Monetary Policy, FX Markets, and Feedback under Uncertainty in an Opening Economy

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September 2009

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[*] This is abbreviated from DRG (Reserve Bank of India) Study No. 32, 2009. It was presented at the MFC11at IGIDR, at RBI and at the 41st MMF meeting at Bradford, U.K; we thank the participants for valuable comments and questions. We also thank DRG, RBI for the invitation, an anonymous DRG referee, Romar Correa and Sitikantha Pattanaik for comments, Sanchit Arora for excellent research assistance, Reshma Aguiar and T.S. Ananthi for secretarial assistance.

Abstract

We focus on options for monetary policy from interactions between it and Indian foreign exchange (FX) markets. A brief survey covers recent rapid changes providing a snapshot of current microstructure, and of monetary policy institutions. Hourly, daily, and monthly data sets for FX markets and policy variables are used to empirically test (i) whether FX market intervention is able to influence levels, returns and volatility, (ii) the influence of microstructure variables, (iii) whether markets anticipate policy, and (iv) the slope of the speculative market demand curve. Intervention affects both the level of the exchange rate and its volatility. Macroeconomic fundamentals represented by interest rate differentials have weak effects on exchange rate levels and volatility but strong effects on FX market turnover. Microstructure variables are important. Merchant turnover is a driving force, perhaps because of the large inflows in the period as noted also in the survey of markets. Current intervention, volatility and expected volatility increase dealer turnover, but anticipated intervention decreases it, suggesting it is optimal to reveal information about future intervention. A theoretical derivation supports this result for greater uncertainty about fundamentals. The estimated speculative demand curve is downward sloping; expectations are stabilizing and not perverse. The results imply intervention and signaling may be a more effective way of influencing exchange rates in the Indian context than interest rate changes. The latter should be targeted to the domestic cycle. An effective combination of signals and surprises can help the central bank reduce speculative positions, while supporting the cycle.

JEL codes: E58, F31

Key words: FX markets, Market Microstructure, Central Bank Intervention, Signals

1. Introduction

We focus on options for monetary policy arising from the interaction between monetary policy and the Indian foreign exchange (FX) market. Since both markets and the institutions of monetary policy have changed rapidly we survey these changes and provide a snapshot of current microstructure, and institutions. The survey brings out the growing links between money and FX markets, the sophistication and variety of participants and institutions, and policy trilemmas in dealing with large cross border flows in a rapidly growing emerging market, where fundamentals are uncertain.

The literature suggests, on the whole, that moderation of monetary interest rate response is called for under greater uncertainty[1]. The latter is high in an emerging market slowly moving towards deeper markets and more capital account convertibility. Therefore additional policy instruments maybe required for adequate response to the domestic cycle. The additional instrument we examine is intervention in FX markets, whether such intervention should be announced or secret, and if there is a role for signaling an exchange rate target?

Even if several instruments are used they can be aligned so the markets get a clear signal on the policy stance. For example, when inflation exceeds the target, if a more moderate rise in interest rates is required for the real cycle, intervention to appreciate the exchange rate will work to reduce demand, import costs and inflation and can allow the more moderate interest rate rise[2].

Limited volatility in nominal exchange rates around a competitive real exchange rate can contribute to policy objectives of moderating the business cycle while maintaining

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[1] There are a number of papers in this field. Some key references are Weiland (2003) and Svensson and Williams (2005). If robust preferences are assumed, the objective becomes to prevent the worst-case scenario, and can imply a large monetary policy response. Onatski and Stock (2002) examine robust preferences. Goyal (2009) shows shocks that reduce natural rates and therefore require a reduction in policy rates dominate in a small open emerging market economy with a dualistic labour market.

[2] Even countries following inflation targeting such as the Czech Republic, reconcile it with managed floats by ensuring interest rates remain the primary tool of monetary policy, and any intervention works in the same direction as interest rate changes (Holub, 2004).

growth. It reduces the inflationary impact of external price shocks if the nominal exchange rate moves in the opposite direction, for example, an appreciation accompanying a rise in world commodity prices. In addition, limiting volatility reduces entry of noise traders, but some volatility reduces currency risk by encouraging hedging and increasing risk for speculators, thus preventing episodes of high volatility[3]. Currency risk, and reducing it, is especially important for an opening economy. If the policy is credible and markets respond to signals, intervention requirements are minimized and policy is freed to attend to the domestic cycle. Exchange rate fluctuations have hindered Indian monetary policy response to domestic needs in the recent past.

But it needs to be researched whether such a transparent policy would be supported by the market or serve as an invitation to speculators. In this context we briefly survey the relevant market microstructure literature, and test hypotheses about the role of different participants in Indian FX markets [4], impact of central bank (CB) intervention, and strategic interaction with markets.

To the extent behaviour is forward-looking, taking markets into confidence, or strategic revelation of information, can sometimes help achieve policy objectives. But it is also necessary at times to surprise markets (i) since markets can get caught in a trap of self-fulfilling expectations around unsustainable positions (Woodford, 2003), (ii) to prevent the build-up of speculative positions. Blinder et. al (2008) show that the two ways in which communication makes monetary policy more effective is by creating news or reducing uncertainty. But surprise can be compatible with more transparency if it is linked to random shocks to which the system is subject. Then communication enhances news.

Optimal information sharing or signaling is derived in a modified version of the Bhattacharya and Weller (1997) model of strategic interaction between differentially

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[3] The RBI view is that since exchange volatility is rising more hedging tools are required, and volatility must be restricted until agents learn to manage. The point made here is that ensuring some volatility will improve incentives to hedge.

[4] Equations of the type common in the FX market microstructure literature (Lyons 2001, Dominguez and Frankel 1993, Dominguez 2003), giving the response of the spot exchange rate to signed order flow, intervention, and other relevant variables, are estimated.

informed speculators and the CB, adapted to Indian conditions. Shocks affect the information extraction. It turns out that, in the model, greater uncertainty about fundamentals makes it more worthwhile for the CB to reveal some information about a target. The result is discussed in the context of the literature on signaling and credibility (Krugman, 1991, Vitale, 2003).

Using hourly, daily, and monthly data sets on FX market rates and turnover, on policy rates and on liquidity provision, we empirically test (i) the extent to which FX market intervention is able to influence levels, returns and volatility, (ii) the influence of microstructure variables, (iii) the extent to which markets anticipate policy, and (iv) the slope of the speculative market demand curve.

We find that intervention affects both the level of the exchange rate and its volatility[5]. Macroeconomic fundamentals represented by interest rate differentials have weak effects on exchange rate levels and volatility but strong effects on FX market turnover. Microstructure variables are important. Merchant turnover is a driving force, perhaps because of the large inflows in the period as noted also in the survey of markets. Current intervention, volatility and expected volatility increase dealer turnover, but anticipated intervention decreases it, suggesting it is optimal to reveal information about future intervention. The speculative demand curve is downward sloping; expectations are stabilizing and not perverse.

Given this evidence of the impact of policy on markets, intervention and signaling may be a more effective way of influencing exchange rates in the Indian context than interest rate changes. The latter should be targeted to the domestic cycle. Linking exchange rate signals to random supply shocks makes surprise consistent with improved communication. More transparency can reduce speculative positions. Two-way movement within an implicit ten percent band around a competitive exchange rate can

[5] Intervention data are only available ex-post, at the monthly frequency. Past research with this data has found that intervention does not affect the level of the rupee, but it reduces volatility (Pattanaik and Sahoo, 2003, Edison, 2007). Although the studies control for endogeneity using two-stage least squares techniques, our use of GMM and instruments for expected variables is more robust. These studies have also not used market microstructure variables.

encourage hedging while maintaining export competitiveness. A diffuse target is advantageous when speculators are active.

The structure of the study is as follows: Section 2 gives a brief outline of the development of Indian FX and money markets and consequences for the conduct of monetary policy, empirical tests are reported in Section 3, Section 4 adapts a model of strategic information revelation in FX to Indian conditions, and Section 5 concludes and draws out policy implications.

2. FX markets: Structure and International Developments

FX markets have special features[6]. They are the most liquid markets with daily market turnover at $ 3.2 trillion (BIS 2007). But since they are decentralized they are fragmented and less transparent. There is no incentive to share information on order flows. The majority of transactions are bilateral and they occur in opaque markets without a physical market place. Although new technologies are causing change, these special features continue to dominate. Electronic systems such as Electronic Broking System (EBS) or Reuters D3000, established in 1993, account for 85 percent of interbank trading. They provide ex ante anonymous limit order bid ask pricing to dealers. Although voice trading dominates in customer trades, electronic portals are being introduced here also. Electronic systems allow netting, lower settlement and counterparty risk, have operational benefits such as reducing human error and have driven a large increase in liquidity. But they do not increase the transparency of the foreign exchange market since system governing boards treat electronic order flow as strictly confidential. Therefore information on order flow remains sectoral. Trades are initiated based on macro data and differential order flow information, with the aim of rebalancing portfolios.

Participants are heterogeneous with diverse information sets and reaction speeds, so that market efficiency does not hold, and profit opportunities persist for informed traders. Central banks have a dominant position. Although the interdealer market continues to account for the majority of transactions (59%) this share has decreased through the

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[6] This section is largely based on material in Lyons (2001), Sarno and Taylor (2002), Sagar and Taylor (2007), largely the latter.

nineties because of the growth of large financial customer groups such as hedge funds. Corporate treasuries have also become sophisticated. Sudden shifts in positioning by large hedge funds that have the fastest reaction speeds and operate with high leverage can magnify shocks to FX markets. They implement currency programs to secure a notional capital value that may be a benchmark risk free rate. Despite such activity currency markets remained largely stable during the financial crisis of 2008, partly because risk management procedures had been improved after the LTCM crisis. Banks impose position limits for individual traders, and risk capital made available is a function of past performance. Incentives to take risk are reduced because losses reduce the trader's risk capital while profits are shared with the bank (Geithner, 2004).

Indian FX markets

Indian FX markets continue to be far behind international, but are changing rapidly. The major changes are in the expansion of turnover and of instruments available for hedging as exchange rate volatility rises with a more open capital account, the advent of electronic trading and communication platforms, which reduce transaction costs and risks, and in the profile of customers as capital flows have become the prime mover of exchange rate. Intra day trade was first permitted for banks in 1978, but the Indian FX market really grew after liberalization[7], as the Sodhani Committee's (June 1995) comprehensive blueprint for reform was followed. The Tarapore Committee on Fuller Capital Account Convertibility (2006) also made several recommendations for these markets.

The average daily turnover in Indian FX markets, which was about US $ 3.0 billion in 1998-99, grew to US $ 48 billion[8] in 2007-08. The inter-bank to merchant turnover ratio halved from 5.2 during 1997-98 to 2.3 during 2007-08 reflecting the growing participation in the merchant segment of the foreign exchange market. The spot market remains the most important FX market segment accounting for 51 per cent of the total turnover. Its share has declined marginally in recent years due to a pick up in the turnover in derivative segment. Even so, Indian derivative trading remains a small fraction of that

[7] Unless otherwise mentioned, Ayyapan Nair and Amaresh Samantaraya provided the information in this section, on the basis of various RBI publications and internal memos.
[8] BIS (2007) notes that this was the fastest rate of growth amongst all world FX markets.

in other developing countries such as Mexico or South Korea. Short-term instruments with maturities of less than one year dominate, and activity is concentrated among a few banks (IMF 2008).

