The Reserve Bank of India's Reaction to Exchange Rate Variation: A time-varying parametric approach

A Vadivel
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A Vadivel is TTI Fellow, Institute of Economic Growth, Delhi
email: arjunavadivel@gmail.com

M Ramachandran is Professor, Department of Economics, Pondicherry University, Puducherry.
email: ramchn2003@yahoo.co.in

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ABSTRACT

This paper explores the intervention of the Reserve Bank of India in foreign exchange markets. Since the exchange rate has been fluctuating because of external capital flows, the RBI had to intervene to bring stability in the foreign exchange market. The empirical examination of this issue is conducted by using the flexible least square (FLS) method. The study used four different variants of the reaction function to know the time-varying nature of the variables. The results revealed an asymmetry in the RBI's intervention in exchange rate and reserve accumulation—it has frequently penalised the rupee's appreciation and defended its depreciation.

Keywords: Exchange rate, foreign exchange reserve, time-varying

JEL codes: C32, F31

1 INTRODUCTION

The former RBI Governor Dr Y V Reddy stated that the official intervention in the foreign exchange market from 1990 to 2000 was a journey from agony to comfort. However, the comfortable situation that prevailed in 2000 turned out to be a problem of plenty in March 2012 when reserve accumulation peaked at US$ 294.397 billion. Hence, the RBI has been confronting problems like inadequacy of reserves, exchange rate volatility, and excessive appreciation of the rupee due to huge inflows of foreign exchange at some point of time, and has had to adjust its policy of exchange rate intervention to changing circumstances in the foreign exchange market.

Because circumstances have been changing, an econometric model that assumes its parameters are constant would lead to misleading policy prescriptions. Similarly, the reasons for the accumulation of foreign exchange reserves have differed over time. Therefore, the present paper aims at modeling the RBI's exchange rate intervention through a reaction function that allows its parameters to vary over time. There are several methods in the literature to estimate the time-varying parameters of an econometric model, which fall into three broad categories.

(1) The parameters of the model can vary over a sub-set of the sample and, if so, an optimisation exercise can be used for the sub-set of the sample to obtain model parameters.

(2) The parameters of the model are assumed to follow a stationary stochastic process. Its best example is the random coefficient model of Rao (1965).

(3) The parameters are generated through a non-stationary stochastic process. This class includes the mixed estimation method of Cooper (1973), Kalman filter model of Athans (1974), time-varying coefficients model of Chow (1984), the FLS method of Kalaba and Tesfatsion (1988 and 1989), the recursive model of Rao (1991), and the optimal control model of Rao and Nachane (1988)[1].

We propose to use the FLS method of Kalaba and Tesfatsion (1988 and 1989) as it is computationally straightforward and permits the exact sequential updating of the FLS estimates as additional observations are obtained.

2 THE FLEXIBLE LEAST SQUARE (FLS) APPROACH

The FLS approach introduced by Kalaba and Tesfatsion (1988, 1989) formulates a time-varying linear regression problem as follows. Suppose noisy observations, $y_1,\ldots,y_T$ over a time-span $1,\ldots,T$ have been generated by a linear regression model with coefficients

[1] An excellent review of all these methods is available in Rao (2000).

that evolve only slowly over time. Let y_t denotes the dependent variable; x_t denotes a vector of regressors and b_t denotes a vector of regressor coefficients observed at time *t*. the measurement specification can be expressed as

$$y_t = x_t^{'} b_t \qquad t = 1,\ldots,T \qquad (1)$$

Instead of imposing strict time constancy on the coefficients, the FLS approach captures time variation through a prior dynamic specification, called smoothness, prior for successive coefficient vectors:

$$b_{t+1} \approx b_t \qquad t = 1,\ldots,T-1 \qquad (2)$$

The measurement and dynamic specifications reflect the prior beliefs of linear measurement and coefficient stability in a simple, direct way, without any distributional assumptions about the error term required for ordinary least square (OLS) or Kalman filter estimation[2].

Two basic types of model specification errors are associated with each possible coefficient sequence estimate $b = (b_1,\ldots,b_t)$.

First, b could fail to satisfy the prior measurement specification because of a discrepancy between the observed dependent variable y_t and the estimated linear regression model $x_t^{'} b_t$ at each time *t*. This discrepancy could arise because of misspecification, wrong functional form, etc.

Second, b could fail to satisfy the prior dynamic specification because of a possible coefficient variation for the included variables. Suppose the cost assigned to b for the first type of error is measured by the sum of squared residual measurement errors.

$$r_M^2(b;T) = \sum_{t=1}^{T} \left[y_t - x_t^{'} b_t \right]^2, \qquad (3)$$

and the cost assigned to b for the second type of error is measured by the sum of squared residual dynamics errors.

$$r_D^2(b;T) = \sum_{t=1}^{T-1} \left[b_{t+1} - b_t \right]^{''} D \left[b_{t+1} - b_t \right] \qquad (4)$$

where D is a suitably chosen scaling matrix that makes the cost function essentially invariant to the choice units for the regressor variables.

[2] The flexible least square (FLS) method is a generalisation of Kalman filtering, as discussed in several works (such as Lutkepohl 1993). Typically, Kalman filtering requires the analyst to assume a particular stochastic structure for the time-varying coefficients, and that the disturbances follow a specific distribution; but we can seldom know beforehand the stochastic process that moves the coefficients, and may have little confidence that the disturbances are normal.

Kalaba and Tesfatsion define the FLS solution as the collection of all coefficient sequence estimates *b*, which yields vector-minimal sums of squared measurement and dynamic errors for the given observations, i.e. it attains the residual efficiency frontier (REF). The REF reveals the cost in terms of residual measurement error that must be paid to achieve the zero residual dynamic error (time-constant coefficients) required by OLS estimation.

How might the REF be found? The incompatibility cost function $C(b;\delta,T)$ that attains the REF for all possible choices is formed by taking the weighted sum of these two types specification error as follows.

$$C(b;\delta,T)=\frac{\delta}{1-\delta}\sum_{t=1}^{T-1}\left[b_{t+1}-b_t\right]^{''}D\left[b_{t+1}-b_t\right]+\sum_{t=1}^{T}\left[y_t-x_t^{'}b_t\right]^2, \qquad (5)$$

where O δ 1 is the weight factor that assigns a relative priority to the two priors in the model specification.

The OLS method is just a special case of FLS in that a restriction is imposed that fixes the potentially time-varying coefficients to constant values. Indeed, it can be seen from Equation 5 that FLS $\rightarrow$ OLS as $\delta \rightarrow 1$. In other words, the OLS solution lies at one end of the REF, so it is just a limiting case of FLS.

As Equation 5 indicates, the incompatibility cost function $C(b;\delta,T)$ generalises the goodness-of-fit criterion function for OLS estimation by permitting the coefficient vector *b* to vary over time. The incompatibility cost function is strictly a convex function of the coefficients sequence estimation *b* and there exists a unique estimate *b*, which attains the minimum cost. The use of a quadratic loss function implies that the resulting problem can be solved within the framework of optimal control. The FLS solution is defined to be the collection of all coefficient sequence estimates, which minimize the incompatibility cost function. The coefficient sequence estimates (*b*) that attain this frontier are referred to as FLS estimates.

