≠ 0. However, in practice, it is usually difficult to choose the appropriate value for p or q. Best fit model has been chosen based on minimizing minimize the Bayesian Information Criterion (BIC)

2. FARIMA (p,d,q) where p,q= [0,2]

**TABLE 5.2: BIC VALUES OF ALL MODELS ESTIMATED**

| | q=0 | q=1 | q=2 |
|---|---|---|---|
| p=0 | -72235.45 | -72291.24 | -72296.42 |
| p=1 | -72309.63 | -72306.49 | -72296.80 |
| p=2 | -72314.67 | -72305.56 | -72300.81 |

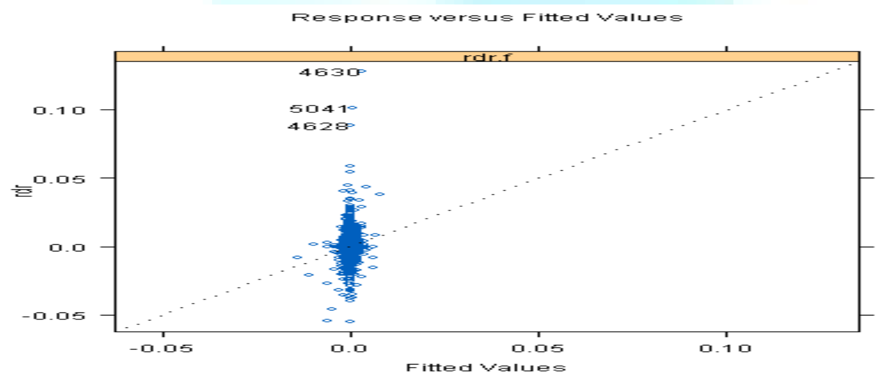
For p = 2 and q = 0 BIC value is least hence FARIMA (2, d, 0) fits the data best

Table (5.3) FARIMA (2, .004, 0) implementation statistics

| | Value | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| d | 0.0040 | 0.0167 | 0.2410 | 0.8096 |
| AR(1) | -0.1129 | 0.0198 | -5.7011 | 0.0000 |
| AR(2) | 0.0344 | 0.0142 | 2.4188 | 0.0156 |

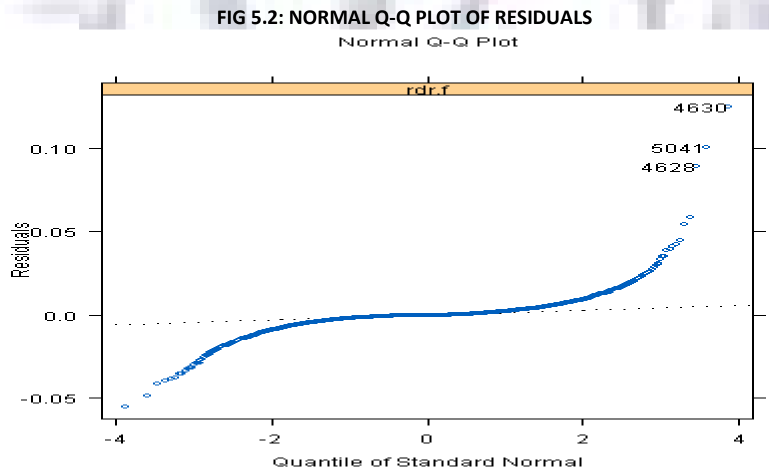
Log-likelihood: 36171.03
BIC: -72314.67
Residual scale estimate: 0.0048
Total residual
Degree of freedom: 9238 9234

**FIG 5.1: PLOT OF RESPONSE VS. FITTED VALUES**

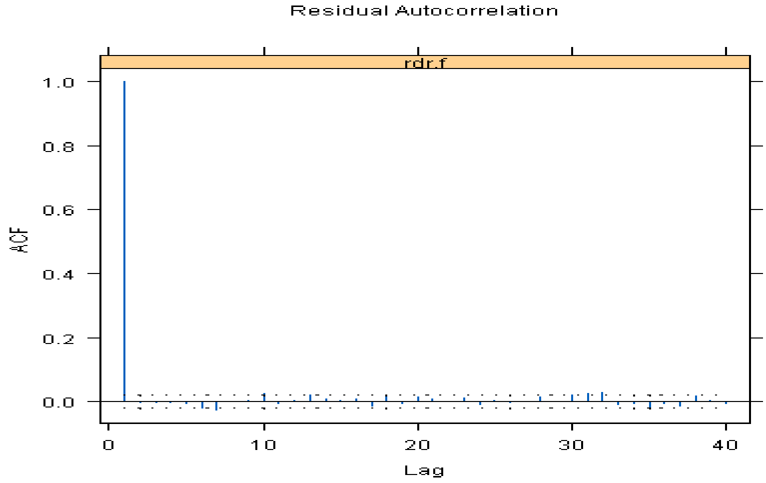



Rdr: - Rupee Dollar returns

**FIG 5.2: NORMAL Q-Q PLOT OF RESIDUALS**



FIG(5.3) ACF OF RESIDUALS




As from the above figures it can interpreted that FARIMA(2,0.004,0) models have explained long memory behavior of the INR-USD continuous returns

## CONCLUSIONS

Various studies are done on analysis of financial time series using ARMA/GARCH process in context of Indian exchange markets but exchange rate returns are highly persistent , i.e., that an unexpected shock to the underlying variable has long lasting effects. In the last few years, more applications have evolved using long memory processes, which lie halfway between traditional stationary I(0) processes and the non-stationary I(1) processes. In the case of continuous log returns of INR-USD exchange rate for last 37 years R\S test statistics confirms the presence of long memory effect and fractionally integrated process explains variations more effectively. Whittle's Method rightly estimates fractional differencing parameter. While for INR-USD returns FARIMA (0,d,0) doesn't appear stationary , hence short memory component is also induced to allow for long memory and short memory at the same time. FARIMA (p,d,q) model with $p \neq 0$ or $q \neq 0$ are analyzed BIC criterion shows for p=2, d = 0.004 and q = 0 model appears most stationary.

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