Central Bank Intervention in Foreign Exchange Market under Managed Float: A Three Regime Threshold VAR Analysis of Indian Rupee-US Dollar Exchange Rate

Ghosh, Sunandan and Kundu, Srikanta

Centre for Development Studies, Centre for Development Studies

23 April 2019

Central Bank Intervention in Foreign Exchange Market under Managed Float: A Three Regime Threshold VAR Analysis of Indian Rupee-US Dollar Exchange Rate

Sunandan Ghosh♣* and Srikanta Kundu♦

Abstract: We try to comprehensively analyze the nuances of Central Bank's intervention in the foreign exchange market under a managed float exchange rate regime. We employ a three regime threshold VAR model and identify two endogenously determined threshold values of exchange rate cycle beyond which the Reserve Bank of India (RBI) intervenes in the Indian Rupee–US Dollar (Re/$) exchange rate market. We find that, as FIIs flow in, RBI's interventions, mainly through open market operations, are successful in bringing the Re/$ exchange rate within the desired band. Within the band, the RBI tries only to mitigate domestic inflationary conditions.

Key words: Central bank intervention, Foreign exchange market, Managed float, Threshold VAR

JEL classification: E58, F31

Declarations of interest: None

Financial support: None

♣ Centre for Development Studies, Prasanth Nagar, Ulloor, Thiruvananthapuram - 695011, Kerala, India. Email: sunandan@cds.edu. Phone: +91 0471 2774 227.

♦ Centre for Development Studies, Prasanth Nagar, Ulloor, Thiruvananthapuram - 695011, Kerala, India. Email: srikanta@cds.ac.in. Phone: +91 0471 2774 213.

* Corresponding author

1. Introduction

There exists a plethora of studies analyzing the role of Central Bank's intervention in the foreign exchange (forex) market. However, there is a lack of literature comprehensively analyzing the effectiveness of Central Bank's intervention in the forex market under a managed float exchange rate regime. The analysis becomes even more nuanced when the central bank (CB) has other objectives (like inflation targeting) and/or when it does not reveal the band of the managed float. This paper makes a modest attempt to understand the nuances of such intervention when the CB tries to maintain the exchange rate within a desired band along with keeping a check on the domestic inflation level as foreign capital flows in.

Economic theory tells us that intervention in the forex market by the CB is contingent upon the country's exchange rate regime. Theoretically, the CB needs (does not need) to intervene if the country follows a fixed (flexible) exchange rate regime. Such behavior on part of the CB of a country becomes pivotal when we allow for capital flows ending up in the 'impossible trinity' of the Mundell-Fleming framework[1]. When foreign capital flows into an economy, broadly two things can happen. If the country follows a flexible exchange rate regime (no intervention by the CB) capital flows would lead to an appreciation of the domestic currency which in turn may lead to current account deficit. However, if the country follows a fixed exchange rate regime, the CB would intervene by buying up foreign exchange to keep the exchange rate unchanged leading to an increase in the foreign exchange reserve of the country (Corden, 1994).

Following the 'impossible trinity', it is obvious that the CB would give-up fixed exchange rate regime if the economy prefers an independent monetary policy along with free capital flows. However, capital flows can lead to inflationary situations if the CB does not take any sterilization measures. Thus, majority of the countries, particularly the developing ones, find it apt to follow a managed float regime[2] which helps them to keep exchange rates within a desired band[3] along with mitigating inflationary pressures that may arise due to partial intervention. Hence, the role of the CB becomes a mix of intervention and non-intervention depending on the desired and realized values of the exchange rates.

Empirical studies have extensively investigated the effectiveness of intervention of the CB in the forex market and using linear models, in the sense that parameters are considered to be fixed across time, have found mixed evidences (Baillie and Osterberg, 1997; Beine et al, 2002; Bonser-Neal and Tanner, 1996). However, linear models have been criticised on the ground that they fail to capture the effectiveness of CB intervention in the forex market as the behavior of the CB changes in different scenarios (Hsieh, 1989, 1993; Brooks, 2001; Basci and Caner, 2005). One set of literature tried to address the problem using nonlinear regime switching models, focusing particularly on the effectiveness of such intervention in tackling volatility of exchange rates (Krager and Kuglar, 1993; Lee and Lai, 2011; Suardi, 2008; Taylor and Peel, 2000). As discussed above, the notion of a managed float exchange rate regime is non-intervention within a desired band coupled with intervention outside the desired band. Hence, a very low value of the conditional variance of exchange rate cannot

[1] Aizenman (2013), however, argues that foreign exchange reserves act as a buffer and helps particularly the developing economies by relaxing the policy trilemma constraints at least in the short-run.

[2] See IMF (2016) for a detailed listing of countries according to their exchange rate regimes.

[3] Such that the domestic currency neither depreciates enough to initiate a speculative attack on the domestic currency leading to a currency crisis; nor appreciates enough to adversely affect the exports, jeopardizing the current account balance.

ensure the possibility of it not going outside the desired band. Therefore, the primary objective of the CB might well be to keep the exchange rate within a desired band rather than merely addressing exchange rate volatility. Further, we argue that the non-linear models used in the existing literature (including the two regime double threshold GARCH model employed by Suardi, 2008) are not sufficient to comprehensively analyze the effectiveness of CB intervention under a managed float regime.

This paper analyzes the problem using a threshold vector autoregressive (TVAR) model. We argue that the CB of a country following a managed float exchange rate regime would act differently under three distinct scenarios – (i) zone of no intervention (within a desired band), (ii) zone of intervention when the exchange rate tends to reach the lower value of the band and (iii) zone of intervention when the exchange rate tends to reach the upper value of the band. Accordingly, the number of regimes in the TVAR model is chosen to be three. Further, as discussed later, Likelihood Ratio (LR) tests reject the null hypothesis of linear VAR model against both two-regime and three-regime TVAR models. In this paper we consider the case of India and analyze the effectiveness of the interventions of the Reserve Bank of India (RBI) in influencing the Indian Rupee-US Dollar (Re/$) exchange rate[4].

The stated aim of RBI is to dampen the fluctuations of the exchange rate. However, it has regularly intervened in the forex market through sale and purchase of foreign currency. Interestingly, the details are not made public (Basu, 2009; Behera et al, 2008). Still, the bulging foreign exchange reserve held by RBI[5] speaks volumes about its intervention in the forex market (Baig et al, 2003). Moreover, India has adopted a managed float exchange rate regime since 1994 with an inflation targeting framework (IMF, 2016)[6]. Hence, it is highly probable that RBI attempts to keep the exchange rate within a desired band which is not disclosed to avoid speculative attacks on the Indian Rupee (Re)[7]. However, the Re/$ exchange rate has continually increased over time and hence, one might think that RBI doesn't try to maintain a band per say and it intervenes only to smoothen out excessive volatility in exchange rates.