In Kalaba and Tesfatsion (1988, 1989) a procedure is developed for sequentially generating the FLS solution. The algorithm gives directly the estimates $b_t^{FLS}(\delta,t)$ for the time-*t* coefficient vector b_t conditional on the observations $y_1,\ldots,y_T$ as each successive observation y_t is obtained. The algorithm also yields smoothed (back-updated) estimates for all intermediate coefficients vectors for times 1 through *t*–1 conditional on the observations $y_1,\ldots,y_T$.

3 EMPIRICAL RESULTS OF THE FLEXIBLE LEAST SQUARE (FLS) METHOD

This study used weekly secondary data collected from the Reserve Bank of India Handbook of Indian Economy and the Bombay Stock Exchange from 1 August 1995 to 26 July 2013. The variables included are foreign currency assets, exchange rate, volatility of foreign currency assets, and BSE-SENSEX. We estimate the intervention reaction function to infer the characteristics of the RBI's intervention policy in the foreign exchange market during the managed float regime. Considering the empirical finding that the official response to the exchange rate variation is time varying, we use the FLS method to obtain time varying parameters of the intervention reaction function. The following four specifications of reaction functions are estimated:

$$\tilde{R}_t = a_{ot} + a_{1t}\tilde{e}_{t-1} + V_t$$
$$\tilde{R}_t = a_{o1} + \alpha_{1t}\tilde{e}_{t-1} + \alpha_{2t}\,\sigma_{t-1} + v_t$$
$$\tilde{R}_t = \alpha_{ot} + \lambda_{1t}\tilde{e}^{a}_{t-1} + \lambda_{2t}\tilde{e}^{a}_{t-1} + \alpha_{2t}\sigma_{t-1} + v_t \qquad (6)$$
$$\tilde{R}_t = \alpha_{0t} + \lambda_{1t}\tilde{a}^{a}_{t-1} + \lambda_{2t}\tilde{a}^{a}_{t-1} + \Upsilon_{1t}s_{t-1} + \alpha_{2t}\,\sigma_{t-1} + v_t$$

where

$\tilde{R}$ is weekly percentage change in foreign currency asset holdings of the RBI;

$\tilde{e}$ is weekly percentage change in Re/US$ exchange rate;

σ is conditional volatility of incremental foreign currency assets of the RBI obtained from an appropriate GARCH generalised autoregressive conditional heteroskedasticity model;

$\tilde{e}^{a}$ is exchange rate measure having negative sign;

$\tilde{e}^{d}$ is exchange rate measure having positive sign; and

s_t stock return measured as percentage change in BSE Sensex.

The coefficients and in the third and fourth specifications of equation (6) measure the RBI's response to the appreciation and depreciation of the rupee, respectively; hence, intervention turns out to be asymmetric if. $\lambda_{1t} \pm \lambda_{2t}$.

First, we examine the time-varying nature of the parameters in the model. In this regard, we plot the residual efficiency frontier (REF) in Figures 1 to 4, wherein the measurement errors are on the vertical axis and the residual dynamic errors are on the horizontal axis. The shape of the frontier indicates if the OLS solution can provide the best description of the observations. The left extreme point of the frontier, also called the OLS extreme point, gives the minimum possible values of measurement error subject to the condition that dynamic errors are zero; hence, this extreme point exhibits the cost in terms of residual measurement errors that must be accepted for choosing the fixed coefficient solution. The extreme point on the right hand side gives the minimum possible values of dynamic errors subject to the condition that measurement errors are zero. Thus, the right extreme point reveals the minimum time variation in coefficients that must be allowed in order to have no residual measurement errors—a perfect fit of the regression model.

Figure 1 Residual Efficiency Frontier for specification 1

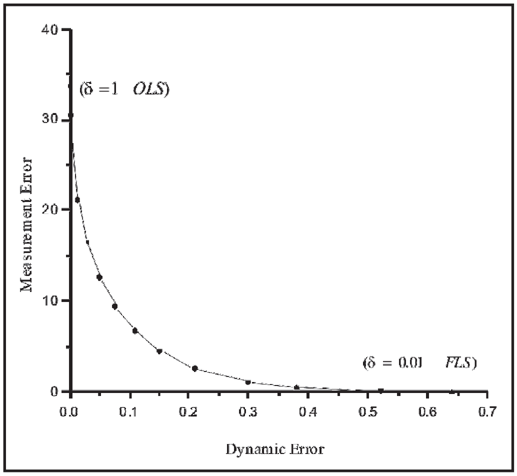


Figure 2 Residual Efficiency Frontier for specification 2

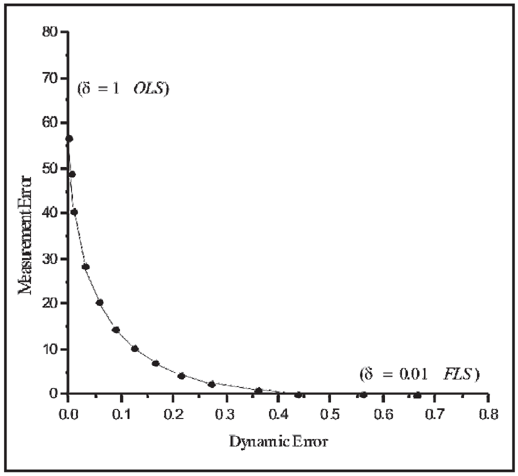


Figure 3 Residual Efficiency Frontier for specification 3

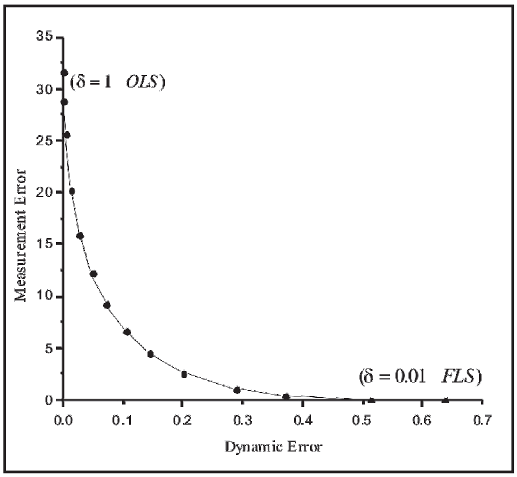
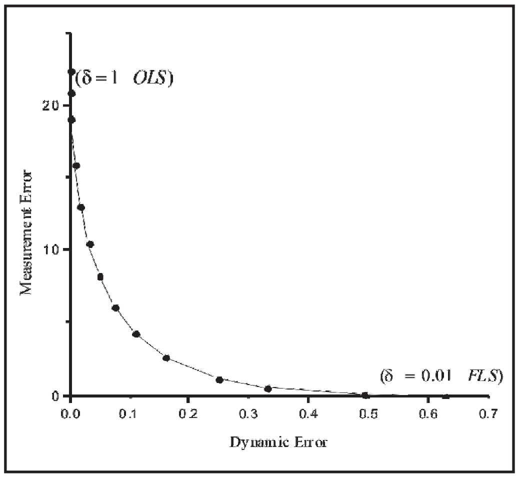


Figure 4 Residual Efficiency Frontier for specification 4



In Figures 1 to 4, the efficiency frontier for four different specifications of intervention reaction function is plotted. If parameters of the true model are time-invariant, then the efficiency frontier must be flat in the neighbourhood of the OLS extreme point. On the contrary, if the true model has time-varying coefficients, the frontier must be steeply sloped in the neighborhood of OLS extreme point; hence, the OLS solution may not provide good fit of the observations. The plots in Figures 1 to 4 indicate that the efficiency frontier for all four specifications are fairly steeply sloped; hence, allowing a small degree of time variation in coefficients results in a larger reduction in measurement error. This is evidence that some of the coefficients in the intervention reaction function are changing through time.