Still, the derivative segment of the FX market has also been evolving. Cross- currency derivatives with the rupee as one leg were introduced with some restrictions in April 1997. Rupee-foreign exchange options were allowed in July 2003. Exchange traded currency futures were started in 2008[9]. The most widely used derivative instruments are the forwards and foreign exchange swaps (rupee-dollar). As elsewhere, FX transactions are mostly over-the-counter structured by banks. But there is a user demand for liquid and transparent exchange traded hedging products. They are also easier to regulate. The nondeliverable forward (NDF) market has been growing, but still accounts for only about a quarter of onshore trading. Such markets create problems for policy but normally wither away as domestic markets deepen. The Indian forward market is fairly liquid up to one year. The price movement in the near-term bucket reflects rupee liquidity in the interbank market and overnight interest rates but the six-month and one-year rates are determined also by expected future liquidity. Importers and exporters also influence the forward markets. Forward rates in a particular segment may not be in alignment with other segments due to the excess supply/demand from importers/exporters in that segment.

The Clearing Corporation of India Ltd. (CCIL) set up by the RBI in 2001 now settles 90-95 percent of interbank rupee-dollar transactions. Foreign exchange trades are settled through multilateral netting thus saving transaction cost. All spot, cash, tom transactions and forward trades are guaranteed for settlement from the trade date reducing foreign exchange settlement and counterparty risk. Swaps and options are essentially inter–bank transactions, and account for about 50 percent of CCIL trade settlement (IMF, 2008).

The Reserve Bank has been gradually eliminating restrictions on FX markets. Historically, the availability of hedging tools against foreign exchange risk has been limited to entities with direct underlying foreign exchange exposures. However, since

[9] At present, in the absence of full rupee convertibility, a future contract cannot result in the delivery of foreign currency, but is netted out in rupees, reducing its usefulness for hedging.

now, a larger set of economic agents are exposed to foreign exchange risk there is a shift to the concept of "economic exposure", which refers to the effect of exchange rates on a firm's value. There are gradual steps to enable corporates greater flexibility in managing their exposures. For example, it has been proposed to permit agents to book forward contracts without production of underlying documents up to an annual limit of US $ 100,000, which can be freely cancelled and rebooked. Cancellation and rebooking of forward contracts and swaps in India have been regulated to reduce rupee volatility. There is a move to allow banks to fix their own NOPL and AGL limits based on their risk appetite and ability to manage exposure, with adequate prudential regulation and supervision to cover systemic risk and prevent excessive leverage.

A conviction of possible two-way movement of the exchange rate, large enough to deliver a substantial loss to one-way bets is, however, a pre-requisite for hedging or the laying off of currency exposure. Despite deepening FX markets, the moderate two-way movement within an implicit 5 percent band seen over 2004-06 was not sufficient to overcome strong expectations of medium term appreciation given India’s high growth rate. In 2007, market expectations of the Rupee-USD rate had even reached 32. Many corporates borrowed abroad based on such expectations, increasing currency risk. Some had entered into so called hedging deals, which were actually bets on the value of the Swiss Franc. With the volatility in currency markets and steep rupee depreciation in 2008 many firms lost money. Many such deals, where Indian banks were often a front for foreign banks, sidestepped existing rules that prevented leverage or underlying risk that exceeded export income. Although firms were not allowed to write options deals were structured so that in effect firms were writing options. The deals were so complex that firms sometimes did not understand what the risks they were taking. Thus availability of more instruments alone only makes leveraged speculation or bets on future currency value possible. Establishing inducement to hedge through sufficient flexibility of the exchange rate is more important. So are transparency, clarity and information.

Customers have changed from passive price takers with emphasis on financing and other banking services relating to foreign trade, to Foreign Institutional Investments (FIIs), corporates availing External Commercial Borrowing (ECB), corporates involved in mergers and acquisitions, etc. Many customer corporates today maintain large treasuries as sophisticated as those of the banks.

2.2. Money market developments

Substantial developments in the Indian money market include newer instruments, broader participation, building of market infrastructure, and strengthening of prudential practices. The liquidity adjustment facility (LAF), made operational in June 2000, provides standing facilities to curb short-term volatility in liquidity conditions. Daily open market operations (OMOs) smooth and guide short interest rates. Liquidity is injected by accepting repo[10] bids, with an overnight maturity, from banks and primary dealers, while it is absorbed through the acceptance of reverse repo bids. Liquidity operations are conducted regularly by means of daily tenders under a uniform price auction. The repo and the reverse repo rates are two policy rates specified for lending and borrowing of funds. Liquidity conditions are influenced either by rejecting bids or by changing the LAF rates, at discrete intervals. The overall quantity to be absorbed/injected is determined from the RBI's assessment of the banking system's liquidity requirements. Additional liquidity is made available to banks through the standing facility of export credit refinance. The RBI also conducts longer-term repo auctions at a fixed rate or at variable rates depending on market conditions. It has moved to more active liquidity management, with frequent OMOs, but more medium-term instruments such as government securities with 1–2 week maturities are required for fine-tuning (IMF, 2008). In the period of large capital flows, the LAF was largely used to absorb liquidity.

2.3. Monetary Policy

A key challenge facing India and other emerging market economies (EMEs) is grappling with inherently volatile capital flows relative to domestic absorptive capacity. Reserve accretion reflects attempts to build-up reserves to be able to meet unpredictable and temporary imbalances in international payments, thus providing confidence to financial markets. Second, it reflects concerns with the large appreciation in the exchange rate that would have occurred, had these inflows not been absorbed by the monetary authorities.

[10] Repos are financial instruments for the temporary exchange of cash against securities with a transfer of ownership.

However, market purchases by the central bank to support the exchange rate, expand the base money, which requires sterilization, i.e., sales of government or central bank securities against purchases of foreign securities. Apart from sterilization in the form of open market operations, another key instrument of sterilization, at least in the emerging context, is the control over cash reserve ratios. Other instruments of sterilization include: shifting of public sector and government deposits from commercial banks to the central bank; foreign exchange swaps; fiscal tightening; liberalization of trade policies and capital outflows; and finally, a greater degree of flexibility in the exchange rate. Thus a mix of quantitative and market-based instruments can be used.

In the period since October 1995, capital flows to India accelerated, although there were brief episodes of reversals. In response, the RBI broadly followed the same strategy of absorbing excess inflows in to its foreign exchange reserves while also permitting movements in the exchange rate of the rupee consistent with underlying fundamentals. The period since 1996 has also seen efforts to increase the stock of marketable debt with it through conversion of special securities. Other steps were taken such as further liberalization of the capital account, pre-payment of external debt, tightening of interest rate ceilings for non-resident deposits and greater exchange rate flexibility. But by 2003-04, the stock of government debt securities was nearing depletion. In addition, quasi-fiscal costs would have undermined the Reserve Bank's profitability and strength of its balance sheet. Therefore the Market Stabilization Scheme (MSS) (consisting of 91-day to 1-year government bonds) was introduced in March 2004 with interest costs borne by the Government, and explicitly shown in the Budget. During 2007-08 net inflows leapt to US $ 109.6 billion from US $ 46.4 in the previous year. The MSS ceiling was repeatedly raised. Although the medium term policy was to gradually reduce CRR to its statutory minimum, in response to unprecedented surge in foreign capital inflows, CRR was reactivated since December 2006 as a monetary policy instrument in the sterilization process. Sterilization measures such as increase in CRR and MSS had to be reversed under outflows as reserves fell by more than $50 billion and RBI dollar sales sucked out liquidity, during the 2008 global financial crisis.

3. Empirical Tests

3.1. Variables and Data

Variable definitions are given in Table 1. Apart from exchange rate return and volatility variables, there are policy and market variables. Policy variables include intervention in FX markets, policy rates and dummies. Since intervention data is not available at the daily frequency, lafps is used as a proxy. Daily liquidity absorption generally rises when intervention is releasing rupees into the market[11]. Apart from intervention to reduce volatility the RBI has also been accumulating foreign exchange reserves in the face of large inflows of foreign capital. Weekly data on foreign exchange assets is available so that monthly change in foreign exchange assets held by the RBI is derived as fxach, an alternative measure of intervention[12]. The basic variables listed are further transformed in regressions as necessary, to take care of properties of the data generating process at different frequencies. Rules are followed in naming these transformations. For example, ch at the beginning of a variable denotes the first difference; sq at the beginning of a variable denotes the squared value.

In FX market variables, total dollar net demand, totps, is also broken up into dealer or interbank net demand, and that originating with customers or "merchants" as it is called in the data set. These dealer and customer demands are the order flow variables used in FX market microstructure studies. Since we are interested in analyzing total market transactions, we also calculate total turnover, totturn, which is similarly broken up into transactions due to dealers and transactions due to customers.

[11] This is only a proxy since daily liquidity management is not solely concerned with exchange rate management, but also takes into account mismatches arising from government borrowing requirements, fluctuation of government balances with RBI having implications for market liquidity and overall monetary management. In addition, at the time of steep inflows during 2006-07 MSS was actively used for sterilization.

[12] The standard narrow definition of intervention is CB purchases and sales of foreign exchange against domestic currency. Dominguez and Frankel (1993) define it more broadly as any official transaction or announcement intended to influence the exchange rate or stock of foreign exchange reserves. Hüfner (2004) argues that change in reserves may be a more comprehensive measure of intervention than officially released data on intervention, because measurement depends on what the CB sees as intervention, but all transactions are reflected in the balance sheet. Passive intervention is said to be customer initiated but is actually a misnomer, since the CB can always select the timing. The RBI's intervention data reflects purchase and sale of the US dollar including purchase/sale leg of swaps and outright forwards.

Table 1: Variables	
Variables	**Definition**
chloge	log of exchange rate (e) at 5:30 pm (INR/USD) day t+1 minus log e at t
cmr	call money rate, (i) average daily (ii) monthly as average of daily cmr
crr	cash reserve ratio
dealerratio	dturn/totturn
dps	interbank purchase minus sale of USD (millions) in spot and forward markets (excluding swap and forward cancellation)
dturn	interbank purchase and sale of USD (m) in spot, forward, and swap markets
dvcmr	takes value 1 from March 20, 2007 to August 17, 2007
dvgr	takes value 1 from December 26, 2006 to May 2008
dvexpec	takes value 1 for two days prior to intervention days
dvintv	takes value 1 for days when RBI was intervening in FX markets
echav	log difference of (i) daily RBI reference exchange rates, (ii) monthly average e
egarch11	egarch (1,1) volatility for monthly exchange rate including two AR terms
eegarch1	egarch (1,6) volatility measure for daily exchange rate
esd	standard deviation of exchange rates derived from average of (i) daily rates for the monthly data set (ii) hourly quotes from the reuters 3 month data set for daily data set
fxach	Change in foreign exchange assets held by RBI (monthly)
idiff	call money rate minus US federal fund rate (ffr)
intvnet	net purchase (+) minus sales (-) of USD (m)
lafps	purchase minus sale in repo/ reverse repo auctions in LAF, that is, net injection (+) minus net absorption (-) of liquidity by RBI
mps	purchase minus sale of USD (m), by merchants in spot and forward markets (excluding swap and forward cancellation)
mturn	purchase and sale of USD (m), by merchants in spot, forward and swap markets
r	repo rate or rate at which RBI lends in the LAF
rr	Reverse repo rate or rate at which RBI absorbs liquidity in the LAF
totps	total purchase minus sale of USD (m) spot and forward, excluding swap and forward cancellation (purchase + , sale -)
totturn	total spot, forward, swap, purchase and sale of USD (m), interbank and merchant

After a series of reforms starting in the late nineties, foreign exchange markets had acquired a degree of depth by 2002; money markets also changed with the starting of the liquidity adjustment facility or LAF around this time, as we saw in the preceding section. Therefore our monthly data set starts in 2002 and continues to May 2008. Since all the required series were not available in the early years, the daily data set runs from

November 2005 to May 2008. The source for these two data sets is the RBI database. A third data set from Reuters gives hourly changes in the exchange rate over the period September-November 2007.