Such understanding of the functioning of RBI coupled with limited public information of the RBI's forex market interventions has generated a plethora of literature examining the role of RBI in addressing volatility of exchange rate. However, the results are again mixed – some find RBI has been successful in reducing the volatility (Baig et al, 2003; Behera et al. 2008) while others find the opposite (Goyal et al, 2012; Inoue, 2015). Analyses of different time periods coupled with different time series models may end up with these types of conflicting results. Now, it is highly probable that RBI does try to contain the exchange rate within a band which itself is not fixed but adjusts over time according to expectations and RBI intervenes only when the exchange rate approaches an alarming zone (either towards the upper band or towards the lower band) and it does not intervene when the exchange rate is

---

[4] Apart from reasons as specified later, Aizenman (2013) identifies India as a prime example of heavily using sterilization to counter potential inflationary effects of ballooning foreign exchange reserves and hence, makes the case of India a very apt choice for the purpose of analyzing central bank's behaviour under managed float exchange rate regime.

[5] India's foreign exchange reserve increased exponentially since 1993, touching a record high of $400 billion in October, 2017.

[6] Till 1991, India followed a fixed exchange rate regime. 1992 was the year of dual exchange rate regime and India finally adopted a managed float in 1994.

[7] Whether RBI has actually managed the exchange rate with a target or not is also contested. Some empirical studies suggest that it does manage (Kohli, 2003; Jha, 2008) while others inferred that it can't (Pattnaik et al., 2003; Moore and Pentecost, 2006; Inoue and Hamori, 2009).

within the band (within the band the RBI just tackles the domestic inflationary conditions). Hence, such conflicting results are a direct outcome of the misspecification of the model where it is assumed that intervention of RBI is same for all kind of situations while, in reality, RBI may be intervening only when the exchange rate moves away from the desired band and doesn't intervene across all values of exchange rate just to address volatility. Thus, it is obvious that whether RBI has been successful in calming down exchange rate fluctuations or not would be a futile exercise until one looks into (1) when does RBI intervene and (2) whether RBI has been successful in bringing the exchange rate back within the desired band when it drifts away (in either direction).

It is in this context we make an attempt to find out when does RBI intervene to influence the Re/$ exchange rate and examine whether it has been successful in attaining its goal of bringing the Re/$ exchange rate within a desired band along with keeping a check on the domestic inflation level as FII comes in[8]. We argue that the adjustment of the band, which itself is unknown, is a result of expectation based on the historically realized values. Hence, RBI would intervene if the exchange rate depreciates (or appreciates) by a significant magnitude beyond the expected (or desired) levels.

We start with identifying these desired levels of the Re/$ exchange rate. For the purpose we employ the Hodrick-Prescott (HP) filter to decompose the data into trend and cyclical components which can respectively be interpreted as the expected value of Re/$ exchange rate and the deviation of the Re/$ exchange rate from the long run expected value. A small absolute value of the cyclical component implies that the actual realization of Re/$ exchange rate is equivalent to the expected value. Moreover, a large deviation, either positive or negative, beyond some critical level, can be identified as the 'intervention zone(s)'. Next, two unknown critical values of the cyclical component have been considered as the two threshold values of the three regime TVAR model and are estimated by the method of nonlinear least square. Finally, we try to analyze whether RBI has been successful in bringing the exchange rate back within the desired band if it has drifted away. This we have done by analyzing the short-run dynamics using TVAR analysis within each of the three zones as identified by the threshold values. One must note that these relationships would vary according to the three regimes (exchange rates are within a desired band, exchange rate depreciating significantly from the expected value and exchange rate appreciating significantly from the expected value) as the interventions of RBI would vary across different regimes.

We have found that RBI does not intervene in the Re/$ exchange rate market when the Re/$ exchange rate lies within a desirable band as endogenously determined by the two threshold values and it only tries to mitigate domestic inflationary conditions within the band. However, RBI does intervene in the forex market to influence the Re/$ exchange rate when the Re depreciates (or appreciates) more than the expected value indicated by the zone above (below) the upper (lower) threshold and, most importantly, such interventions are successful in bringing the Re/$ exchange rate within the desired band. Further, we find that, like other developing country counterparts, the RBI allows for depreciation of Re more than appreciation. Hence, proper theoretical understanding of the CB's functioning under a managed float exchange rate regime coupled with proper econometric modelling can resolve the ambiguity in the existing literature (Baig et al, 2003; Behera et al. 2008; Goyal et al,

[8] Both FII and FDI come to India and are equally important for the Indian economy. However, unlike FDIs, FIIs are highly volatile and sudden changes in the inflow of net FII may call for drastic measures by RBI which are not required in the case of FDI due the steady nature of its flow.

2012; Inoue, 2015) while analyzing the effectiveness of CB's intervention in forex market. We also find that open market operation is more effective as a policy tool of RBI as compared to CRR.

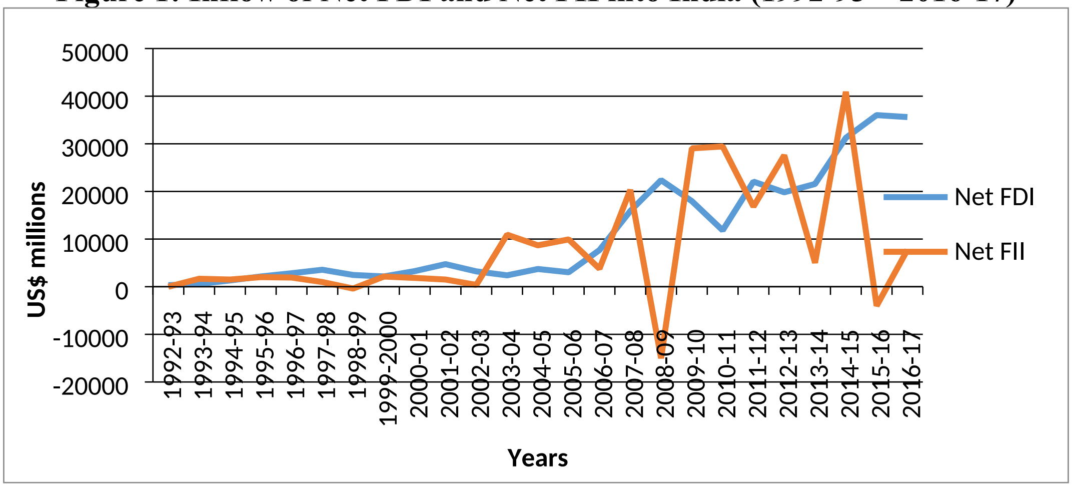
The organization of the paper is as follows. Section 2 presents the data and descriptive statistics of the variables used in this study. Section 3 provides the methodology of the analyses. Empirical results are given in Section 4. Section 5 summarizes the findings and concludes.

2. Data and Descriptive Statistics

The variables used in this analysis comprises of net Foreign Institutional Investment (FII), inflation (INF), net open market purchase of securities by RBI (OMO), change in the Cash Reserve Ratio (DCRR) and the exchange rate cycle of the Re/$ exchange rate (ERS).