Further, time variation in each coefficient is examined using the estimates of mean, standard deviation, and coefficient of variation of each parameter in the reaction functions for alternative values of δ . The alternative value of δ is presented in Table 1. In case of the OLS weighting scheme producing a bias, the coefficient means tend to shift and standard deviation tends to increase monotonically as we change δ value by a small amount. However, the mean coefficients and standard deviation stabilise as we move δ value towards zero.

Table 1 Summary statistics of FLS estimates

Specification : $\widetilde{R}_t = \alpha_{0t} + \alpha_{1t}\widetilde{e}_{t-1} + \nu_t$

α	α_0	α_1	δ	α_0	α_1
1	0.375	-0.271	0.50	0.343	-0.176
	(0.007)	(0.008)		(0.026)	(0.021)
	[0.53]	[-0.85]		[2.04]	[-3.23]
0.999	0.375	-0.271	0.40	0.341	-0.171
	(0.007)	(0.008)		(0.027)	(0.022)
	[0.53]	[-0.85]		[2.15]	[-3.54]
0.99	0.372	-2.40	0.30	0.341	-0.168
	(0.016)	(0.012)		(0.028)	(0.024)
	[0.86]	[-1.21]		[0.028]	(0.024)
0.95	0.364	-0.222	0.20	0.340	-0.165
	(0.016)	(0.012)		(0.030)	(0.026)
	[1.20]	[-1.52]		[2.40]	[-4.23]
0.90	0.358	-0.209	0.10	0.339	-0.163
	(0.018)	(0.014)		(0.032)	(0.028)
	[1.39]	[-1.77]		[2.56]	[-4.62]
0.80	0.351	-0.196	0.05	0.339	-0.163
	(0.021)	(0.016)		(0.033)	(0.029)
	[1.62]	[-2.20]		[2.64]	[-4.83]
0.70	0.327	-0.187	0.01	0.339	-0.162
	(0.023)	(0.018)		(0.034)	(0.030)
	[1.78]	[-2.57]		[2.73]	[-5.01]
0.60	0.345	-0.181			
	(0.024)	(0.019)			
	[1.92]	[-2.90]			

Note: Figures in (#) and [#] are respectively the standard deviation and coefficient of variation.

Figure 5a Plots of time varying α_{0t}

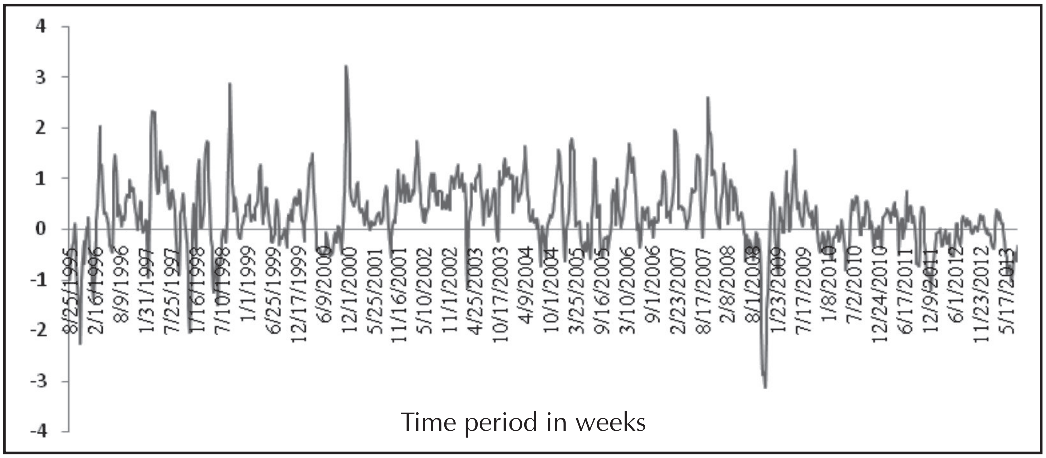
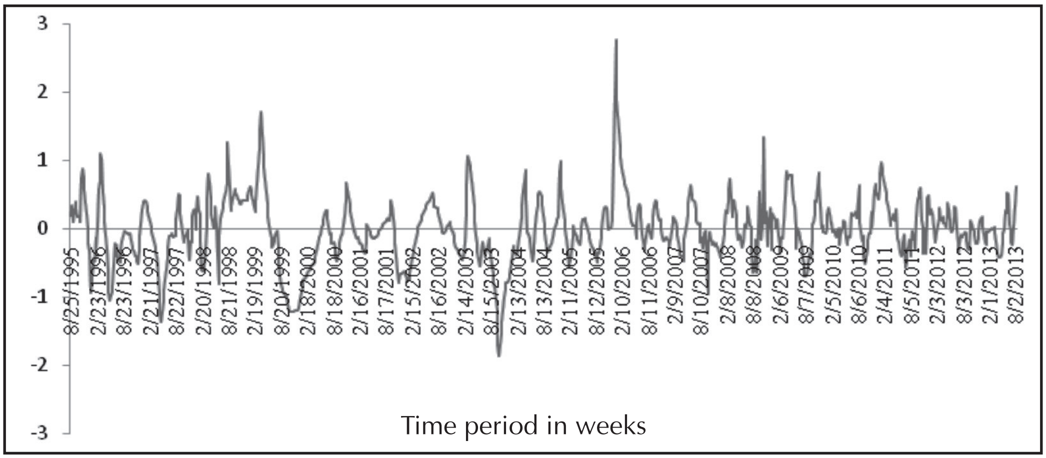


Figure 5b FLS coefficient α_{1t}



The plots of time-varying drift in Equation 6 are presented in Figure 5a. It is obvious that the coefficient fluctuates highly throughout the sample period. More interestingly, the plots in Figure 5b confirm that the RBI's reaction to the variation in the exchange rate does not always lean against the wind. If the intervention aims at leaning against the wind and thereby stabilising the exchange rate, the coefficient must remain in the negative region during the entire sample period. However, while the coefficient seems to be largely in the negative region during 1996 to 2002, the RBI did sometimes subsequently lean with the wind. This proves that the policy of official intervention in the foreign exchange market is not consistent; hence, there seems to be some hidden objectives apart from avoiding undue fluctuations in the exchange rate.