Separate GARCH models at the daily and hourly frequency provide a measure of exchange rate volatility. A number of GARCH models were estimated by maximizing the log-likelihood through an iterative process. The best were selected based on diagnostics such as AIC, F-tests, and the Q test. The latter checks the null hypothesis that there is no remaining residual autocorrelation, for a number of lags, against the alternative that at least one of the autocorrelations is nonzero. The null is rejected for large values of Q. The best fitting equations are given below. Standard error is in ( ), p-value in [].

Monthly [egarch(1,1)]

$$echav_t = \mu_0 + \mu_1 echav_{t-1} + \mu_2 echav_{t-2} + \varepsilon_t$$

$$= \underset{(0.173)}{1.796} + \underset{(0.059)}{1.34}\mathrm{echav}_{t-1} - \underset{(0.06)}{0.38}\mathrm{echav}_{t-2}$$

$$E(\varepsilon_t / \varepsilon_{t-1}) = 0$$

$$\ln(\sigma_t^2) = \beta_0 + \sum_{i=1} \beta_i \theta z_t + \gamma\{|z_t| - \mathrm{E}|z_t|\} + \sum_{j=1} \delta_j \ln(\sigma^2_{t-j})$$

$$z_t = \varepsilon_t / \sqrt{\sigma_t^2}$$

$$\ln(\sigma_t^2) = \underset{(0.45)}{-4.38} - \underset{(0.23)}{0.92} z_t - \underset{(0.116)}{0.16}\{|z_t| - \mathrm{E}|z_t|\} - \underset{(0.074)}{0.71}\ln(\sigma^2_{t-1})$$

Log likelihood = -29.8

Q (32) = 39.87 [0.160]

Daily [egarch(1,6)]

$$echav_t = \alpha_0 + \alpha_1 echav_{t-1} + \varepsilon_t$$

$$= 0.009 + 0.99996\, echav_{t-1}$$

(0.02) (0.00043)

E($\varepsilon_t / \varepsilon_{t-1}$)=0

$$\ln(\sigma^2) = \beta_0 + \sum_{i=1} \beta_i [\theta z_t + \gamma\{|z_t| - E|z_t|\}] + \sum_{j=1}^{6} \delta_j \ln(\sigma^2{}_{t-j})$$

$$= -0.61 + 0.56 z_t + 0.06\{|z_t| - E|z_t|\} + 0.72\ln(\sigma^2_{t-1}) + 0.097\ln(\sigma^2_{t-2}) + 0.445\ln(\sigma^2_{t-3})$$

(0.05) (0.037) (0.019) (0.08) (0.128) (0.099)

$$- 0.41\ln(\sigma^2_{t-4}) - 0.26\ln(\sigma^2_{t-5}) + 0.36\ln(\sigma^2_{t-6})$$

(0.102) (0.13) (0.08)

Log likelihood = 1677.31

Q (36) = 29.76 [0.76]

The simple standard deviation (esd) of daily exchange rates was also used as a volatility measure at the monthly frequency. Since hourly exchange rates were only available for a limited three-month data set, esd for daily exchange rates could only be calculated for this limited period.

3.2. Analysis of data

Sample statistics for key variables from monthly and daily data are presented in Tables 2 and 3 respectively, and graphs against time and the autocorrelation functions after that. Three period autocorrelation coefficients were derived using the model Y(t)=a+bY(t-1)+cY(t-2)+dY(t-3)+e(t).

Table 2: Daily sample statistics							
	Mean	**Kurtosis**	**Skewness**	**SD**	**ρ1**	**ρ2**	**ρ3**
eegarch1	0.022	25.49	3.86	.027	0.20 (0.00)	-0.007 (0.88)	0.58 (0.00)
idiff	1.42	51.69	5.09	3.21	0.99 (0.00)	-0.33 (0.00)	0.10 (0.27)
lafps	-11961.97	2.65	-0.41	25481.78	0.71 (0.00)	0.22 (0.03)	-0.058 (0.52)
mturn	4806.05	3.33	0.70	2530.62	0.40 (0.00)	0.29 (0.00)	0.16 (0.02)
dturn	14974.33	2.82	0.13	7697.89	0.52 (0.00)	0.18 (0.01)	0.15 (0.02)
dps	-261.16	7.80	-1.645	483.18	0.47 (0.00)	0.06 (0.39)	0.24 (0.001)
mps	54.49	7.74	1.18	520.05	0.48 (0.00)	-0.01 (0.86)	0.15 (0.03)
totps	-206.23	7.93	0.72	526.04	0.41 (0.00)	0.23 (0.01)	0.03 (0.697)

Note: p-values, which give the level of significance, are in brackets

daily\monthly

Table 3: Correlations with echav						
	echav	**idiff**	**dps**	**mps**	**totturn**	**intvnet**
echav		0.17	0.18	-0.57	-0.10	-0.26
idiff	-0.03		0.56	-0.22	-0.70	-0.47
dps	0.15	0.14		-0.39	-0.55	-0.66
mps	-0.15	-0.08	-0.45		0.11	0.57
totturn	0.03	0.19	-0.19	-0.13		0.57
lafps	-0.10	0.30	-0.04	-0.03	0.22	

Note: The lower panel reports correlations between the order flows at the daily frequency and the upper panel reports the monthly frequency. In the monthly frequency lafps is replaced by intvnet.

The sample statistics (Tables 2, 4) show since skew is not zero, kurtosis is far from 3 and first order autocorrelation especially is high and significant, the distributions are far from normal. Cross correlations between market and policy variables (Tables 3, 5) are higher at the monthly (upper triangle) compared to the daily frequency. This follows: the level of simultaneity should be higher as more information is shared with passing time. Volatility variables (Table 5) show a high correlation between dturn and mturn. Monthly intvnet is strongly correlated with market variables, and all these variables are strongly correlated with idiff. Table 3 with echav shows idiff to be strongly correlated with lafps, dps, totturn, intvnet; dps is strongly correlated with mps and totturn, mps with echav, while monthly intvnet is strongly correlated with idiff and market variables.

Table 4: Monthly sample statistics

	Mean	Kurtosis	Skewness	SD	ρ1	ρ2	ρ3
dturn	197523.6	3.39	1.22	131885.6	0.65 (0.00)	-0.05 (0.72)	0.42 (0.001)
idiff	2.42	5.27	-0.65	2.04	0.52 (0.00)	0.24 (0.07)	0.01 (0.92)
intvnet	2927.61	5.41	1.23	3521.93	0.11 (0.46)	0.18 (0.19)	0.38 (0.03)
mturn	61707.08	3.86	1.30	44141.98	0.57 (0.00)	0.36 (0.01)	0.08 (0.51)
esd	0.20	5.94	1.72	0.18	0.26 (0.06)	0.06 (0.66)	0.00090 (0.99)
egarch11	0.19	2.94	13.29	0.22	-0.20 (0.12)	3472763 (0.12)	0.0099 (0.12)
echav	-0.0011	5.42	-0.61	0.0050	0.37 (0.004)	-0.05 (0.71)	-0.07 (0.71)
dps	-2697.37	6.18	-1.89	4669.93	0.55 (0.00)	0.17 (0.22)	-0.06 (0.63)
mps	1366.86	3.70	0.39	3530.25	0.25 (0.03)	-0.03 (0.79)	0.36 (0.002)
totps	-1330.52	4.08	-1.36	4559.46	0.51 (0.00)	0.34 (0.01)	-0.12 (0.298)

Note: p-values in brackets

The strong cross-correlations suggest that some instrument variable technique would be required to extract information on the effectiveness of intervention and market interactions. The non-normality of the distributions implies that GMM estimation is required.

daily\monthly

Table 5: Correlations with the volatility variable

	egarch11	idiff	intvnet	mturn	dturn	mps	dps
eegarch1		-0.06	0.14	0.04	0.08	0.11	-0.04
idiff	0.05		-0.47	-0.67	-0.70	-0.20	0.56
lafps	0.12	0.30		0.55	0.57	0.57	-0.66
mturn	-0.15	0.22	0.19		0.97	0.06	-0.50
dturn	-0.15	0.18	0.22	0.84		0.11	-0.56
mps	-0.03	-0.08	-0.03	0.06	0.14		-0.38
dps	0.13	0.14	-0.04	-0.05	-0.23	-0.45	

Note: The lower panel reports correlations between the order flows at the daily frequency and the upper panel reports the monthly frequency. In the monthly frequency eegarch1 is replaced by egarch11 and lafps is replaced by intvnet

The graphs of the auto-correlation function (Appendix[13] Charts 1 and 2) show autocorrelation, but this does not lie outside the confidence bands except for daily mturn and dturn implying that these variables should be first differenced.

The graphs of the variables (Appendix Charts 3 and 4) show larger fluctuations and/or trend growth in the later period suggesting the use of the dummy variable dvgr, which takes the value of unity from December 1, 2006, to capture market deepening. There is also an outlier in the sharp fluctuations in call money rates coinciding with the period March 5, 2007 to August 6, 2007, when limits were placed on LAF reverse repo (absorption of liquidity) at Rs. 3,000 crores. The variable dvcmr is to take care of this. The last graph of Chart set 3 shows that a rise in the dealer share in the turnover is not associated with large changes in the exchange rate. During the period of the greatest changes the dealerratio was flat. The graphs do not show any seasonality.

The graphs suggest a possible unit root in monthly mturn dturn toturn, which was confirmed by formal tests. Unit root tests were conducted using the Phillips Perron test (result available on request). All variables were stationary except monthly mturn dturn and toturn. Therefore first differences of these variables were used.

[13] Only a few graphs are presented in the Appendix. Others are available on request.

Granger causality analysis done with two sets of stationary variables at the daily and monthly frequency (Tables 6 and 7) show evidence of simultaneous causation between market and policy variables. Policy variables idiff and intvnet affect market variables, which affect the exchange rate and its volatility. Policy variables also directly affect volatility. Market variables have more feedback on policy at the monthly frequency implying that policy reacts with a lag. The order flow variables, mps and dps are not exogenous as in the market microstructure literature, implying that simultaneity handling techniques such as GMM are required (Table 7).