In this study we have chosen FII over foreign direct investment (FDI). FDI goes in to the production and remains in the host nation for considerably longer periods of time unlike FII which is highly volatile[9]. Both FII and FDI inflows are significant for the Indian economy. Net inflow of FDI into the Indian economy has increased steadily from US$ 315mn in 1992-93 to US$ 35.6bn in 2016-17. Net inflow of FII into the Indian economy has increased from US$ 1mn in 1992-93 to US$ 40.9bn in 2014-15 and then again falling to US$ 7.7bn in 2016-17. These sudden changes in the inflow of net FII, as compared to net FDI (see Figure 1), may call for drastic measures by RBI to intervene in both forex market to influence the Re/$ exchange rate and domestic market to mitigate inflationary situations.

Figure 1: Inflow of Net FDI and Net FII into India (1992-93 – 2016-17)



Source: Authors' calculation using data from RBI

The time series of annual INF is calculated from the consumer price index (CPI) by the formula $((CPI_t - CPI_{t-4})/CPI_{t-4})$. We calculate DCRR as $(CRR_t - CRR_{t-1})$. Exchange rate cycle, ERS, is calculated from the quarterly data of Re/$ exchange rate by HP filtering. A detailed discussion of HP filtering to separate trend and cyclical component is provided later in Section 3. All data except CPI is taken from the official website of RBI

[9] There has been a considerable volume of literature that tried to analyze the determinants of foreign capital inflow (in particular FII) in to India [Chakrabarti (2001), Rai and Bhanumurthy (2004) and Sikdar (2006)]. See Coondoo and Mukherjee (2004) for an explanation of the volatility of FII for the case of India.

while data on CPI, to compute INF, has been taken from Federal Reserve Economic Data (FRED).

The period of this study is 1997Q4 to 2016Q2 (75 quarters) owing to availability of quarterly data over all the variables used in this study. We have chosen quarter as the unit of time for our analysis as opposed to month (Baig et al, 2003; Behera et al, 2008 and Inoue, 2015) or day (Goyal et al, 2012) because macroeconomic changes in a large economy like India take time to adjust; for example, a monetary policy taken by RBI would very unlikely be able to achieve its targets in a month[10], not to speak of a day.

In Table 1 we present the summary statistics for all five variables[11] used in this study. FII, INF and OMO are found to be positively skewed, whereas the skewness of DCRR is negative. Though the skewness of ERS is negative, the magnitude is very small. The value of kurtosis is around 3 for FII, INF and ERS, but OMO and DCRR have kurtosis greater than 3. Except ERS all the variables are not normal suggested by Jarque-Bera (JB) test.

Table 1: Descriptive statistics of all the variables

	FII	INF	OMO	DCRR*	ERS
Mean	2942.536	7.007	61.167	-0.078	0.025
Median	1041.500	6.387	-8.401	0.000	-0.002
Maximum	19251.000	17.858	909.940	1.000	5.766
Minimum	-6564.070	0.468	-265.464	-2.750	-5.044
Std. Dev.	5017.709	3.399	240.703	0.527	2.107
Skewness	0.993	0.855	1.884	-2.252	-0.093
Kurtosis	3.792	3.576	6.207	12.035	3.498
Jarque-Bera	14.084	10.046	75.482	314.230	0.872
Probability	(0.00)	(0.01)	(0.00)	(0.00)	(0.65)
ADF	-5.684	-4.160	-4.590	-7.804	-4.700
$p-$value	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
$Q(4)$	12.61	116.81	40.673	2.467	48.582
$p-$value	(0.01)	(0.00)	(0.00)	(0.65)	(0.00)
WDmax**	17.4838	22.1433	17.9345	30.8889	25.2888

*CRR is found to be $I(1)$ variable with ADF test statistic and p-value is -1.6945 and 0.74 respectively. Hence, we have taken first difference of CRR for the VAR analysis.
** The critical value of WDmax test at 5% level of significance is 15.59.

We have performed augmented Dicky-Fuller (ADF) test for unit root and found all the variables as stationary. As our data is in quarterly frequency we have calculated Ljung-Box test up to forth order autocorrelation and found that except DCRR all the variables have significant autocorrelation.

Given stationary series of FII, INF, OMO, DCRR and ERS we tested for structural stability of individual time series. In absence of structural breaks in the individual series one might infer a stable linear econometric relationship among the variables. The assumption of a stable linear econometric relationship among the variables would not hold true in the presence of

[10] However, we have done the same analyses using monthly data and found no statistically significant results (which are available on request). This further supports our choice of quarter as the unit of time.
[11] Seasonality of all the variables are tested by method of seasonal dummy variable and found no seasonality in all the variables.

structural breaks. In presence of structural breaks, therefore, one might opt for either phase wise linear models or nonlinear models (see Siliverstovs and van Dijk, 2003 for a detailed exposition). Given our objective of analyzing the relationship(s) of the above mentioned variables in different regimes, we have performed multiple structural break tests (Bai and Perron; 1998, 2003) for each series as a justification of choice of nonlinear models. The results of WDmax test[12] of no structural break against any unknown number of structural break is given in Table 1. The test rejects the null hypothesis of no break for all the variables.

3. Methodology

As mentioned earlier, the objectives of this paper are to find out when does RBI intervene to influence the Re/$ exchange rate and examine whether RBI has been successful in attaining its goal of bringing the Re/$ exchange rate within a desired band along with keeping a check on the domestic inflation level as FII comes in. To do so, we have employed a three regime threshold VAR (TVAR) model where the threshold variable is taken as the past values of difference between Re/$ exchange rate and its long run trend value, which can be explained as an exchange rate cycle[13]. Two threshold values, specifying three different regimes, are considered as unknown and estimated along with other parameters. As a nonlinear model, TVAR allows different parameters in different regimes, which can capture impact of RBI's intervention (either through OMO or CRR) on INF, Re/$ exchange rate and net FII inflow depending upon the regime itself. However, it must be noted that both OMO and CRR are endogenous in nature and are not exogenously chosen by RBI.

As discussed earlier, the existing studies find conflicting results on the effectiveness of RBI's intervention in the forex market (Baig et al, 2003; Behera et al. 2008; Goyal et al, 2012; Inoue, 2015). According to our understanding, such results are obtained predominantly because of inappropriate econometric modelling which fail to capture the nuances of a managed float regime. We have considered a linear VAR model considering the above mentioned variables and compare the results with those of TVAR analysis so as to compare the effectiveness of linear and non-linear models in comprehensively capturing the nuances of CB intervention in forex market under a managed float exchange rate regime.

3.1. Vector Autoregressive Model

The VAR model is specified as

$$y_t = C + A_1 y_{t-1} + A_2 y_{t-2} + \dots + A_p y_{t-k} + \varepsilon_t \quad (1)$$

where, $y_t = (FII \;\; INF \;\; OMO \;\; ERS)'$ or $y_t = (FII \;\; INF \;\; DCRR \;\; ERS)'$, C is 4×1 vector of constants, A_i $(i = 1,\dots, k)$ is 4×4 matrix of slope coefficients, ε_t is the error term with $E(\varepsilon_t) = \mathbf{0}$, and $Var(\varepsilon_t) = \Omega_{4 \times 4}$, and k is a positive integer representing the number of lags.