The second specification of Equation 6 includes the volatility of the exchange rate as an additional variable, as the official intervention mainly aims at minimising the volatility of the exchange rate rather than targeting the exchange rate at some predetermined level. The fluctuation in α_{1t} does not seem to be significantly dissimilar to the one produced in Figure 6c. The fluctuation in the coefficient with respect to volatility reflects the RBI's primary concern regarding exchange rate stability. The coefficient exhibits significant spikes, especially when the rupee is under pressure to depreciate from economic and financial crises and excessive cross-border capital flows during the sample period.

Table 2 Summary statistics of FLS estimates

Specification : $\tilde{R}_t = \alpha_{0t} + \alpha_{1t}\tilde{e}_{t-1} + \alpha_{2t}\sigma_{t-1} + \nu_t$

δ	α_{0t}	α_{1t}	α_{2t}	δ	α_{0t}	α_{1t}	α_{2t}
1	0.180	-0.262	0.216	0.50	0.167	-0.153	0.169
	(0.006)	(0.009)	(0.006)		(0.030)	(0.020)	(0.020)
	[0.84]	[-0.90]	[0.78]		[4.87]	[-3.57]	[3.21]
0.999	0.180	-0.262	0.216	0.40	0.154	-0.151	0.181
	(0.006)	(0.009)	(0.006)		(0.031)	(0.021)	(0.021)
	[0.84]	[-0.90]	[0.78]		[5.51]	[-3.021]	[3.20]
0.99	0.140	-0.225	0.250	0.30	0.141	-0.150	0.194
	(0.011)	(0.011)	(0.007)		(0.032)	(0.023)	(0.023)
	[2.13]	[-1.28]	[0.74]		[6.28]	[-4.13]	[3.16]
0.95	0.180	-0.191	0.184	0.20	0.128	-0.149	0.209
	(0.017)	(0.012)	(0.009)		(0.034)	(0.024)	(0.024)
	[2.55]	[-1.67]	[1.42]		[7.24]	[-4.40]	[3.11]
0.90	0.196	-0.185	0.156	0.10	0.113	-0.148	0.225
	(0.020)	(0.013)	(0.012)		(0.035)	(0.025)	(0.025)
	[2.82]	[-1.99]	[2.01]		[8.52]	[-4.68]	[3.06]
0.80	0.197	-0.169	0.144	0.05	0.105	-0.148	0.233
	(0.024)	(0.015)	(0.015)		(0.036)	(0.026)	(0.026)
	[3.31]	[-2.49]	[2.82]		[9.34]	[-4.83]	[3.03]
0.70	0.189	-0.161	0.149	0.01	0.098	-0.148	0.241
	(0.026)	(0.017)	(0.017)		(0.037)	(0.027)	(0.027)
	[3.79]	[-2.90]	[3.01]		[10.13]	[-4.94]	[3.003]
0.60	0.178	-0.156	0.158				
	(0.028)	(0.019)	(0.018)				
	[4.30]	[-3.25]	[3.19]				

Note: Figures in (#) and [#] are respectively the standard deviation and coefficient of variation.

The estimates of coefficient means, standard deviation, and coefficient of variations for alternative values of δ for the basic model are presented in Table 2. We move the value of δ closer to unity and it stabilises in the neighbourhood of OLS extreme point. The standard error corresponding to this coefficient is also rising and stabilising in the extreme. The same observations can be made from the plots of standard errors obtained from the remaining specifications of the reaction function as we go through plots presented in the respective figures. This evidence confirms the fact that coefficients in all the four specifications of Equation 6 tend to vary depending upon the movements in the explanatory variables that figure in the equations.

Figure 6a FLS coefficient α_{0t}

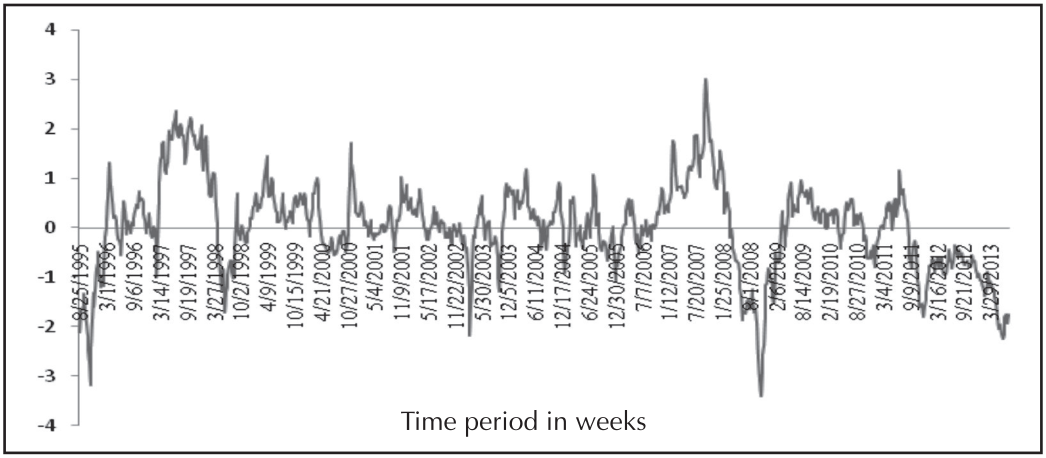


Figure 6b FLS coefficient α_{1t}

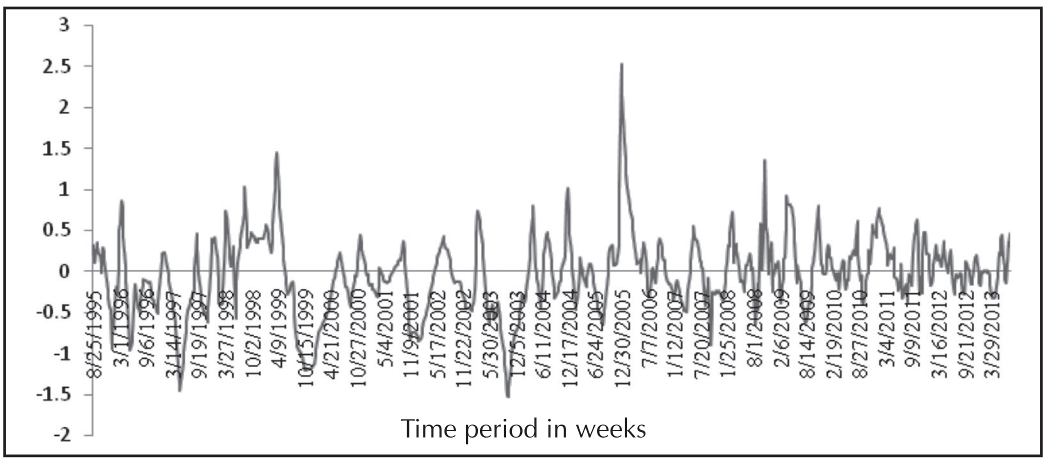
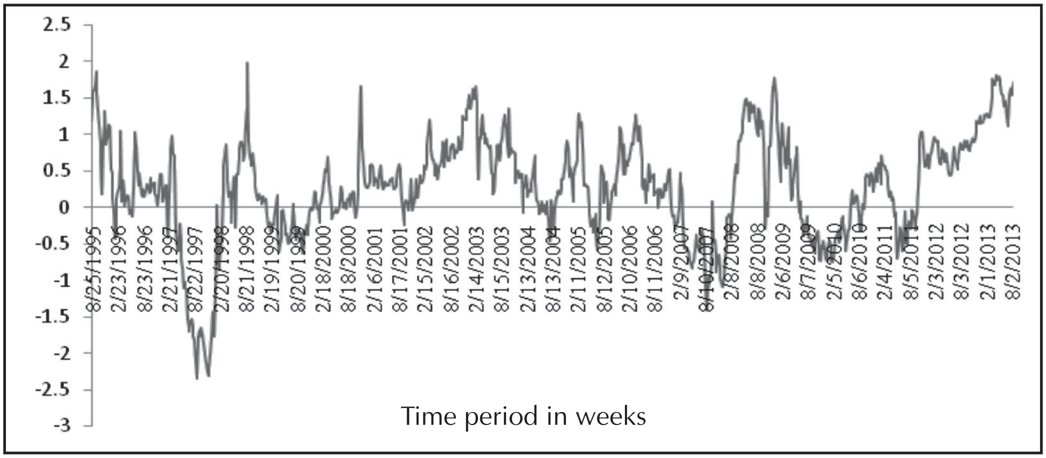