Table 6: Granger causality for exchange rate

Monthly		**Daily**	
Causality from	**to**	**Causality from**	**to**
chtotturn (0.0033) dps (0.0213) echav (0.0984) intvnet (0.1089)	idiff	echav (0.0042) totturn (0.0348)	idiff
echav (0.0335)	mps	dps (0.0224) totturn (0.0776) lafps (0.2213) idiff (0.2526)	mps
echav (0.0038) chtotturn (0.0829)	dps	idiff (0.0001) mps (0.0782)	dps
dps (0.1253) echav (0.1513)	chtotturn	dps (0.0477) lafps (0.0635)	totturn
echav (0.0432) chtotturn (0.0494) idiff (0.2366) dps (0.2761)	intvnet	mps (0.0501) totturn (0.1946) idiff (0.2718)	lafps
chtotturn (0.1758)	echav	dps (0.2747)	echav

Note: Based on VAR Monthly- idiff mps dps chtotturn intvnet echav; VAR Daily- idiff mps dps totturn lafps echav;
p values shown in brackets. The coefficients are in ascending order. Variables with p- values exceeding 0.3 are not reported

Table 7: Granger causality for exchange rate volatility

Monthly (egarch 11)		Monthly (esd)		Daily	
Causality from	**to**	**Causality from**	**to**	**Causality from**	**to**
chdturn (0.000) intvnet (0.0010) chmturn (0.0029) egarch 11 (0.0188)	Idiff	chmturn (0.0905) esd (0.1500) chdturn (0.1594) mps (0.2083)	idiff	mps (0.0500) mturn (0.0941)	idiff
chdturn (0.000) mps (0.0002) intvnet (0.0237) idiff (0.1711)	chmturn			dturn (0.0001) mps (0.0196) eegarch1 (0.2601)	mturn
chdturn (0.0086) chmturn (0.0785) intvnet (0.1043) idiff (0.1293)	mps	idiff (0.0444) chmturn (0.0591) esd (0.1637) chdturn (0.2287) intvnet (0.2686)	mps	idiff (0.1533)	mps
idiff (0.0001) chdturn (0.0064) egarch 11 (0.0998)	intvnet	idiff (0.0283) chdturn (0.0809) esd (0.2015)	intvnet	mps (0.0265) mturn (0.2236)	lafps
mps (0.0625) chmturn (0.0832) intvnet (0.0963) idiff (0.1216)	chdturn	chmturn (0.3047)	chdturn	lafps (0.0466) eegarch1 (0.0545) mturn (0.1257) mps (0.2868)	dturn
intvnet (0.1533) idiff (0.2027) chmturn (0.2766)	egarch11	chdturn (0.0385) intvnet (0.2191)	esd	lafps (0.2092) dturn (0.2488) idiff (0.2720)	eegarch1

Note: Based on VAR monthly- idiff chmturn mps intvnet chdturn egarch11; idiff chmturn mps intvnet chdturn esd; VAR daily- idiff mturn mps lafps dturn eegarch1; p values shown in brackets with the coefficients. Variables with p-values exceeding 0.3 are not reported.

3.3. Estimation

Next, we turn to regression analysis to extract information on the determinants of exchange rate returns, volatility, and dealer turnover. Since the analysis of data identified non-normality and simultaneity among the variables, a nuanced estimation process is required.

Table 8: Determinants of monthly exchange rates

Echav	OLS robust 1	OLS robust 2
idiff	-0.0003335 (0.375)	-0.000465 (0.178)
mps	-1.10e-06 (0.000)	-1.12e-06 (0.000)
dps	-9.45e-08 (0.488)	2.19e-08 (0.899)
chtotturn	9.46e-09 (0.265)	5.45e-09 (0.422)
intvnet	2.40e-07 (0.295)	
fxach		4.02e-07 (0.004)
dvgr	-0.0028 (0.095)	-0.0041 (0.002)
dvcmr	-0.0041 (0.081)	-0.0034 (0.140)
_cons	0.0020 (0.208)	0.0022 (0.084)
No. of obs	62	75
F	7.70 (7, 54)	11.61 (7, 67)
Prob >F	0.0000	0.0000
R- squared	0.4499	0.4730
Root MSE	0.00374	0.00379
ovtest (F)		1.30 (3, 64)
VIF		1.89
d- statistic		1.975 (8, 75)

Note: p values and degrees of freedom for the F test shown in brackets. P- value represents a probability of getting a test value greater than the observed one if the null hypothesis is true. The null of a zero coefficient is rejected only if p is less than 0.1 or 0.05. Therefore the p- value directly gives the significance level.

We start with OLS regressions of monthly echav (Table 8 and 9). Although autocorrelation and heteroscedasticity are potential problems, three strategies are successively tried to make valid inference possible. First, transformations of variables; second the Newey West correlation matrix, which gives robust standard errors; third, the

Prais-Winston heterogeneity consistent estimator based on the Cochrane-Orcutt procedure.

Macroeconomic fundamentals represented by idiff are only weakly significant in one of the regressions. Merchant order flow is strongly significant and tends to appreciate the exchange rate. This is intuitive since there were strong foreign inflows in this period. Market turnover and dps is not significant. The intvnet variable is not significant but fxach is and both tend to depreciate the exchange rate. This is intuitive since net dollar purchases should have that effect. Intervention largely purchased foreign currency in this period. The two dummies are significant. The restriction on absorption, captured in dvcmr, tended to appreciate the exchange rate because reduction in sterilization may have implied reduction in dollar buying. We find that while intvnet is insignificant, fxach, a broader measure that tracks the effect of intervention on the CB balance sheet, is significant (Table 8).

In Table 9, which compares different OLS estimation methods with volatility measured as standard deviation (esd), mturn, intvnet, chintvnet and its lags significantly reduce volatility while dturn, chdturn and its lags increase volatility. Table 10 compares the effect of fxach and intvnet on volatility and shows a weakly significant negative effect of fxach and a strongly significant negative effect of intvnet. Volatility continues to be increased by chdturn. It may be that RBI measurement of intervention focus more strongly on active intervention designed to reduce volatility.

These OLS regressions give interesting results, and are designed to make robust inference possible despite problems. The diagnostic tests reported are reasonable. In the non-robust OLS (Table 9) archlm tests for auto regressive conditional heteroscedasticity, the large p-values imply the absence of arch effects. Durbina is for autocorrelation in the presence of a lagged dependent term (Table 9). Ovtest is for omitted variables, vif, for the variance inflation factor, shows the absence of multicollinarity, as variance inflation is small (Table 8).

Table 9: Determinants of monthly exchange rate volatility, OLS

Esd	OLS	OLS robust	Prais-Winston
idiff		0.012 (0.182)	
mturn		-3.04e=06 (0.010)	
dturn		1.63e-06 (0.001)	
chdturn	1.29e-06 (0.582)		1.79e-06 (0.000)
L.chdturn	1.23e-06 (0.012)		1.30e-06 (0.003)
chtotturn	3.68e-07 (0.854)		
intvnet		-0.0000173 (0.004)	
chintvnet	-0.0000219 (0.000)		-0.0000222 (0.000)
L.chintvnet	-0.0000211 (0.000)		-0.0000222 (0.000)
L.esd	0.279 (0.021)	0.265 (0.047)	0.218 (0.095)
L2. esd			0.115 (0.301)
_cons	0.117 (0.000)	0.018 (0.713)	0.106 (0.000)
No. of obs	52	62	52
F	7.01 (6, 45)	4.07 (5, 56)	7.35 (6, 45)
Prob >F	0.0000	0.0032	0.0000
R^2	0.4831	0.3847	0.4950
Adj R^2	0.4142		0.4276
Root MSE	0.12005	0.12721	0.11866
Durbina	0.000(0.9922)		0.519 (0.4714)
Archlm	2.677 (0.1018)		1.694 (0.1930)

Note: p values and degrees of freedom for the F test shown in brackets with the coefficients. Arch effects are rejected if the archlm test value is large and exceeds the critical value from the χ^2 distribution. That is, if the p- value is large

However, the correlations indicate a possible simultaneity bias, especially with monthly data. OLS regressions with daily data and OLS regressions for dturn did not give satisfactory results because of severe non-normality. So we turn to generalized method of moments (GMM) estimations. This is used for non- normal data with heteroscedasticity or autocorrelation. It is a generalization of the instrument variable estimator. The instruments have to be orthogonal or uncorrelated with the error term. If the number of instruments is large the overidentification restrictions or rank condition is satisfied. The Hansen J tests the specification. The null is that the instruments are valid. It is chi squared in the number of overidentifying restrictions. The null cannot be rejected if the p value and the value of the statistic are high. If the number of instruments is exact then GMM is equivalent to OLS. The Newey West correlation matrix used gives robust errors.

Table 10: The effect of different measures of intervention on volatility

	esd – robust	**esd – robust**
chdturn	9.64e-07 (0.021)	1.15e-06 (0.017)
intvnet	-0.0000152 (0.003)	
fxach		-7.14e-06 (0.171)
dvgr	0.104 (0.009)	0.096 (0.029)
L. esd	0.366 (0.008)	0.294 (0.021)
_cons	0.119 (0.000)	0.119 (0.000)
No of obs.	62	76
F	5.06 (4, 57)	3.99 (4, 71)
Prob >F	0.0015	0.0057
R^2	0.3551	0.2620
Root MSE	0.12909	0.14478

Note: p values and degrees of freedom for the F test shown in brackets

GMM can also be used to estimate forward-looking behaviour by instrumenting expectations under the assumption of orthogonal errors. In the GMM estimations upto 4 lagged values of the variables were used as instruments. The Hansen J test was satisfied.

Table 11 gives GMM estimations of monthly and daily echav. Since policy is more endogenous at the monthly frequency the two intervention variables are instrumented at this frequency, and chtotturn at the daily. Lagged idiff weakly appreciates the rupee at the daily frequency. As in the monthly OLS regressions, mps and dps appreciate the currency and so does dvcmr. Although fxach significantly depreciates the currency, intvnet is not significant. At the daily frequency, although the R^2 is low, lafps significantly depreciates the currency, as does the change in total turnover.

Table 11: Determinants of exchange rates, GMM Estimation			
echav	**Monthly**		**Daily**
	GMM 1	**GMM 2**	**GMM**
L. idiff			-0.0000977 (0.109)
mps	-1.31e-06 (0.000)	-9.10e-07 (0.000)	
sqmps			2.86e-10 (0.200)
dps		-1.89e-07 (0.179)	
sqdps			-3.11e-10 (0.004)
chtotturn			7.01e-08* (0.036)
intvnet		-1.52e-07* (0.441)	
fxach	8.66e-07* (0.000)		
lafps			7.92e-09 (0.066)
dvcmr		-0.00282 (0.137)	
dvgr	-0.0046 (0.000)	0.00203 (0.030)	
L.echav	0.163 (0.014)	0.184 (0.020)	
_cons	-0.00017 (0.641)	0.00014 (0.712)	
No of obs.	71	44	97
F	37.66 (4, 66)	31.91 (6, 37)	1.66 (5, 91)
Uncentered R^2	0.4258	0.5085	0.0836
Root MSE	0.003927	0.003915	0.001351
Hansen J- stat	10.907 χ^2 (18)	21.346 χ^2 (18)	25.998 χ^2 (19)

Note: * variables are instrumented in each regression, p values and degrees of freedom of the F and χ^2 shown in brackets

Table 12 reports the GMM estimations for Garch measures of volatility, with intvnet instrumented for the monthly regression and dturn for the daily. At the monthly frequency, chintvnet significantly reduces volatility while dturn and sqdps increase it. At the daily frequency, dturn increases volatility but mturn and sqdps reduce it.