3.2. The Threshold Vector Autoregressive (TVAR) Model

The three regime TVAR model is specified as

[12] As we are not doing subsample analysis, we have not computed the sequential break test and the corresponding break dates.

[13] When the actual value of the Re/$ exchange rate is more (less) than the expected value, we would say that the Re has depreciated (appreciated) more than its expected value.

$$y_t = \begin{cases} C_1 + A_{11}y_{t-1} + A_{12}y_{t-2} + \dots + A_{1k}y_{t-k} + \varepsilon_t & if\ ERS_{t-1} \leq \gamma_1 \\ C_2 + A_{21}y_{t-1} + A_{22}y_{t-2} + \dots + A_{2k}y_{t-k} + \varepsilon_t & if\ \gamma_1 < ERS_{t-1} \leq \gamma_2 \\ C_3 + A_{31}y_{t-1} + A_{32}y_{t-2} + \dots + A_{3k}y_{t-k} + \varepsilon_t & if\ ERS_{t-1} > \gamma_2 \end{cases} \quad (2)$$

where y_t is defined as before. γ_1 and γ_2 are two unknown parameters, called threshold values, to be estimated. C_j $(j = 1,2,3)$ are 4×1 constant vectors for jth regime and A_{ji} $(i = 1,\dots,k; j = 1,2,3)$ are 4×4 coefficient matrices. γ_1 is typically estimated as negative whereas the same for γ_2 is positive. $\gamma_1 < ERS_{t-1} \leq \gamma_2$ implies the previous exchange rate is closer to its expected value with some deviation in either direction whereas $ERS_{t-1} \leq \gamma_1$ and $ERS_{t-1} > \gamma_2$ is capturing the too much appreciation and depreciation in the immediate past of Indian rupee vis-à-vis US \$, respectively. The number of lag (k) in both the models is determined by minimizing the BIC criteria.

Equation (2) can be re-written in a more compact way by the following equation

$$\begin{aligned} y_t = &\left(C_1 + A_{11}y_{t-1} + A_{12}y_{t-2} + \dots + A_{1k}y_{t-k}\right)I\left(ERS_{t-1} \leq \gamma_1\right) \\ &+ \left(C_2 + A_{21}y_{t-1} + A_{22}y_{t-2} + \dots + A_{2k}y_{t-k}\right)I\left(\gamma_1 < ERS_{t-1} \leq \gamma_2\right) \\ &+ \left(C_3 + A_{31}y_{t-1} + A_{32}y_{t-2} + \dots + A_{3k}y_{t-k}\right)I\left(ERS_{t-1} > \gamma_2\right) + \varepsilon_t \end{aligned} \quad (3)$$

where, $I(\cdot)$ is the indicator variable which takes value one if the argument of the indicator variable is true and zero otherwise.

The parameter vector θ consisting all the elements of C_1, C_2, C_3 and A_{ji} $(i = 1,\dots,k; j = 1,2,3)$ have been estimated by nonlinear least square by minimizing the function

$$\hat{\theta} = \text{argmin}_{\theta} \sum_{t=1}^{T} \varepsilon_t^2 \quad (4)$$

where, $$\begin{aligned} \varepsilon_t = y_t &- \left(C_1 + A_{11}y_{t-1} + A_{12}y_{t-2} + \dots + A_{1k}y_{t-k}\right)I\left(ERS_{t-1} \leq \gamma_1\right) \\ &- \left(C_2 + A_{21}y_{t-1} + A_{22}y_{t-2} + \dots + A_{2k}y_{t-k}\right)I\left(\gamma_1 < ERS_{t-1} \leq \gamma_2\right) \\ &- \left(C_3 + A_{31}y_{t-1} + A_{32}y_{t-2} + \dots + A_{3k}y_{t-k}\right)I\left(ERS_{t-1} > \gamma_2\right) \end{aligned}$$

The estimated parameters are asymptotically following normal distribution (See Hamilton J.D. (1994) for details).

3.3. Testing linearity against threshold VAR

We have done a linearity test of VAR model against a nonlinear threshold VAR model considering ERS_{t-1} as a threshold variable. To test the null hypothesis of linear VAR model (number of regime, $m = 1$) against the alternative of threshold VAR model with m=2 and 3, we have followed the multivariate generalization of linearity test developed by Hansen (1999) and Lo and Zivot (2001). The likelihood ratio (LR) test statistic is given by

$$LR = T\left(\ln\left|\hat{\Sigma}_0\right| - \ln\left|\hat{\Sigma}_1\right|\right)$$

where $\hat{\Sigma}_0$ and $\hat{\Sigma}_1$ are the covariance matrices of the error term for the null and the alternative model respectively. The $p-$values of the LR test are calculated using bootstrap method.

3.4. Hodrick-Prescott (HP) filtering

It is mentioned earlier in this paper that whether RBI will intervene in the forex market or not depends on the appreciation and depreciation of the Re/\$ exchange rate in an expected sense and not in an absolute term. We have performed ADF test and found that Re/$ exchange rate series for the time period of the present study contain stochastic trend. Hence, we have decomposed it into trend and cyclical components using HP filtering and removed the trend component from the Re/$ exchange rate series to get a stationary cyclical component. Fluctuations around the trend line are considered to be short run cyclical fluctuations (which can be considered as expected appreciation or depreciation). HP filtering is widely used in case of macroeconometrics as a standard tool to separate out long run trend value from the short run fluctuations (cyclical components). The HP filter smoothed time series $\hat{\tau}_t$ can be calculated by minimizing the formula –

$$\sum_{t=1}^{T}(x_t - \tau_t)^2 + \lambda\sum_{t=2}^{T}((\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1}))^2$$

where, λ is a nonnegative smoothing parameter, taking a value 1600 for quarterly data; T is the total sample size and x_t is the observed realization of exchange rate. τ_t is referred as the trend component and the difference between x_t and τ_t is referred as the cyclical component, specifically, exchange rate cycle (ERS) in our analysis.

4. Estimation Results

In this section we present the estimation results of our analyses. We begin with the results of linear VAR models. Two different VAR models have been estimated[14] separately by taking either OMO or DCRR along with other three variables, mentioned above. In these models, it is clear that all the four variables are positively affecting their future values implying existence of significant auto correlation. Apart from that, it has been found that there is a positive impact of OMO on inflation. This result is trivial, as higher OMO implies higher purchase of securities by RBI leading to increase in the supply of Re in the economy and hence, in turn, causing higher inflation. The estimated coefficient is 0.00197 (significant at 10% level). As per the impact of exchange rate is concerned, it has been found that ERS is positively affecting FII (significant at 5% level). This implies that a depreciation of Indian rupee will increase the inflow of FII into the economy.