Figure 6c FLS coefficient α_{2t}



The third specification of Equation 6 is more crucial in the present context, as it captures the asymmetric response of the RBI to exchange rate fluctuations. Further, the estimates of coefficient of mean, standard deviation, and coefficient of variation of alternative δ values are presented in Table 3. The coefficient of volatility presented in Figure 6c seems to behave in a manner similarly to that in Figure 7d. However, the plots of λ_{1t} and λ_{2t} measuring the official response to appreciating and depreciating rupee respectively in Figures 7c and 7d reflect some striking features concerning the asymmetry in exchange rate intervention. The magnitude of the coefficient with respect to the appreciating rupee is larger than the coefficient with respect to the depreciating rupee. This observation indicates that the RBI has been more aggressive against the appreciating rupee than against the depreciating rupee. This finding is consistent with the evidence obtained from earlier studies (Ramachandran and Srinivasan 2007). Moreover, there is clear evidence of asymmetry during 1998–2000 and 2007–2008. During these periods, the coefficient with respect to the appreciating rupee remains positive, while that with respect to the depreciating rupee remains negative. This implies that the RBI was leaning against the wind when the rupee was under pressure to depreciate, but was leaning with the wind when the rupee was under pressure to appreciate. If the RBI practised such an asymmetric intervention policy, it is very hard to explain how much of the reserve accumulation took place during 2006–2008 (Vadivel 2009).

This study further probes this issue by incorporating stock market development as an additional variable in the model as it is described in the fourth specification of Equation 6. The reason for including this variable is supported by the evidence from boom in stock market the RBI could accumulate more than 50 per cent of current reserve holdings.

Table 3 Summary statistics of FLS estimates

Specification: $\tilde{R}_t = \alpha_{ot} + \lambda_{1t}\tilde{e}^{a}_{t-1} + \lambda_{2t}\tilde{e}^{a}_{t-1} + \alpha_{2t}\sigma_{t-1} + v_t$

δ	δ_{0t}	λ_{1t}	λ_{2t}	α_{2t}	δ	α	λ_{1t}	λ_{2t}	α_{2t}
1	0.118	0.199	-0.234	0.287	0.50	-0.029	-0.105	0.034	0.298
	(0.004)	(0.004)	(0.006)	(0.009)		(0.030)	(0.206)	(0.017)	(0.024)
	[1.11]	[0.64]	[-0.80]	[0.98]		[-31.74]	[-5.96]	[15.33]	[2.43]
0.999	0.118	0.199	-0.234	0.287	0.40	-0.020	-0.125	0.038	0.284
	(0.004)	(0.004)	(0.006)	(0.009)		(0.032)	(0.025)	(0.018)	(0.025)
	[1.11]	[0.64]	[-0.80]	[0.98]		[-48.62]	[-5.53]	[1.974]	[3.32]
0.99	0.013	0.159	-0.132	0.361	0.30	-0.010	-0.141	0.040	0269
	(0.008)	(0.009)	(0.008)	(0.011)		(0.033)	(0.023)	(0.020)	(0.026)
	[18.64]	[1.72]	[-1.85]	[0.94]		[-99.40]	[-4.99]	[15.08]	[3.02]
0.95	-0.027	-0.097	-0.059	0.365	0.20	0000.97	-0.155	0.042	0.254
	(0.009)	(0.012)	(0.017)	(0.014)		(0.034)	(0.024)	(0.021)	(0.028)
	[-15.84]	[3.78]	[-4.84]	[0.96]		[10929.0]	[-4.78]	[15.47]	[3.35]
0.90	-0.040	0.048	-0.025	0.359	0.10	0.011	-0.167	0.043	0.239
	(0.018)	(0.013)	(0.011)	(0.014)		(0.036)	(0.025)	(0.022)	(0.029)
	[-13.74]	[8.78]	[-12.84]	[1.16]		[100.48]	[-4.67]	[16.01]	[3.37]
0.80	-0.046	-0.013	0.005	0.343	0.05	0.017	-0.172	0.044	0.231
	(0.023)	(0.016)	(0.013)	(0.017)		(0.023)	(0.026)	(0.023)	(0.029)
	[-15.15]	[-36.47]	[73.09]	[1.55]		[16.33]	[-4.63]	[16.32]	[-4.63]
0.70	-0.043	-0.053	0.020	0.328	0.01	0.021	-0.176	0.044	0.225
	(0.026)	(0.018)	(0.014)	(0.020)		(0.037)	(0.027)	[-4.61]	(0.033)
	[-18.31]	[-10.26]	[21.68]	[1.87]		[53.68]	(0.024)	[16.56]	[4.10]
0.60	-0.037	-0.082	0.029	0.313					
	(0.028)	(0.019)	(0.015)	(0.022)					
	[-23.32]	[-7.15]	[16.75]	[2.16]					