Table 12: Determinants of exchange rate volatility		
	GMM: Monthly	**GMM: Daily**
	esd	**eegarch 1**
idiff		-0.0007 (0.134)
sqdps	5.90e-10 (0.112)	-2.55e-09 (0.007)
dturn		1.30e-06* (0.012)
chdturn	6.85e-07 (0.068)	
L.chdturn	9.19e-07 (0.008)	
mturn		-3.63e-06 (0.000)
intvnet	-0.0000137* (0.054)	
dvgr		-0.0065 (0.2216)
dvcmr		-0.0050 (0.060)
L.esd	0.353 (0.000)	
L2.eegarch1		0.7066 (0.000)
rr		0.0187 (0.015)
_cons	0.104 (0.000)	-0.0998 (0.019)
No of obs	44	97
F	5.25 (5, 38)	12.28 (8, 88)
Uncentered R^2	0.7194	0.7104
Root MSE	0.122	0.01661
Hansen J- stat	29.356 χ^2 (24)	22.213 χ^2 (19)

Note: * variables are instrumented in each regression, p values and degrees of freedom of the F and χ^2 shown in brackets

Table 13 estimates the determinants of dealer turnover. At the monthly frequency idiff significantly raises chdturn, but is not significant at the daily frequency. At the monthly frequency, dps significantly reduces change in dealer turnover while mps has opposite signs in two regressions. But chmturn significantly raises chdturn in all regressions.

Table 13: Determinants of dealer turnover						
chdturn			**Monthly**			**Daily**
	GMM 1	GMM 2	GMM 3	GMM 4	GMM 5	GMM
idiff	11175.19 (0.000)	11994.4 (0.000)	1781.16 (0.084)	4747.32 (0.000)	14743.46 (0.000)	-163.23 (0.207)
mps	2.04 (0.008)	2.95 (0.000)			2.33 (0.000)	
dps	-1.76 (0.001)	-3.30 (0.000)				
chmturn	1.42 (0.000)	1.25 (0.000)	2.67 (0.000)	2.48 (0.000)	1.61 (0.000)	1.35 (0.000)
chintvnet	3.68* (0.000)				5.40 (0.000)	
F. chintvnet		-1.53* (0.011)				
chfxach				5.08* (0.000)		
F. chfxach			-2.47* (0.000)			
lafps						0.01 (0.249)
dvgr	21370.57 (0.011)	19783.3 (0.194)			49644.54 (0.000)	-1500.46 (0.003)
dvcmr	39557.38 (0.000)	42542.79 (0.001)		17745.07 (0.005)	29399.31 (0.000)	958.97 (0.244)
egarch 11	29852.36 (0.000)	8828.88 (0.000)				
esd			36963.59 (0.001)	64031.1 (0.000)		
F.esd					93332.21* (0.000)	
eegarch 1						25103.96* (0.039)
L2. eegarch1						-49945.66 (0.000)
_cons	-52011.89 (0.000)	-56493.09 (0.000)	-9983.57 (0.019)	-22313.09 (0.000)	-71556.59 (0.000)	1223.86 (0.011)
No. of obs	43	41	70	71	43	94
F	165.97 (8, 34)	161.03 (8, 32)	96.46 (4, 65)	109.07 (5, 65)	163.29 (7, 35)	13.83 (7, 86)
Uncentered R^2	0.5357	0.4805	0.5052	0.7095	0.5577	0.2969
Root MSE	30733	32972	32806	25303	29996	3033
Hansen J-stat	21.718 χ^2 (22)	30.436 χ^2 (22)	31.947 χ^2 (22)	26.858 χ^2 (22)	20.490 χ^2 (22)	26.523 χ^2 (20)

Note: * variables are instrumented in each regression. P> than the t-statistic is given in brackets for the coefficients. This gives their significance level. Degrees of freedom of the F and χ^2 distributions are also given in brackets

Interestingly chintvnet significantly increases dturn when instrumented and otherwise, but expectations of chintvnet reduce chdturn. Similarly chfxach significantly raises chdturn but expectations of chfxach significantly reduce chdturn. Exchange rate volatility and instrumented future expectations of volatility strongly increase chdturn. Reduction in

LAF liquidity absorption and in cmr volatility, captured in dvcmr, raises chdturn. T-values are very high in these regressions suggesting strong effects. The dummy variable dvgr for market deepening weakly raises chdturn at the monthly level in some regressions but reduces it at the daily level. This growth dummy controls for market deepening over the period. The daily and monthly regressions also cover different periods of changing market depth, but results are similar. In the first of the two monthly GMM regressions, egarch11 is used as the volatility variable while in the others esd is used. Results are similar with either measure. As suggested by the correlations, strong interactions between policy and market variables are discovered at the monthly frequency.

Table 14: Daily regressions with market information on intervention

	esd: OLS robust	chloge: OLS robust
idiff	-0.0035 (0.291)	
chdps		6.77e-07 (0.001)
L. mturn	5.45e-06 (0.024)	
dvintv	-0.0210 (0.027)	0.00068 (0.075)
chlafps	-4.19e-07 (0.060)	
dvexpec	-0.0168 (0.018)	0.00035 (0.588)
L. chloge		0.424 (0.014)
_cons	0.0056 (0.708)	-0.00017 (0.425)
No. of obs	49	36
F	2.07 (5, 43)	5.86 (4, 31)
Prob > F	0.0876	0.0012
R-squared	0.2776	0.4475
Root MSE	0.02231	0.00097

Note: p values shown in brackets with the coefficients

Finally, robust OLS regression (Table 14) with the Reuters hourly data, using an intervention dummy, also finds that intervention depreciates the exchange rate and reduces volatility. The dummy for expected intervention (dvexpec) also significantly reduces volatility; but its coefficient for chloge is positive (implying depreciation) but not significant.

4. The Strategic Use of Information

The regressions show dealer turnover to be forward looking and strategic since they respond to expected intervention. Therefore, a simplified version of the Bhattacharya and Weller (1997) one period model of strategic interaction between a CB and FX market players, where each tries to infer the other's stochastic information from market outcomes, maybe useful to derive optimal policy. The bilateral structure of FX markets implies that dealer's have their own specific information.

The model is modified for an economy subject to large cross border movements of foreign capital and uncertainties about fundamental determinants of the real exchange rate. The CB wants to prevent deviation of the exchange rate from its competitive equilibrium value, and limit its loss from FX transactions, for intervention that differs from that required for accumulating reserves against the short-term component of inflows. Since the economy is subject to different types of inflows, the two are not always equal, but short-term inflows are a subset of intervention. The latter affects foreign currency reserves. Thus, the CB is willing to make a loss on intervention for insurance but not on other types of intervention. In the model, the CB's loss is speculators' gain; the CB would want to limit that. For a linear speculative demand function optimal intervention and optimal choice of the current spot exchange rate are equivalent. The CB also has some weight on an exchange rate target, which may be implicit. Our estimations show that interventions affect the level of the exchange rate even though the Indian CB has no formal exchange rate target.

4.1. Objective functions

The CB's objective function can be written as:

$$\max_{P_O} E_0 \left\{ \left(Q^B - F_0\right)\left(\widetilde{P}_1 - P_0\right) - w\left(P_0 - T\right)^2 \right\} \qquad (1)$$

Variables with a tilde are random variables, and E_t denotes expectation at time *t*. Q^B is the CB's purchase or sale of foreign currency at t=1 (+ denotes purchase), P_0 is the spot exchange rate[14] at t = 0 (rupees per \$), $\widetilde{P}_1$ is the spot exchange rate at t = 1, F_0 is short term foreign inflow at t = 0, T is the current exchange rate target, w is the CB's preference weight on its targeting objective: $w \in [0, \infty)$.

Apart from acquiring short-term inflows, the CB's intervention in the spot market limits the variability of the exchange rate around the target value *T*. It would also like to make profits on its intervention but is prepared to make losses to build reserves against volatile inflows. Thus there is a trade off between targeting the exchange rate and the expected cost of doing so. The CB is assumed to be risk neutral with respect to intervention costs. The first term of (1) gives the capital gain or loss on the bank's position in the spot market. The second term captures the CB's concern for stabilizing the spot exchange rate around a target.

The CB trades in the spot market with foreign exchange speculators, who are uniformly distributed on the unit interval [0, 1]. They are atomistic price takers, and their demands derive from maximization of Neumann- Morgenstern expected utility functions, with constant absolute risk aversion. That is, they have negative exponential utility functions with identical risk aversion coefficient θ, so they maximize a simple function of mean and variance of speculative profit:

$$\max_{Q_i^S} \left[E_0\left(\widetilde{P}_1 \middle| I_i\right) - P_0\right] Q_i^S - \frac{\theta}{2} \mathrm{var}_0\left(\left[\widetilde{P}_1 - P_0\right] Q_i^S \middle| I_i\right) \tag{2}$$

Both mean and variance are evaluated conditional upon the private information set of speculator I, I_i (containing a private signal S_i and P_0). The demand function, obtained from the first order condition of the above optimization problem, takes the form:

$$Q^S\left(P_0, i\right) = \frac{E_0\left(\widetilde{P}_1 \middle| I_i\right) - P_0}{\theta\, \mathrm{var}_0\left(\widetilde{P}_1 \middle| I_i\right)} \tag{3}$$

[14] The interest differential is taken as given at zero, so that the spot rate would equal the forward rate.

4.2. Information

Apart from assumptions on preferences, the structure of information on the random variables assumed below justifies the above form of optimization. Period one spot exchange rate is:

$$\tilde{P}_1 = \tilde{\mu} + \tilde{\varepsilon}_P \tag{4}$$

All market participants observe the realization of the random component $\tilde{\mu}$ (normally distributed with mean μ and precision τ_μ) before any trade takes place. Precision $(\sigma^2)^{-1}$ of a distribution is the inverse of its variance σ^2. The component $\tilde{\varepsilon}_P$ is not directly observed, but all market participants have a prior that $\tilde{\varepsilon}_P$ is normally distributed with mean zero and precision τ_P.

Speculator $i \in [0,1]$ also receives a private signal $\tilde{S}_i$, conveying information on the unobserved component of the fundamental, $\tilde{\varepsilon}_P$.

$$\tilde{S}_i = \tilde{\varepsilon}_P + \tilde{\gamma}_i \tag{5}$$

Since ex ante, all speculators receive equally informative signals about the fundamental, $\tilde{\gamma}_i$ is normally distributed with mean zero and precision τ_γ. The precision τ_γ is a measure of the positive correlation in the messages across speculators. When $\tau_\gamma = 0$, the correlation between messages is zero, and as τ_γ becomes large, the correlation approaches unity.