On the other regression, where we have considered DCRR as an instrument of RBI, we have found an increase in ERS will significantly increase FII and reduce DCRR. Further, DCRR negatively affects ERS. The estimated coefficient is -0.93927 which is significant at 1% level.

4.1. Results of testing linearity against TVAR model

The results of threshold tests are reported in Table 2. The null hypothesis (H_0) considers a linear VAR model against the alternative of TVAR model with two or three regimes[15]. The computation is based on Hansen (1996). We have considered 15% trimming observations while doing the test. Two null hypotheses, namely, one regime versus two regimes and one regime versus three regimes have been rejected indicating a three regime TVAR model, which is akin to our understanding of the intervention of CB in the forex market corresponding to three different regimes, would be a more robust methodology. For both the

[14] The detailed results are not given in the text to minimize the space and are available on request.

[15] We tried to perform nonlinearity test of two regimes vs. three regimes, but the programming failed to provide the result. However, as discussed earlier, analysis of two-regime non-linearity is redundant in this case as either we would have a situation of a linear single regime framework or a non-linear three regime framework.

tests the p-values are 0.00 when we estimate including OMO. When we consider DCRR, the p-values are 0.00 and 0.1.

Table 2: Results for testing linearity against threshold VAR model

	1 versus 2	1 versus 3
Test statistic	61.14966	101.3435
p-value	(0.00)	(0.00)
Test statistic	55.40611	82.79983
p-value	(0.00)	(0.10)

4.2. Estimation results of three regime TVAR model

As discussed in Section 3 we have specified three regime TVAR models considering two different specifications[16]. In the first specification we have taken four variables, specifically, FII, INF, OMO and ERS, where the lag values of ERS has been considered as the threshold variable. In the second specification, instead of OMO we have considered DCRR as the instrument of RBI. We use these two different specifications to understand the relative effectiveness of the two instruments used by RBI to achieve its dual goal.

The model that we estimate (as described in equation 3) is a four equation VAR model for three regimes with each equation having 15 parameters. Further, we have two threshold values which are estimated as parameters. Hence, in our model we have 62 parameters in total which are being estimated from 75 observations[17]. The number of lag(s) in both the TVAR models is determined by minimizing Bayesian information criterion (BIC).

4.2.1. Results of specification I

Here we provide the estimated results of the first specification where we consider OMO as the instruments. Two thresholds values, γ_1 and γ_2 turn out to be (-1.49) and $(+1.81)$. Couple of points are warranted here. First, the two endogenously determined threshold values show that the three regime specification is a correct one. The threshold value of (-1.49) determines the limit when the RBI intervenes when the Re appreciates more than expected appreciation while the threshold value of $(+1.81)$ determines the limit when the RBI intervenes when the Re depreciates more than expected depreciation. Second, the intervention is earlier (-1.49) if there is unexpected appreciation as compared to depreciation $(+1.81)$. Hence, like other developing country counterparts, the RBI allows for depreciation of Re more than appreciation to boost exports.

The threshold values divide all observations in three regimes – Regime I $(-5.04 \leq ERS_{t-1} \leq -1.49)$, Regime II $(-1.49 < ERS_{t-1} \leq +1.81)$ and Regime III $(+1.81 < ERS_{t-1} \leq +5.76)$. Thus, RBI would intervene in the forex market if either the Re/$ exchange rate appreciates (Regime I) or depreciates (Regime III) more than expected. Within the band (Regime II), RBI's intervention would be singularly targeted to tackle the domestic

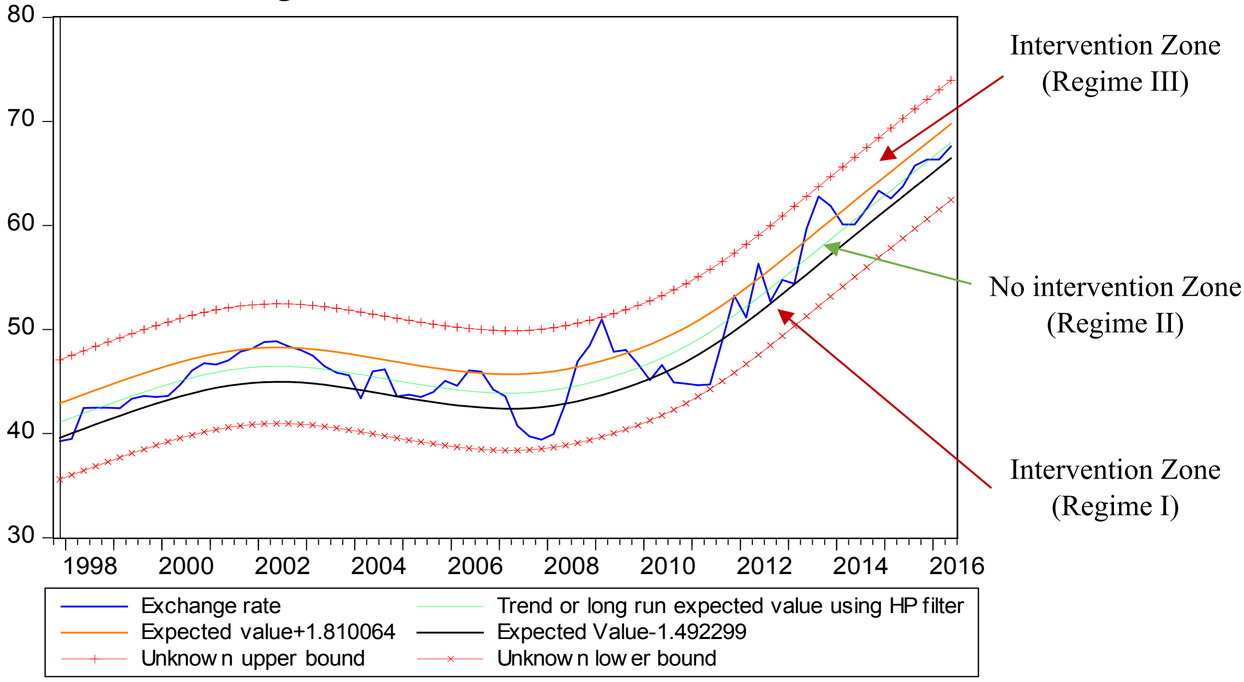
[16] All computations of TVAR estimations have been done using tsDyn package of R.

[17] Such estimation is feasible without any problem as the estimated parameters of the VAR model asymptotically follow normal distribution (Hamilton, 1994).

inflationary conditions and not the Re/$ exchange market. Figure 2 illustrates the two interventions zones (Regimes I and III) and the non-intervention zone (Regime II).

In Regime I we have 17.1% observations of our total sample, in Regime II we have 61.5% observations and 21.4 % in Regime III. Table 3 provides the estimation results.