Figure 7a FLS coefficient α_{0t}

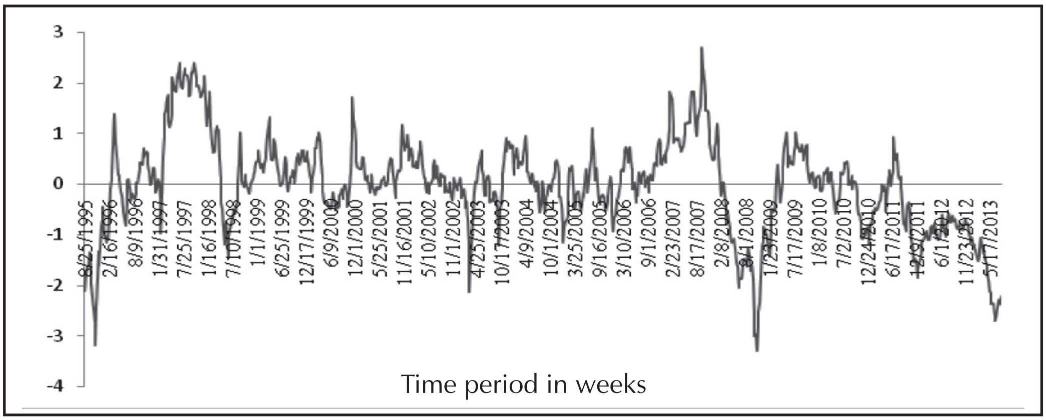


Figure 7b FLS coefficient λ_{1t}

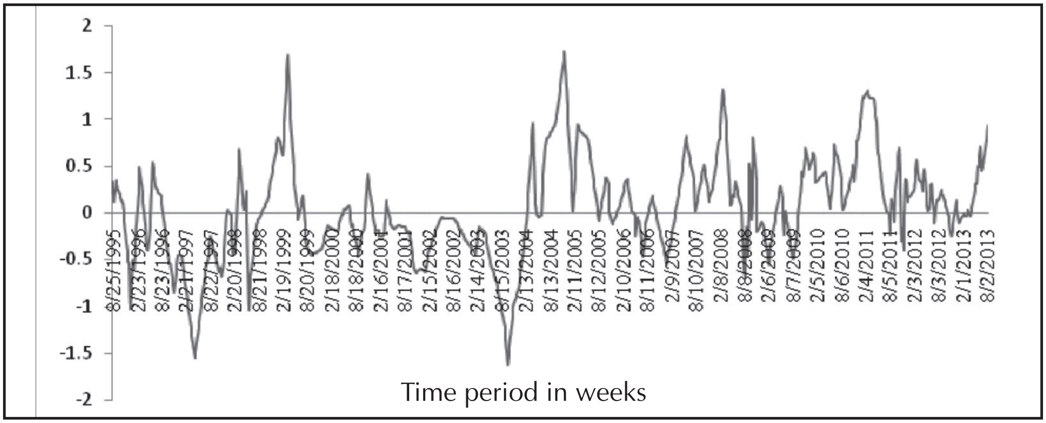


Figure 7c FLS coefficient λ_{2t}

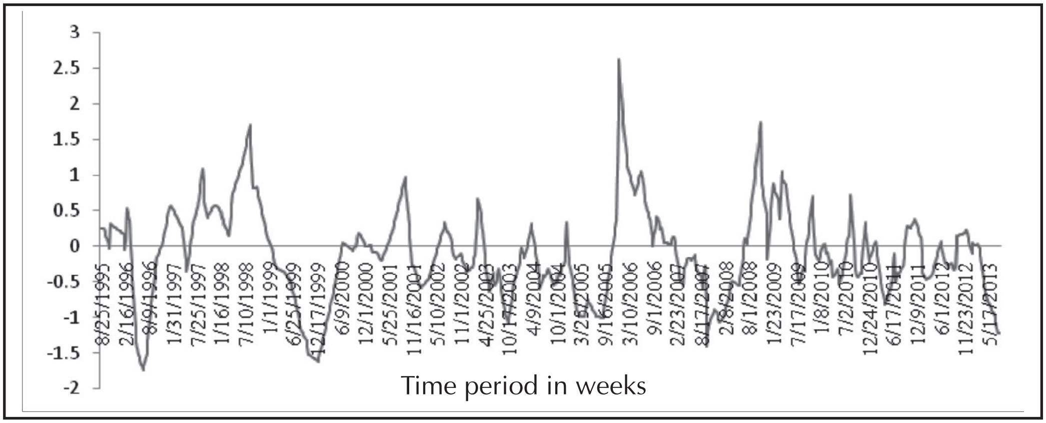
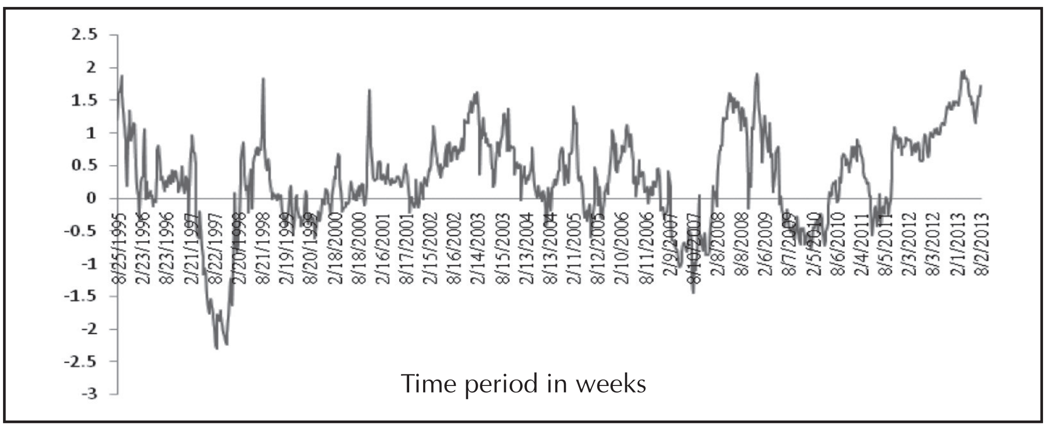


Figure 7d FLS coefficient α_{2t}



Further, the estimates of coefficient of mean, standard deviation, coefficient of variation of alternative δ values are presented in Table 4. The plots of the time-varying coefficient with respect to the stock index return (Υ_1) are produced in Figure 8d. The magnitude of this coefficient is fluctuating around zero; suggesting that the RBI tends to buy in response to rise in the stock return in some time while the RBI is found to sell foreign exchange in response to fall in stock return. Between 2006 and 2008, the coefficient remained in the positive region in the sense that RBI resorted to buy as there was huge inflow of foreign exchange coincided with stock market boom. Subsequently, the coefficient remained in the negative region; this suggests that the RBI was trying to insure against financial turmoil by maintaining adequate reserves even when there was huge capital flight. This is evidence that the RBI has been playing a responsible role in the foreign exchange market to ensure orderly condition.