The CB's exchange rate target is a random variable, $\tilde{T}$:

$$\tilde{T} = \tilde{\mu} + \tilde{\varepsilon}_T \tag{6}$$

For the speculators the prior on $\tilde{\varepsilon}_T$ is that it is normally distributed with mean μ_T^S and precision τ_T^S. Although the target is correlated with currency fundamentals, $\tilde{\mu}$, it may diverge in the short run. An alternative interpretation for $\tilde{\varepsilon}_p$ is 'noise' or uncertainty about fundamentals. Then $\tilde{\varepsilon}_T$ can be regarded as a component of fundamentals. For example, the CB can be regarded as intervening to prevent misalignments, or to adjust the exchange rate in response to temporary supply shocks. The CB has the option to manipulate μ_T^S and precision τ_T^S by releasing information about its target. The CB also has ex ante uncertainty about the realization of $\tilde{\varepsilon}_T$, τ_T, but it is resolved in advance of the CB's intervention activity. The random variables $\tilde{\mu}$, $\tilde{\varepsilon}_P$ and $\tilde{\varepsilon}_T$ are independent.

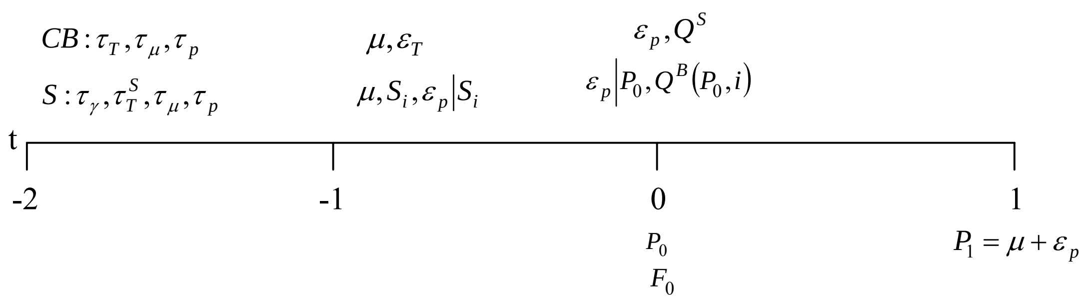


Figure 1: Time line and sequence of events

The time line in Figure 1 gives the sequence of events. Beliefs and individual actions are given above the line and market outcomes below the line. At t = -2 the prior belief about the distributions of the target exchange rate, 'fundamental' determinants of period 1 exchange rates, and speculator's private information are summarized by the precisions for the CBs and the speculators (S) respectively above the line. At t = -1 all observe μ, speculator i observes S_i, and the CB observes ε_T. At t = 0 trades, intervention and foreign inflows occur, and markets clear determining the spot rate. At t = 1, speculators observe the remaining random variable so that no uncertainty remains.

4.3. Equilibrium

Equilibrium in the spot market requires a market clearing condition. Aggregate speculative demand, $Q^S(P_0)$, is given by summing over the demands of i individual speculators $Q^S(P_0, i)$:

$$Q^S(P_0) = \int_0^1 Q^S(P_0, i)di \tag{7}$$

Market clearing therefore implies:

$$Q^B - F_0 + Q^S(P_0) = 0 \tag{8}$$

We conjecture that the aggregate speculative demand function takes the linear form:

$$-Q^S = a_1 + a_2 P_0 + a_3 \varepsilon_P \tag{9}$$

And show the parameters can be derived from the differential information of agents in a rational expectations equilibrium.

4.4. Extraction of information

From (9), the realization of ε_P is fully revealed to the CB. This follows because the CB can observe Q^S from the market clearing condition (8). The conjectured aggregate demand then allows it to infer ε_P from Q^S and P_0. Condition (8) implies the optimal intervention and optimal choice of the current spot exchange rate, P_0, are equivalent as long as $a_2 \neq 0$. Substituting the CB's information on its target, the period 1 spot rate, market clearing, and aggregate demand in its objective function, the first order condition for the optimal choice of P_0 is:

$$P_o = a_4 + a_5 \varepsilon_P + a_6 \varepsilon_T \tag{10}$$

Where

$$a_4 = \frac{a_2 \mu - a_1 + 2w\mu}{2(a_2 + w)}, \quad a_5 = \frac{a_2 - a_3}{2(a_2 + w)}, \quad a_6 = \frac{w}{a_2 + w}$$

Now (10) gives the information speculators are able to extract about $\tilde{\varepsilon}_T$ and $\tilde{\varepsilon}_P$ from observing equilibrium P_0, following the updating, from their private signal S_i at t = -1, of their original priors on these random variables. Through Bayesian updating the posterior precision and expectation of speculator i on $\tilde{\varepsilon}_P$ is derived at t = -1 from the signal S_i, and then updated conditional on the observation of P_0 from (10) for t=1. These expressions are substituted into (3) and then aggregated over speculators to obtain aggregate speculative demand Q^S. On aggregation individual realizations of $\tilde{\gamma}_i$ disappear since they are i.i.d. random variables. As conjectured, Q^S fully reveals ε_P to the CB.

Finally, the expression for Q^S derived from Bayesian updating is substituted in the conjectured speculative demand function (9) and its coefficients obtained by the method of undermined coefficients. That is, the constant term, the coefficients of P_0 and ε_P are equated respectively to a_1, a_2, and a_3. This process gives the values of the coefficients as:

$$a_1 = -\mu a_2 + k\mu_T^S \tag{11}$$

where

$$k = \left[\frac{2w\left(\tau_P + \tau_\gamma - \theta a_2\right)}{\tau_P + 2\theta w} \right] > 0 \tag{12}$$

$$a_2 = -w\left[1+\frac{2\theta w}{\tau_T^S}\right] + \left\{\left[w\left(1+\frac{2\theta w}{\tau_T^S}\right)\right]^2 - \frac{2w\tau_\gamma}{\theta} + 4w^2\left[\frac{\tau_P+\tau_\gamma}{\tau_T^S}\right] + \left[\frac{\tau_\gamma}{\theta}\right]^2\right\}^{1/2} \tag{13}$$

$$a_3 = -\tau_\gamma / \theta \tag{14}$$

Coefficient a_3 gives the influence of fundamentals ε_P on speculative demand. The latter becomes more sensitive to movements in fundamentals if (i) the informativeness of speculators' private signals increases, or (ii) speculators become less risk averse. Since this sensitivity, τ_γ, is a consequence of aggregating individual responses to private signals about fundamentals, it is independent of the speculators' priors about the target.

Substitute (11) in (9) to write the speculative demand function as:

$$Q^S = -k\mu_T^S + a_2\left(\mu - P_0\right) - a_3\varepsilon_P \tag{15}$$

It is shown to depend upon the magnitude of the deviation of the current spot rate from μ, the realization of the common knowledge component of the future spot rate.

Thus analyzing the interaction between the different sources of information in determining individual speculative demand, gives the solution for equilibrium values of a_1, a_2, and a_3. The equilibrium demand function of the speculators, equation (9), summarizes the behaviour of the model. In particular a_2, the slope of the speculative demand curve, determines the net effect of intervention.

4.5. Properties of equilibrium

Figure 2 gives a_2 as a function of the speculators' precision on the distribution of the unobserved component of the target exchange rate, τ_T^S. Curve I is drawn for low and curve II for high values of w (the CB's preference weight on its targeting objective) respectively. If the precision τ_T^S is low a_2 is always positive—as τ_T^S approaches zero, a_2 approaches a positive limiting value. Since a_2 is monotonically declining in τ_T^S, as τ_T^S approaches infinity, a_2 can become negative if w is high.

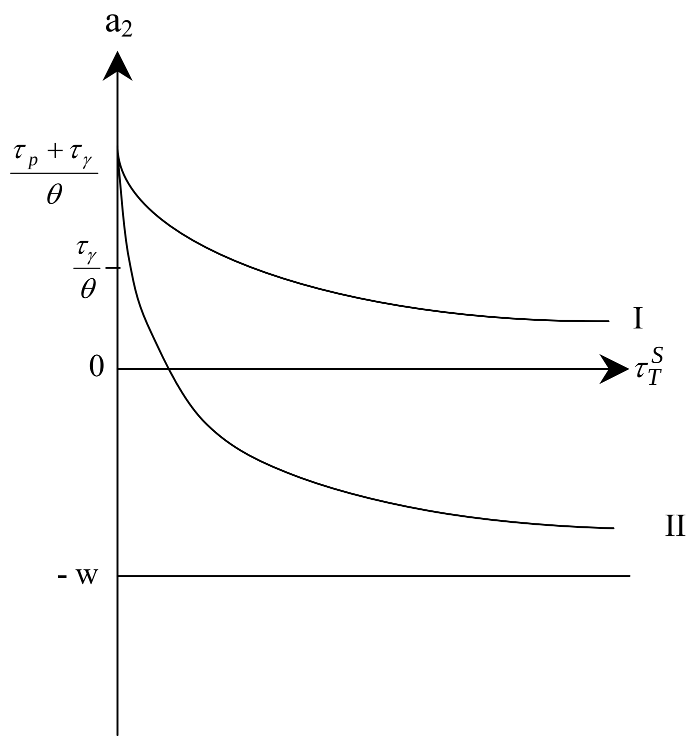


Figure 2: Changes in a_2 with speculators prior precision on the target

Positive a_2 is the normal case of a downward sloping speculative demand curve, where speculative demand falls with the spot rate, and the CB's purchases of domestic currency are associated with an appreciation. Either τ_T^S or w sufficiently small, guarantee that $a_2 > 0$ (Figure 2). The estimations in Section 3 establish that $a_2 > 0$ in the Indian case.

$$\lim_{\tau_T^S \to \infty} a_2 = \begin{cases} \frac{\tau_\gamma}{\theta} - 2w > 0 & \text{if } 2w < \frac{\tau_\gamma}{\theta} \quad \text{curve I} \\ -\frac{\tau_\gamma}{\theta} < 0 & \text{if } \frac{\tau_\gamma}{\theta} < w \quad \text{curve II} \end{cases}$$

The perverse case of $a_2 < 0$ arises when speculators upward revision of expectations of the future spot rate dominates the rise in the current spot rate. The numerator of (3) shows the opposite effect of the current and expected future spot rate on speculative demand.

Since $a_5 > 0$[15] the spot exchange rate is positively correlated with the fundamental variable ε_P in equilibrium (see (10)) and ε_p affects the future spot rate also.

In the perverse case, CB purchases of domestic currency are accompanied by depreciation of the currency, conditional on the realization of the next period fundamental. Speculative demand is upward sloping and responds positively to movements in the spot rate if (i) τ_T^S is large implying speculators have accurate information about the target (ii) τ_P is small or speculators' prior information about fundamentals is imprecise. Despite the apparently perverse response to intervention, persistent intervention, aware of the very high elasticity of expectations in the market, can still achieve targeting benefits. Both the scale of intervention and the spot rate are endogenously determined so there is no unidirectional response of the spot rate to intervention.

4.6. Signals on targets

So far the market was making inferences from CB intervention. When would it be worthwhile for the CB to announce its target or release some information about it? Assume it can credibly transmit a public message $\tilde{m}$ about the unobserved component of its target where, this $\tilde{\eta}$ is normally distributed with mean zero and precision τ_η:

$$\tilde{m} = \tilde{\varepsilon}_T + \tilde{\eta} \tag{16}$$

The CB chooses τ_η by maximizing its ex ante expected utility at t =-2, and transmits the message at t = -1, when its target becomes known to it with certainty. Speculators have the same initial prior on the target as the bank at t =-2, and update according to Bayesian rules:

$$\tau_T^S = \tau_T + \tau_\eta \tag{17}$$

$$\mu_T^S = \left(\tau_\eta / \tau_T^S\right) m \tag{18}$$

Since a_1 is a function of μ_T^S, it now becomes a random variable $\tilde{a}_1$, depending on $\tilde{\mu}$ and $\tilde{m}$.