Figure 2: Zones of intervention and non-intervention



4.2.1.1. Regime I ($-5.04 \leq ERS_{t-1} \leq -1.49$)

In Regime I, when the Re appreciates more than expected (such that $ERS_{t-1} \leq -1.49$), INF is affected only by its past value. OMO is positively affected by both its own lag and the lag of ERS. The estimated coefficients are 0.7101 and 51.854 and both are significant at 5% level. As Re depreciates (ERS increases), there is a tendency of the Re/$ exchange rate to move towards the tolerable zone (zone of non-intervention). However, such initial depreciation is occurring in a situation when Re has already appreciated more than expected and, hence, in order to bring the exchange rate back to the zone of no-intervention, RBI buys more securities from the domestic market and increases the supply of Re further. This proves, along with OMO not Granger causing INF in this regime, that RBI intervenes to bring the Re/$ exchange rate within the tolerable zone and this is captured by ERS positively Granger causing OMO.

In this regime, FII and ERS are affecting each other after one lag. FII is positively affected by the lag of FII, INF and ERS and these are statistically significant at 5%, 1% and 1% level respectively. Depreciation (more than expected) of Re/$ exchange rate generates an expectation that RBI would intervene and in the next period Re/$ exchange rate would appreciate towards the expected value. Such depreciation of $ (vis-à-vis Re) in the next period would lead to exchange rate gain, ceteris paribus, for investors investing in $ in the Indian market. This would increase the volume of flow of FII in the next period. This is exactly captured by FII being positively granger caused by ERS. On the other side, if inflation is on the increase, then RBI would intervene in the domestic market by sale of securities, that is, OMO should come down. As a result, supply of Re comes down and the Re/$ exchange rate appreciates creating a scope of exchange rate gain, ceteris paribus, for investors investing in $ in the Indian market. This would increase the volume of flow of FII in the next period. This is exactly captured by FII being positively Granger caused by INF.

In the ERS equation, it has found that the coefficient of the lag of ERS is -0.0002 and that of FII is 0.4796 which are significant at 1% and 5% level respectively. The relation between FII and ERS is straight forward. As FII increases, supply of $ increases in the economy leading to an appreciation of the Re and, hence, ERS falls.

Thus, in this regime as FII comes in, ERS falls, implying an appreciation of Re. However, as ERS falls, FII also falls which would lead to a depreciation of Re. A depreciation of Re would come along with an increased OMO pushing the Re/$ exchange rate further down towards Regime II.

Table 3: Estimation results of three regime TVAR model (Specification I)

	intercept	FII_{t-1}	$INFY_{t-1}$	OMO_{t-1}	ERS_{t-1}
Regime I ($-5.04 \leq ERS_{t-1} \leq -1.49$)					
FII_t	-4966.4261 (3762.635)	0.6029** (0.229)	1682.8112*** (453.003)	-9.1392 (7.344)	2154.5715*** (586.671)
$INFY_t$	2.4021* (1.254)	-0.0001 (0.000)	0.5961*** (0.151)	0.0018 (0.002)	-0.2921 (0.196)
OMO_t	142.6877 (164.426)	-0.0012 (0.010)	7.0931 (19.796)	0.7101** (0.321)	51.854** (25.637)
ERS_t	1.5789 (1.371)	-0.0002*** (0.000)	-0.1414 (0.165)	-0.0036 (0.003)	0.4796** (0.214)
Regime II ($-1.49 < ERS_{t-1} \leq +1.81$)					
FII_t	2125.9365 (1379.388)	0.4441** (0.168)	-166.5413 (208.071)	2.4288 (3.369)	-104.0673 (549.014)
$INFY_t$	1.7871*** (0.460)	0.0001** (0.000)	0.5783*** (0.069)	0.0025** (0.001)	0.5783* (0.183)
OMO_t	25.3814 (60.279)	0.0009 (0.007)	-2.1549 (9.093)	0.6219*** (0.147)	-29.9172 (23.992)
ERS_t	-0.1942 (0.503)	5.80E-06 (0.0001)	0.0378 (0.076)	-0.001 (0.001)	0.7982*** (0.200)
Regime III ($+1.81 < ERS_{t-1} \leq +5.76$)					
FII_t	-6627.6919 (3971.796)	1.0195** (0.404)	658.3484 (402.197)	-9.8155* (5.181)	2098.5757* (1118.504)
$INFY_t$	0.2987 (1.323)	5.40E-05 (0.000)	1.0078*** (0.134)	0.0019 (0.002)	-0.2748 (0.373)
OMO_t	225.3683 (173.567)	-0.0532*** (0.018)	22.6102 (17.576)	1.1615*** (0.226)	-139.6224*** (48.878)
ERS_t	3.2746** (1.447)	-0.0003** (0.0001)	-0.1284 (0.147)	0.0053*** (0.002)	-0.3239 (0.408)

Standard errors are given in parentheses. *, **, *** imply statistically significant at 10%, 5% and 1% levels respectively.

4.2.1.2. Regime II ($-1.49 < ERS_{t-1} \leq +1.81$)

In the non-intervention zone (Regime II), we have found that FII, OMO and ERS are affected only by their past values, whereas INF is affected significantly by FII, ERS and OMO. The estimated coefficients are 0.0001, 0.5783 and 0.0025 and the corresponding levels of significance are 5%, 10% and 5% respectively. This clearly shows that in this regime RBI intervenes only to control INF and not the Re/$ exchange rate. As OMO increases, that is, net purchase of securities by RBI increases, supply of Re in the domestic market increases which increases INF in turn. Similarly, if the Re depreciates, there will be inflationary tendencies in the economy. Further, when FII increases, there will be an increase in the supply of Re by an equivalent amount of $ inflow and unless sterilized, would lead to inflation. Thus, in this regime, an increase in FII or depreciation of Re (as captured by $\mathrm{ERS} > 0$) would lead to inflation and RBI would use OMO (through sale of securities in the domestic market) to curb inflation.

4.2.1.3. Regime III ($+1.81 < ERS_{t-1} \leq +5.76$)

In the other intervention zone, when Re depreciates more than expected ($ERS_{t-1} > +1.81$), FII, ERS and OMO all are affected by OMO. In this regime, interestingly, we find that INF is explained only by it past value. FII is positively affected by its own lag and the lag of ERS, which are statistically significant at 5% and 10% level and negatively by the lag of OMO which is statistically significant at 10% level. The explanation of positive effect of ERS on FII is same as in case of Regime I. Now, as OMO increases (which implies that net purchase of securities by RBI increases), it leads to an increased supply of Re (equivalent to the amount of securities purchased by RBI) in the economy resulting in a depreciation of the Re (vis-à-vis $). This would lead to an exchange rate loss, ceteris paribus, for investors investing in $ in the Indian market which, in turn, would decrease the volume of flow of FII in the next period. This is captured by FII is negatively affected by the lag of OMO.