Table 4 Summary statistics of FLS estimates

Specification: $\widetilde{R}_t = \alpha_{0t} + \lambda_{1t}\widetilde{e}^{a}_{t-1} + \lambda_{2t}\widetilde{e}^{d}_{t-1} + \gamma_{1t}s_{t-1} + \alpha_{2t}\sigma_{t-1} + \nu_t$

δ	α_{0t}	λ_{1t}	λ_{2t}	α_{2t}	γ_{1t}	δ	α_{0t}	λ_{1t}	λ_{2t}	α_{2t}	γ_{1t}
1	0.102	0.204	-0.214	0.298	0.027	0.50	-0.196	-0.063	-0.080	0.543	-0.006
	(0.004)	(0.004)	(0.006)	(0.009)	(0.002)		(0.028)	(0.017)	(0.018)	(0.025)	(0.007)
	[1.15]	[0.63]	[-0.85]	[0.93]	[1.95]		[-4.37]	[-8.27]	[-7.089]	[1.41]	[-33.54]
0.999	0.102	0.204	-0.214	0.298	0.027	0.40	-0.192	-0.075	-0.806	0.536	-0.008
	(0.004)	(0.004)	(0.008)	(0.009)	(0.002)		(0.029)	(0.018)	(-0.020)	(0.026)	(0.002)
	[1.15]	[0.64]	[1.95]	[0.93]	[1.95]		[-4.60]	[-7.18]	[-7.006]	[1.48]	[-30.70]
0.99	-0.036	0.169	-0.127	0.425	0.021	0.30	-0.186	-0.085	-0.091	0.529	-0.009
	(0.010)	(0.001)	(0.008)	(0.001)	(0.008)		(0.030)	(0.019)	(0.021)	(0.027)	(0.008)
	[-7.78]	[1.73]	[-1.91]	[0.81]	[4.09]		[-4.84]	[-6.69]	[-6.91]	[1.55]	[-28.45]
0.95	-0.139	0.020	-0.081	0.517	0.012	0.20	-0.018	-0.093	-0.095	0.264	-0.009
	(0.040)	(0.012)	(0.010)	(0.014)	(0.002)		(0.030)	(0.091)	(0.021)	(0.028)	(0.008)
	[-3.61]	[3.76]	[-3.75]	[0.84]	[10.56]		[-5.08]	[-6.36]	[-6.84]	[2.94]	[-27.25]
0.90	-0.175	0.056	-0.068	0.545	0.006	0.10	-0.177	-0.100	-0.010	0.514	-0.204
	(0.020)	(0.013)	(0.012)	(0.017)	(0.005)		(0.031)	(0.020)	(0.022)	(0.028)	(0.033)
	[-3.51]	[7.09]	[-5.23]	[0.95]	[23.39]		[-5.34]	[-6.15]	[-6.76]	[1.68]	[-4.38]
0.80	-0.197	0.006	-0.065	0.558	0.0004	0.05	-0.174	-0.103	-0.101	0.511	-0.010
	(0.024)	(0.014)	(-6.64)	(0.020)	(0.006)		(0.031)	(0.020)	(0.020)	(0.028)	(0.007)
	[-3.68]	[72.85]	[-9.65]	[1.12]	[417.40]		[-5.47]	[-6.08]	[-6.73]	[1.71]	[-26.62]
0.70	-0.201	-0.025	-0.069	0.556	-0.003	0.01	-0.172	-0.105	-0.103	0.508	-0.010
	(0.026)	(0.015)	(0.016)	(0.024)	(0.006)		(0.032)	(0.201)	(0.022)	(0.028)	(0.009)
	[-3.91]	[-18.45]	[-7.06]	[1.23]	[-66.98]		[-5.58]	[-6.03]	[-6.71]	[1.73]	[-26.56]
0.60	-0.200	-0.047	-0.075	0.550	-0.511						
	(0.027)	(0.016)	(0.017)	(0.024)	(0.007)						
	(-4.14)	[-10.53]	[-7.14]	[1.33]	[-41.21]						

Note: Figures in (#) and [#] are respectively the standard deviation and coefficient of variation.

The plots of λ_{1t} and λ_{2t} obtained from the fourth specification of Equation 6 are produced in Figures 8b and 8c. The behaviour of these response coefficients are largely dissimilar to the