[15] Follows from substituting the values of a_2 and a_3 in the expression for a_5.

From (10) if $a_2 < 0$

$$\lim_{\tau_\eta \to \infty} P_0 = \mu + \varepsilon_P \tag{19}$$

In this case as the message becomes more informative the market is able to infer the exact next period fundamental from (10), and the CB looses its ability to target the exchange rate, and will therefore optimally choose not to reveal its information.

If $a_2 > 0$

$$\lim_{\tau_\eta \to \infty} P_0 = \mu + \frac{2\theta w}{\tau_P + 2\theta w} \varepsilon_T \tag{20}$$

In this case, however, (20) shows that the signal becomes progressively less informative about fundamentals, so the CB's ex ante utility increases with τ_η. The conditions that make $a_2 > 0$, namely low w and τ_T^S, make it more difficult for speculators to extract information on fundamentals from (10). The CB will reveal information about its target, but speculators will still trade since their individual expectations of the next period rate will differ from the current spot rate. The effectiveness of targeting falls, however, as the markets prior information about fundamentals, τ_P, rises.

4.7. Who gains, who looses?

In the above framework the CB is not maximizing profits, but expects on an average to incur losses during interventions to achieve it's targeting and reserve accumulation objective. Speculators make positive expected profits at the CB's expense. This follows from the conditional expected profit for speculator i:

$$Q^S(P_0, I)\left[E_0\left(\widetilde{P}_1 | I_i\right) - P_0\right] = \frac{\left[E_0\left(\widetilde{P}_1 | I_i\right) - P_0\right]^2}{\theta \operatorname{var}_0\left(\widetilde{P}_1 | I_i\right)} \geq 0 \tag{21}$$

Where the inequality is strict if speculative demand is positive, $Q^S(P_0, i) \neq 0$. Therefore the unconditional expectation of profit is positive for all i. The CB, in trading against rational speculators must expect, on average, to make losses.

However, once the full heterogeneity of FX market participants are introduced in the model, rational speculators can make money from the less informed "noise" traders, and by providing insurance to hedgers. In order to prevent riskless "puts" against the CB, the band of variation of the managed float must not be less than ten percent, since then the risk of loss if the expected movement does not materialize becomes substantial. With a narrow band their loss is capped (Miller, 1997).

4.8 Managed Floating

In the case of a tightly managed float, more relevant to an emerging market such as India, where fundamentals are highly uncertain in a phase of rapid change, we can consider the unobserved component of the fundamental to be zero, since the spot rate is determined by fundamentals as revealed by CBs past targets and the CB's current targeting. This is an extreme case, to which an emerging market is likely to be closer. Speculators receive a private signal about the target, and expected future spot rate equals the expected target.

$$\widetilde{P}_1 = \widetilde{\mu} + \widetilde{\varepsilon}_T \tag{22}$$

$$\widetilde{S}_i = \widetilde{\varepsilon}_T + \widetilde{\lambda}_i \tag{23}$$

$$\widetilde{T} = \widetilde{\mu} + \widetilde{\varepsilon}_T \tag{24}$$

Speculative demand can now be written as:

$$-Q^S = a_1 + a_2 P_0 + a_3 \varepsilon_T \tag{25}$$

And following the earlier procedure for derivation, the spot rate can be written as:

$$P_0 = a_4 + a_5 \varepsilon_T \tag{26}$$

$$a_4 = \frac{a_2 \mu - a_1 + 2w\mu}{2(a_2 + w)} \tag{27}$$

$$a_5 = \frac{a_2 - a_3 + 2w}{2(a_2 + w)} \tag{28}$$

Deriving the value of the coefficients through Bayesian updating and the method of undetermined coefficients, we get:

$$a_3 = \frac{-\tau_\gamma}{\theta} \tag{29}$$

$$a_2 = \frac{\tau_\gamma}{\theta} \tag{30}$$

Therefore, now the perverse case is not possible, and the currency always appreciates on CB purchase. The value of a_2 is fixed and represented by a point on Figure 2.

Substituting the above coefficient values gives:

$$a_5 = 1 \tag{31}$$

$$a_1 = -k_1\mu + k_2\mu_T^S \tag{32}$$

where,

$$k_1 = -\frac{2(\tau_\gamma + w\theta)(2w\theta\tau_T^S + \tau_\gamma\tau_T^S - \theta\tau_\gamma - \theta\tau_T^S)}{\theta + 2(\tau_\gamma + w\theta)} \tag{33}$$

$$k_2 = \frac{2(\tau_\gamma + w\theta)(\theta\tau_T^S\mu_T^S)}{\theta + 2(\tau_\gamma + w\theta)} \tag{34}$$

Since now:

$$\lim_{\tau_\eta \to \infty} P_0 = \left(\frac{\tau_\gamma}{\theta} + 2w - k_1\right)\mu + 2(\tau_\gamma + \theta w)\varepsilon_T - k_2\mu_T^S \tag{35}$$

The perverse case does not exist. Intervention does not reveal the fundamentals as $a_2 > 0$. Since there is no revelation of information from a signal, thee is no conflict with the CB's target. So it is always worth the CB's while to reveal some information about its target.

Revealing some information about the target will allow the CB to achieve its targets partly through speculator trade, with minimal intervention (and therefore loss) and change in the interest rate (and therefore freedom to target the cycle). Such short-term exchange rate target changes in response to temporary supply shocks can reduce inflation, while minimizing decision lags. The homeopathic volatility induced deepens markets and reduce risk by encouraging hedging (Goyal, 2008).

Since political sensitivity to high inflation in a low per capita income country makes the CB unwilling to create inflation surprises and smoothing the impact of highly volatile inflows makes it willing to incur losses, Vitale's (2003) arguments about designing credible signals that make profits from reserve accumulation are not valid for an emerging market. Signals about the expected long run real exchange rate are helpful for exporters, and giving such signals is compatible with short-run nominal rate surprises to prevent the build up of speculative one-way positions. Since exporters would then hedge their short-term positions these fluctuations would not affect them. Thus Krugman's (1991) explicit target band is not required, but a signal of a nominal change will help converge markets to it, and like in his analysis reduce the necessity for active CB action.

5. Conclusion and Policy Implications

We find evidence in both OLS and GMM regressions, and with monthly, daily and hourly data sets, that intervention affects the level of the exchange rate and its volatility. It has tended to depreciate the exchange rate, in the period of estimation, and reduce its volatility. A broader measure of intervention, derived from the RBI balance sheet, affects levels, while the RBI's reported measure affects volatility. Our results are robust also because the estimations use multiple data sets and variable definitions, carefully correct for simultaneity, for properties of the data, and include both policy and market variables.

Since intervention affects both the level of the exchange rate and its volatility, an independent exchange rate policy is feasible. Merchant net demand or order flow affects the level; dealer order flow and turnover variables affect the volatility of exchange rates. Intervention, merchant turnover and order flow increase dealer turnover. So microstructure variables are important. Net demand tends to be more important for levels and turnover for volatility. Merchant turnover is a driving force, perhaps because of the large inflows in the period as noted also in the survey of markets. Volatility and expected volatility increase dealer turnover. So policy should limit volatility in a diffuse ten percent band, but occasional surprise would serve as homeopathic medicine. Anticipated intervention decreases turnover, suggesting it is optimal to reveal information about future intervention. The coefficient of intervention on levels implies the estimated speculative demand curve is downward sloping in the spot rate. So expectations of future exchange rates and intervention are stabilizing and not perverse. A diffuse target contributes to market stability. The model of strategic interaction between the CB and speculators suggests that, to the extent there is greater uncertainty about fundamentals, speculative demand is always well behaved and the CB can optimally reveal more information.

Macroeconomic fundamentals represented by interest rate differentials have weak effects on exchange rate levels and volatility but strong effects on FX market turnover. So policy should reduce arbitrage gaps in interest rates. Estimated strategic market behaviour and model derivations both indicate intervention and signaling may be a more effective influence on exchange rates in the Indian context than interest rate changes. The latter should be targeted to the domestic cycle.

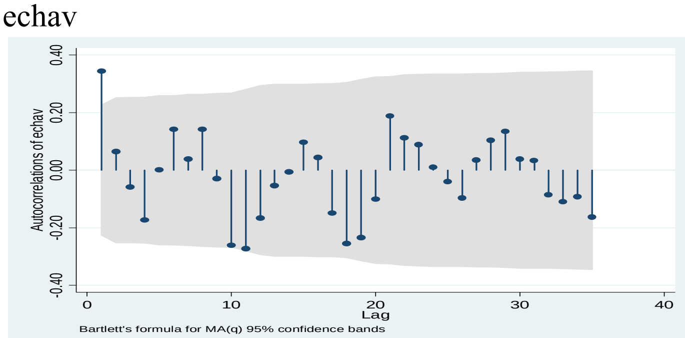
Markets form expectations of intervention activity and respond strategically to it. The increase in dealer turnover with intervention may imply strategic intraday arbitrage, whereby dealers profit at the expense of merchants and the CB. More transparency, whereby merchants are also aware of CB activity and targets may reduce the scope for such arbitrage. The disadvantage is that it may amplify the tendency for market agents to think alike, leading to large swings in variables. But since FX markets are predominantly bilateral and over the counter, agents will always have a range of information.

Signals about exchange rate changes, linked to random supply shocks, can generate surprise or enhance news, even while communicating clearly with the market. The markets will then help to bring them about, reducing the need for CB action. Transparency will reduce speculative positions and two-way movement of the nominal exchange rates will encourage hedging. Guidance to restrain nominal volatility within a ten percent band around a competitive exchange rate, but without committing to specific band edges, will maintain export competitiveness, helping the real sector.