Further, if FII increases, there will be excess supply of $ which would lead to an equivalent increase in Re in the Indian domestic market creating excess liquidity. Hence, RBI would sale securities in the domestic market to reduce the excess liquidity in the domestic market. This is captured by the relation that OMO is negatively caused by FII with the estimated coefficient is -0.0532 which is significant at 1%. Similarly, if the Re depreciates more than expected, then there will be inflationary situation in the domestic market and RBI would sale securities to counter the same. This is again supported by the coefficient -139.6224 significant at 1% level.

In this regime we find that ERS is positively and negatively Granger caused by lag of OMO and lag of FII respectively. An increase in OMO (which implies that net purchase of securities by RBI increases) would lead to an increased supply of Re (equivalent to the amount of securities purchased by RBI) in the economy. This would lead to depreciation of the Re (vis-à-vis $). This is captured by ERS is positively caused by lag of OMO which is significant at 1% level. Now, if FII increases, there will be excess supply of $ which would lead to an equivalent increase in Re in the Indian domestic market creating excess liquidity. Hence, RBI would sale securities in the domestic market to reduce the excess liquidity in the domestic market. This would lead to a reduction in the supply of Re and in turn, an appreciation of the Re/$ exchange rate. This is captured by ERS is negatively caused by lag of FII and significant at 5% level.

Thus, in this regime, we can see that if FII increases, then OMO comes down (RBI sales securities to counter excess liquidity in the domestic market) which in turn, would lead to an appreciation of the Re/$ exchange rate. Thus, when Re depreciates more than expected, OMO acts as an instrument to counter that shock and bring the Re/$ exchange rate within a tolerable zone. Further, in this regime, OMO, though an instrument for tackling domestic inflation, does not affect INF, which is affected only by its past value.

4.2.2. Results of specification II

When we have taken DCRR (instead of OMO) as an instrument of RBI to control exchange rate within a band, the estimated threshold values (γ_1 and γ_2) turn out to be (-1.492) and $(+0.703)$. The estimated value of the first threshold (γ_1) is similar to that in the Specification I. The value of the second threshold (γ_2) is little lesser than that in the specification I. Similar to the previous specification we have considered 15% trimming observation for testing and estimation of Threshold VAR. Total number of observation in these three regimes are 19.2%, 46.6% and 34.2% respectively. The estimation results of the second specification given in Table 4.

Table 4: Estimation results of three regime TVAR model (Specification II)

	Intercept	FII_{t-1}	INF_{t-1}	$DCRR_{t-1}$	ERS_{t-1}
Regime I $(-5.04 \leq ERS_{t-1} \leq -1.49)$					
FII_t	-5986.8137 (3910.5599)	0.5172** (0.2419)	1280.0770*** (431.7873)	6089.8733 (4180.156)	1652.3380*** (557.7184)
INF_t	2.594 (1.6053)	-0.0001 (9.90E-05)	0.7768*** (0.1772)	-1.7828 (1.7159)	-0.04 (0.2289)
$DCRR_t$	0.2315 (0.4887)	-2.20E-05 (3.00E-05)	-0.0168 (0.054)	-0.0987 (0.5224)	-0.0477 (0.0697)
ERS_t	1.1351 (1.3586)	-0.0003*** (8.40E-05)	-0.1519 (0.1500)	1.8467 (1.4523)	0.4478** (0.1938)
Regime II $(-1.49 < ERS_{t-1} \leq +0.703)$					
FII_t	2909.5002* (1535.3504)	0.6237*** (0.1832)	-279.2506 (205.5540)	1563.3223 (2036.6803)	398.8013 (622.4078)
INF_t	1.4923** (0.6303)	0.0001 (7.5e-05)	0.6786*** (0.0844)	1.8602** (0.8361)	0.3862 (0.2555)
$DCRR_t$	-0.1136 (0.1919)	1.1e-05 (2.3e-05)	-0.0101 (0.0257)	-0.1118 (0.2545)	-0.1379* (0.0778)
ERS_t	-0.4545 (0.5334)	-9.1e-06 (6.4e-05)	0.0610 (0.0714)	-0.8364 (0.7076)	0.6757*** (0.2162)
Regime III $(+0.703 < ERS_{t-1} \leq +5.76)$					
FII_t	-1996.7844 (2177.6918)	0.1653 (0.2738)	730.6386** (349.8834)	1880.7787 (1350.7003)	263.4912 (801.7546)
INF_t	-0.0079 (0.8939)	0.0001 (0.0001)	0.9818*** (0.1436)	-0.2014 (0.5545)	-0.0251 (0.3291)
$DCRR_t$	-0.3784 (0.2722)	1.5e-05 (3.4e-05)	0.0405 (0.0437)	0.1446 (0.1688)	-0.0184 (0.1002)
ERS_t	0.6279 (0.7566)	5.7e-05 (9.5e-05)	-0.1407 (0.1216)	-1.4222*** (0.4693)	0.5702** (0.2785)

Standard errors are given in parentheses. *, **, *** imply statistically significant at 10%, 5% and 1% levels respectively.

In Regime I the results are almost similar to those under Specification I. The signs of the estimated coefficients and the respective levels of statistical significance for the FII, INF and ERS equations remain unchanged. However, change in CRR is not affected by any variable in this regime contrary to Specification I where OMO is affected by the lag values of itself and the lag of ERS.

In the non-intervention zone (Regime II) we find that DCRR is positively affecting inflation which is significant at 5% level. This result is counter intuitive as RBI would increase CRR to reduce inflation. Hence, CRR fails to achieve its target of mitigating inflation which OMO successfully does (as we have found under Specification I). This result justifies RBI's decision of keeping CRR unchanged since 2013 Q1 at 4.00. Further, lag values of FII and ERS no more remain statistically significant under this specification. However, as expected, ERS is negatively affecting DCRR (significant at 10% level) as increase in CRR would reduce the supply of Re. The lag of ERS continues to affect ERS under this specification.

In Regime III under this specification, FII is only affected by the lag of INF (positively at 5% level of significance). INF is positively affected only by its lag value at 1% level of significance. ERS is affected negatively by DCRR (significant at 1% level) and positively by its own lag (significant at 5% level). Hence, one may infer that increasing CRR would help RBI to bring the Re/$ exchange rate within the tolerable zone.

5. Conclusion

There is a lack of literature comprehensively analyzing the effectiveness of such intervention under a managed float exchange rate regime. This paper makes a modest attempt to understand when does the RBI intervene in the Re/$ exchange market and whether such intervention is successful in achieving its goal of bringing the Re/$ exchange rate within a desired band along with keeping a check on the domestic inflation level as FII comes in. We find that non-linear models are more robust in capturing the effectiveness of such intervention and hence, we employ a three regime threshold VAR model.