Figure 8a FLS coefficient α_{0t}

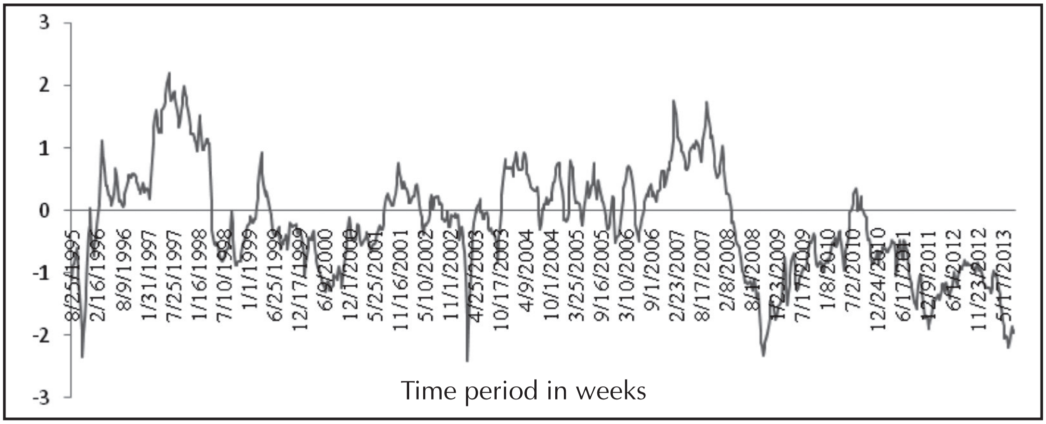


Figure 8b FLS coefficient λ_{1t}

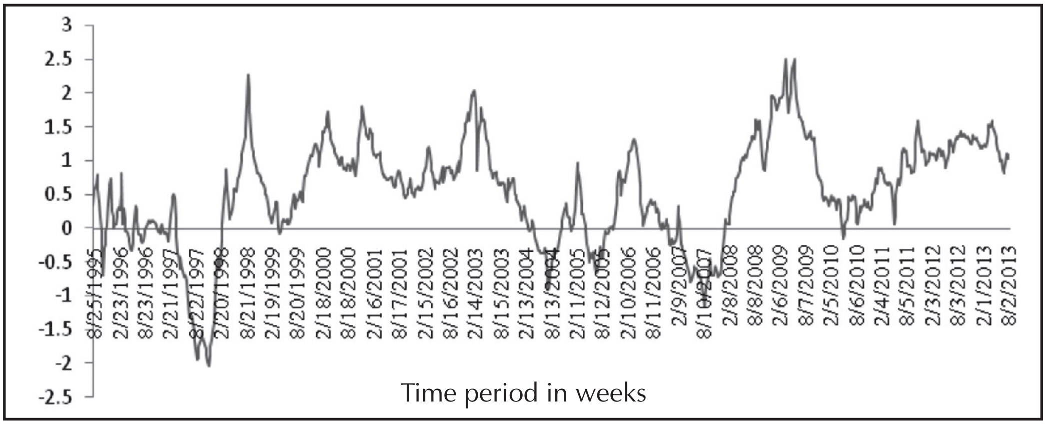


Figure 8c FLS coefficient λ_{2t}

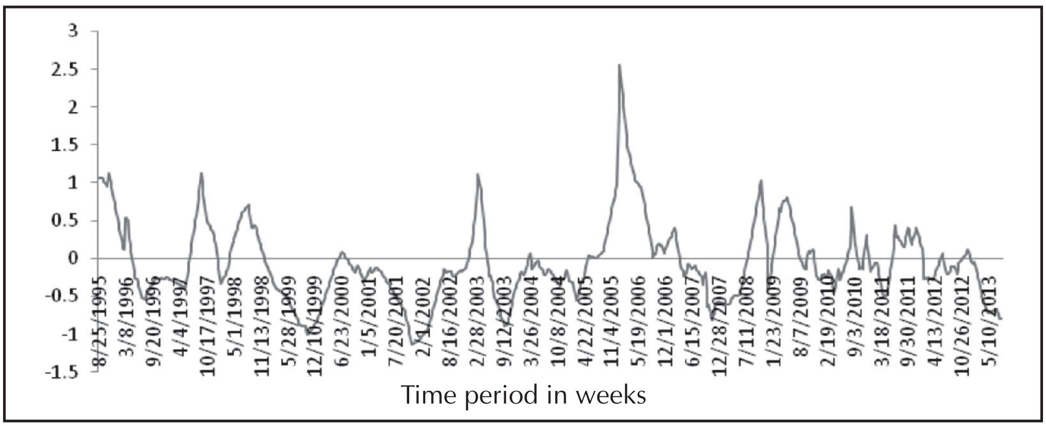


Figure 8d FLS coefficient γ_{1t}

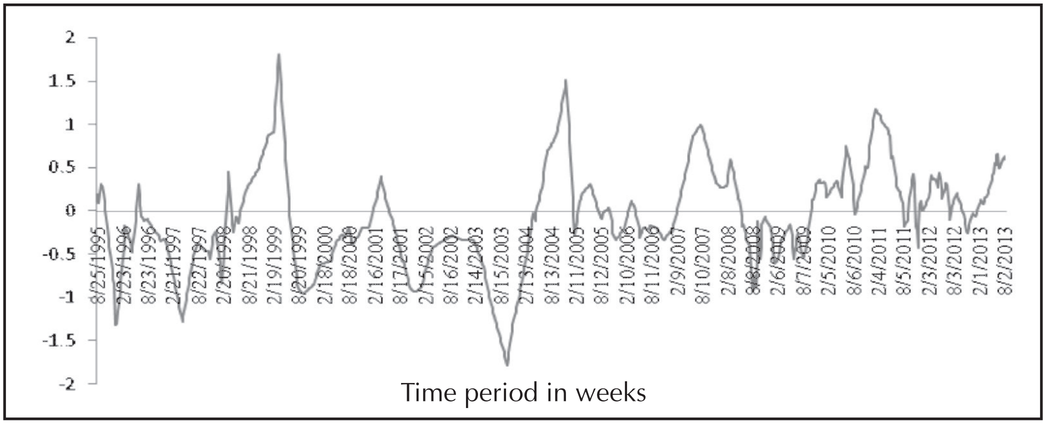
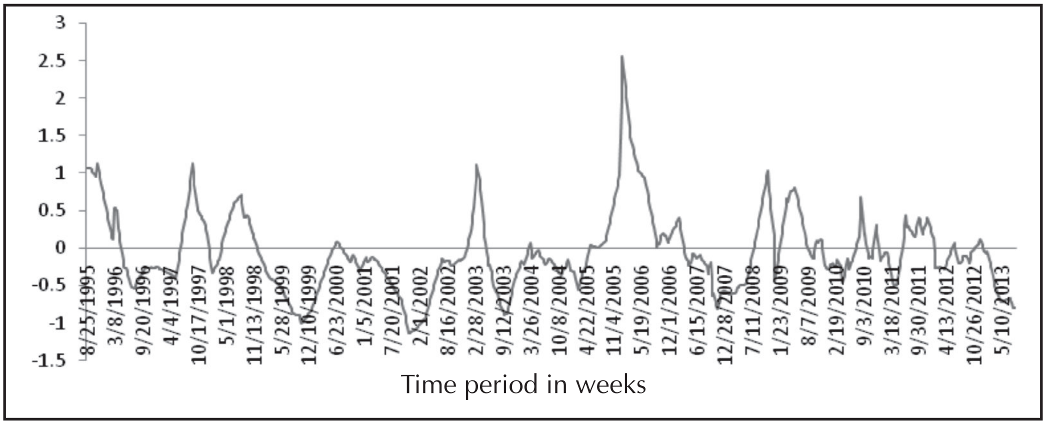


Figure 8e FLS coefficient α_{2t}



plots of the same coefficients obtained from the third specification of Equation 6, which are produced in Figure 8e. The intervention in the foreign exchange market seems to be leaning against the wind irrespective of the direction of the movement of the exchange rate between 1996–2001. On the contrary, the RBI appears to have been buying both when the rupee appreciated and depreciated, during 2002–03. This indicates a strong form of asymmetric intervention in the foreign exchange market that led to the net accumulation of official reserves. A similar trend in the intervention policy can be observed during 2007–08. This again coincides with the period of a stockpile of RBI reserves.

4 CONCLUDING REMARKS

We estimated four alternative variants of intervention reaction functions, and the econometric specifications are largely derived from the theoretical framework. The percentage change in foreign currency assets is used as a measure of official intervention, while the percentage change in exchange rate, conditional volatility of incremental reserves, and stock return are used as explanatory variables. Taking into account the evidence obtained from other empirical studies, we incorporate exchange rate return as two variables—positive and negative—to capture the asymmetric intervention in response to the appreciating and depreciating rupee. The empirical investigation has been carried out using weekly data for the sample period from 4 August 1995 to 26 July 2013.

Since the main objective of the present paper is to examine the time-varying characteristics of official intervention in the foreign exchange market, we estimate the policy reaction function using the FLS approach in which the coefficients are allowed to vary through the sample period. First, we examined the time-varying nature of the parameters in the model. In this regard, the plots of residual efficiency frontier indicated that the efficiency frontier for all four specifications are steeply sloped; hence, allowing some degree of time variation in coefficients results in larger reduction in measurement error. This proves that some of the coefficients in the intervention reaction function are changing through time.

Second, time variation in each coefficient is examined using the estimates of mean, standard deviation, and coefficient of variation of each parameter in the reaction functions for alternative values of δ. The estimates of coefficient means, standard deviation for alternative values of δ for all the variants of reaction function were found to exhibit a shift even for a small change in δ . The standard error corresponding to each coefficient was found to increase with fall in δ and to stabilise in the extreme. This confirmed that OLS optimisation would have produced biased parameter estimates of the reaction function.

The coefficients exhibited substantial variation over the sample period. There is also strong evidence of asymmetry in the exchange rate intervention policy, and such asymmetry was found very strong during excessive capital inflows. It seems that the RBI has been penalising rupee appreciation more severely and defending the rupee value only in times of excessive pressure on rupee to depreciate. The inclusion of return on the stock index as an additional variable in the reaction function did significantly alter the results. In sum, the time-varying nature of the intervention policy indicates that reserve accumulation seems to be larger because of asymmetric exchange rate intervention, which might have been driven by concern over export competitiveness.

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सत्यमेव परमो धर्मः

Institute of Economic Growth
University Enclave, University of Delhi
Delhi 110007, India
Tel: 27667101/288/424; Fax : 27667410
Website : www.iegindia.org