Our analyses confirm that RBI does not intervene when the Re/$ exchange rate lies within a desirable band as endogenously determined by the two threshold values of *ERS* (the difference between actual and expected values of Re/$ exchange rate). Within the band RBI intervenes only to address domestic inflation. However, RBI does intervene in the forex market to influence the Re/$ exchange rate when the Re depreciates (or appreciates) more than the expected value indicated by the zone above (below) the upper (lower) threshold. Moreover, such interventions are successful in bringing the exchange rate within the desired band. These results resolve the ambiguity regarding effectiveness of RBI's intervention in Re/$ exchange rate market in the existing literature (Baig et al, 2003; Behera et al. 2008; Goyal et al, 2012; Inoue, 2015). Further, we find that, like other developing country counterparts, the RBI allows for depreciation of Re more than appreciation.

These findings have two serious implications – (1) Given the realized values of the Re/$ exchange rate, one can estimate the long-run expected value of the Re/$ exchange rate and following this methodology, in turn, can successfully predict not only the time of RBI's intervention, but the direction and magnitude as well. Moreover, for the purpose one does not require to know the exact values of the unknown limits of the band within which RBI tries to arrest the Re/$ exchange rate. (2) Lack of comprehensive understanding of a CB's functioning under managed float exchange rate regime and/or incorrect model specification is the fundamental cause of economists arriving at conflicting results when evaluating the effectiveness of RBI in addressing exchange rate volatility.

We also find that open market operation is more effective as a policy tool of RBI as compared to CRR. This result justifies RBI's decision of keeping the CRR unchanged since 2013Q1. This might well signal the emergence of a strong financial market structure in the Indian economy.

We also find that apart from its past values, net FII inflow in to the Indian economy depends on the difference between actual and expected values of Re/$ exchange rate (*ERS*) and hence, in turn, on RBI's intervention outside the band defined by the endogenous threshold values of *ERS*.

References

1. Aizenman, J. (2013). The Impossible Trinity—from the Policy Trilemma to the Policy Quadrilemma. *Global Journal of Economics*, 2, 1350001.
2. Bai, J. & Perron, P. (1998). Estimating and testing linear models with multiple structural changes. *Econometrica*, 66, 47-78.
3. Bai, J. & Perron, P. (2003). Computation and analysis of multiple structural change models. *Journal of Applied Econometrics*, 18, 1-22.
4. Baig, M.A., Narasimhan, V. & Ramachandran, M. (2003). Exchange market pressure and the Reserve Bank of India's intervention activity. *Journal of Policy Modeling*, 25, 727-748.
5. Baillie, R.T. & Osterberg, W.P. (1997). Why do central banks intervene? *Journal of International Money and Finance*, 16, 909–919.
6. Basci, E. & Caner, M. (2005). Are real exchange rates nonlinear or nonstationary? Evidence from a new threshold unit root test. *Studies in Nonlinear Dynamics and Econometrics*, 9, 1–19.
7. Basu, K. (2009). The mechanics of central bank intervention in foreign exchange markets. *CAE Working Paper*, No. 09-02.
8. Behera, H., Narasimhan, V. & Murty, K.N. (2008). Relationship between exchange rate volatility and central bank intervention: An empirical analysis for India. *South Asia Economic Journal*, 9, 69–84.
9. Beine, M., Bénassy-Quéré, A. & Lecourt, C. (2002). Central bank intervention and foreign exchange rates: new evidence from FIGARCH estimations. *Journal of International Money and Finance*, 21, 115–144.
10. Bonser-Neal, C. & Tanner, G. (1996). Central bank intervention and the volatility of foreign exchange rates: evidence from the options market. *Journal of International Money and Finance*, 15, 853–878.
11. Brooks, C. (2001). A double threshold GARCH model for the French franc/Deutschmark exchange rate. *Journal of Forecasting*, 20, 135–143.
12. Chakrabarti, R. (2001). FII Flows to India: Nature and Causes. *Money and Finance*, 2, 61-81.
13. Coondoo, D. & Mukherjee, P. (2004). Volatility of FII in India. *Money and Finance*, 2, 85-101.
14. Corden, W.M. (1994). *Economic Policy, Exchange Rates and the International System*. Oxford: Oxford University Press.

15. Goyal, A. & Arora, S. (2012). The Indian exchange rate and central bank action: An EGARCH analysis. *Journal of Asian Economics*, 23, 60–72.
16. Hamilton, J. D. (1994). *Time Series Analysis*. Princeton: Princeton University Press.
17. Hansen, B. (1999). Testing for linearity. *Journal of Economic Surveys*, 13, 551-576.
18. Hsieh, D.A. (1989). Modelling heteroscedasticity in daily foreign exchange rates. *Journal of Business and Economic Statistics*, 7, 307–317.
19. IMF (2016). *Annual Report on Exchange Arrangements and Exchange Restrictions*.
20. Inoue, T. (2015). Central Bank Intervention and Exchange Rate Behavior: Empirical Evidence for India. *The Singapore Economic Review*, 60, 1550016.
21. Inoue, T. & Hamori, S. (2009). What explains real and nominal exchange rate fluctuations? Evidence from SVAR analysis for India. *Economics Bulletin*, 29, 2810–2822.
22. Jha, R. (2008). Inflation targeting in India: Issues and prospects. *International Review of Applied Economics*, 22, 259–270.
23. Kohli, R. (2003). Real exchange rate stabilisation and managed floating: Exchange rate policy in India, 1993–2001. *Journal of Asian Economics*, 14, 369–387.
24. Kräger, H. & Kugler, P. (1993). Nonlinearities in foreign exchange markets: a different perspective. *Journal of International Money and Finance*, 12, 195–208.
25. Lee, H.Y. & Lai, H.P. (2011). A structural threshold model of the exchange rate under optimal intervention. *Journal of International Money and Finance*, 30, 931-946.
26. Lo, M.C. & Zivot, E. (2001). Threshold cointegration and nonlinear adjustment to the law of one price. *Macroeconomic Dynamics*, 5, 533-576.
27. Moore, T. & Pentecost, E.J. (2006). The sources of real exchange rate fluctuations in India. *Indian Economic Review*, 41, 9–23.
28. Pattnaik, R.K., Kapur, M. & Dhal, S.C. (2003). Exchange rate policy and management: The Indian experience. *Economic and Political Weekly*, 38, 2139–2154.
29. Rai, K. & Bhanumurthy, N.R. (2004). Determinants of Foreign Institutional Investment in India: The Role of Return, Risk and Inflation. *The Developing Economies*, XLII, 479-493.
30. Sikdar, S. (2006). Foreign Capital Inflow into India: Determinants and Management. *INRM Policy Brief* # 4, ADB: New Delhi.
31. Siliverstovs, B. & van Dijk, D.J.C. (2003). Forecasting industrial production with linear, nonlinear, and structural change models. *Econometric Institute Research Papers*, No. EI 2003-16, Erasmus School of Economics.
32. Suardi, S. (2008). Central bank intervention, threshold effects and asymmetric volatility: Evidence from the Japanese yen–US dollar foreign exchange market. *Economic Modelling*, 25, 628-642.
33. Taylor, M.P. & Peel, D.A. (2000). Nonlinear adjustment, long-run equilibrium and exchange rate fundamentals. *Journal of International Money and Finance*, 19, 33–53.