Appendix:

Charts 1: Monthly autocorrelation functions

echav



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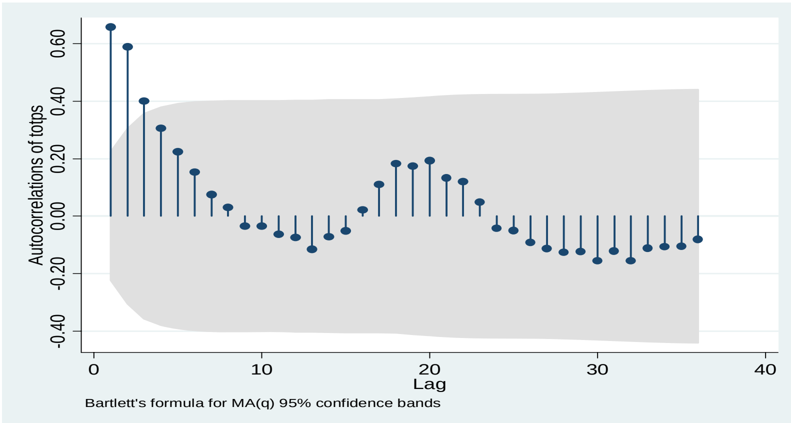

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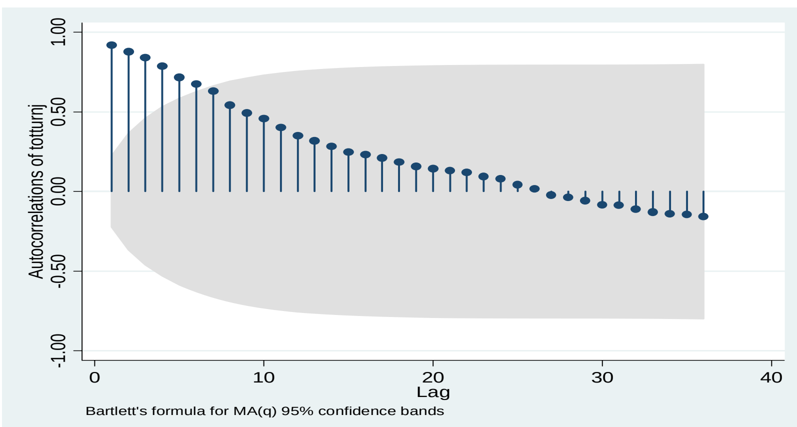

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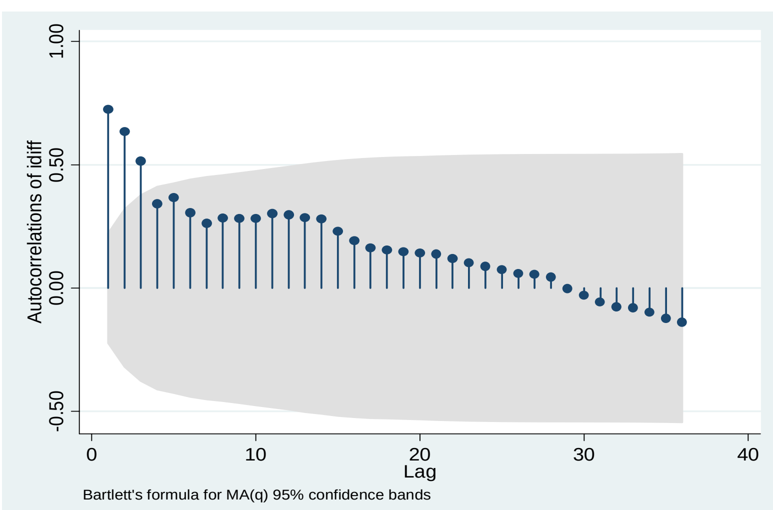

Charts 2: Daily autocorrelation functions

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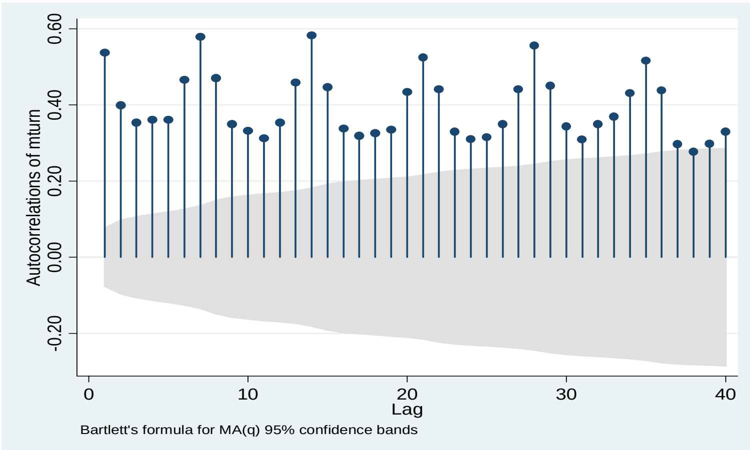

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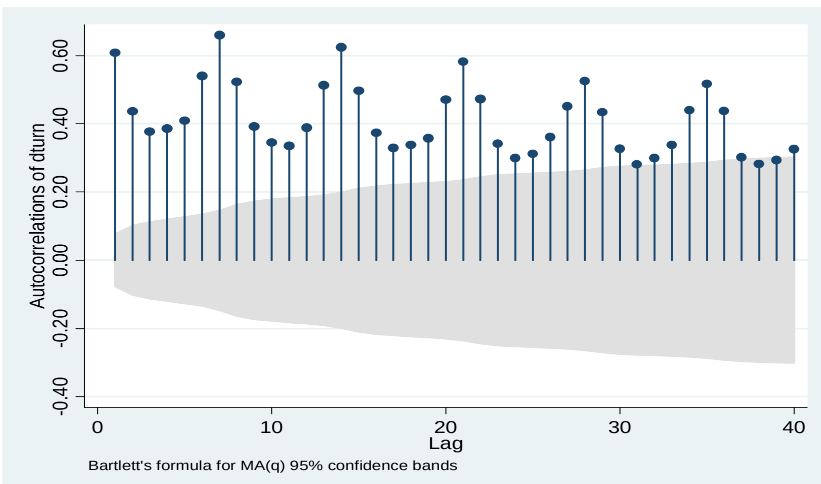

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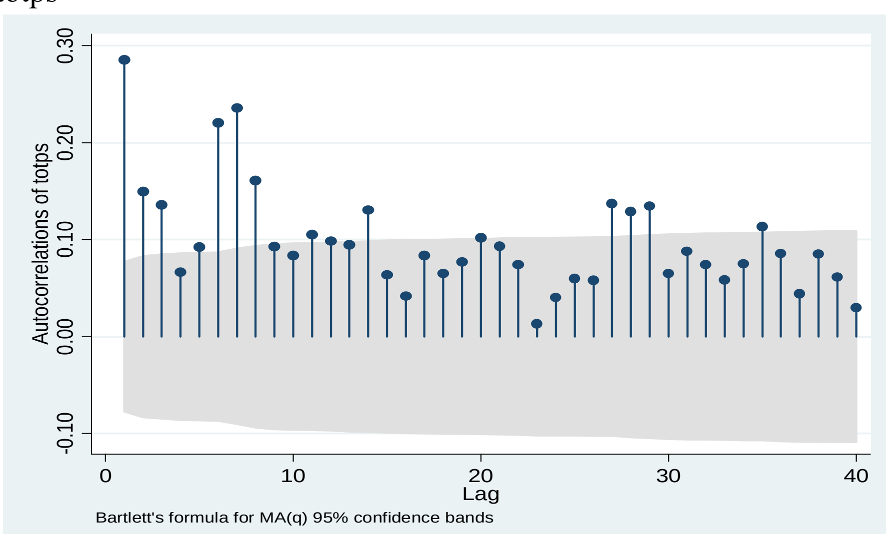

Charts 3: Monthly data graphs

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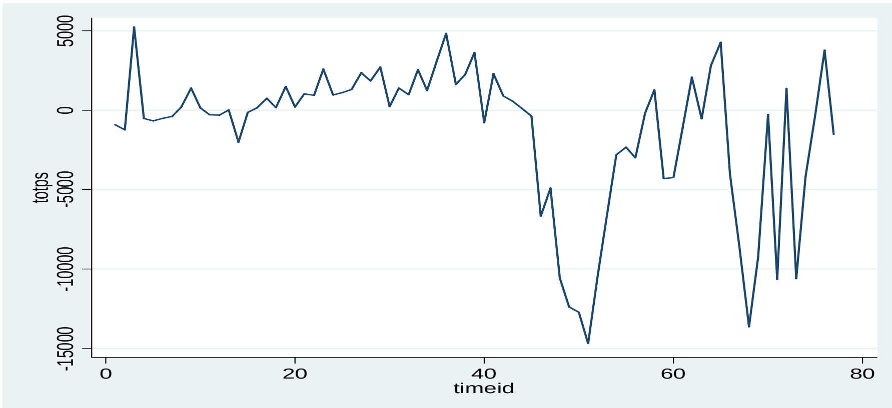

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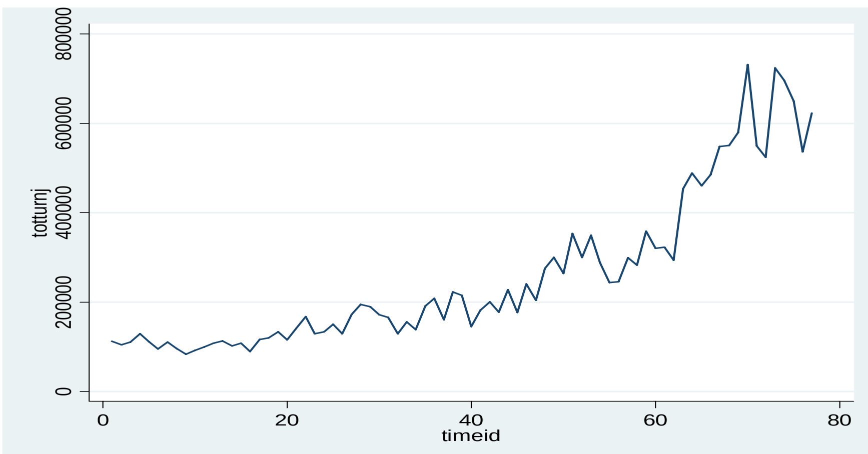

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40=Dec (05)
60=Apr (06)
80=Aug (07)

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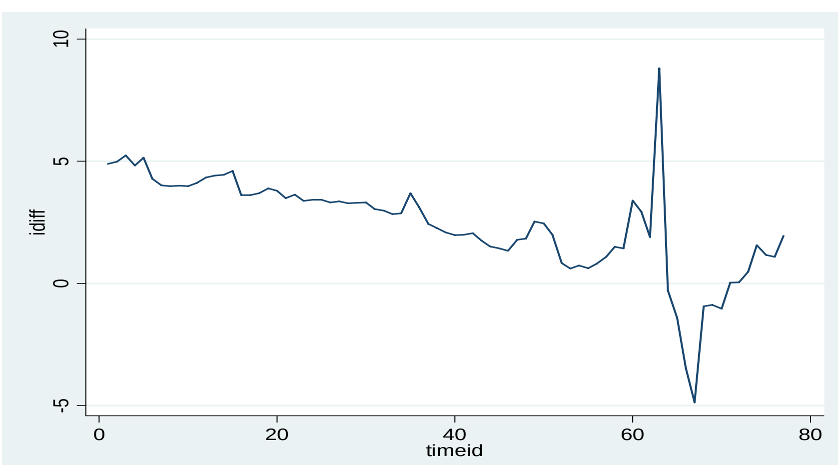

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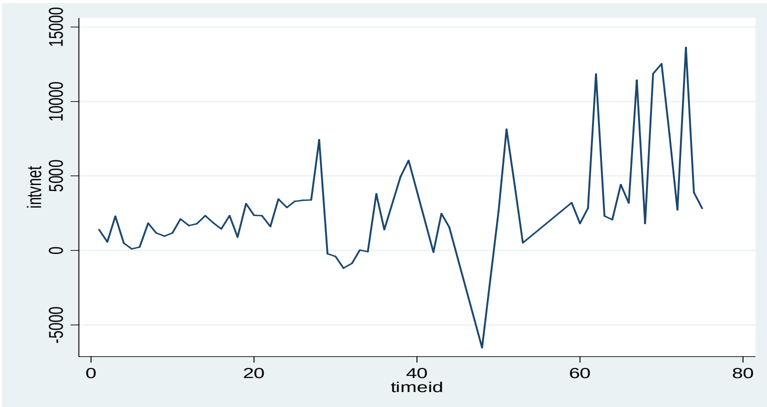

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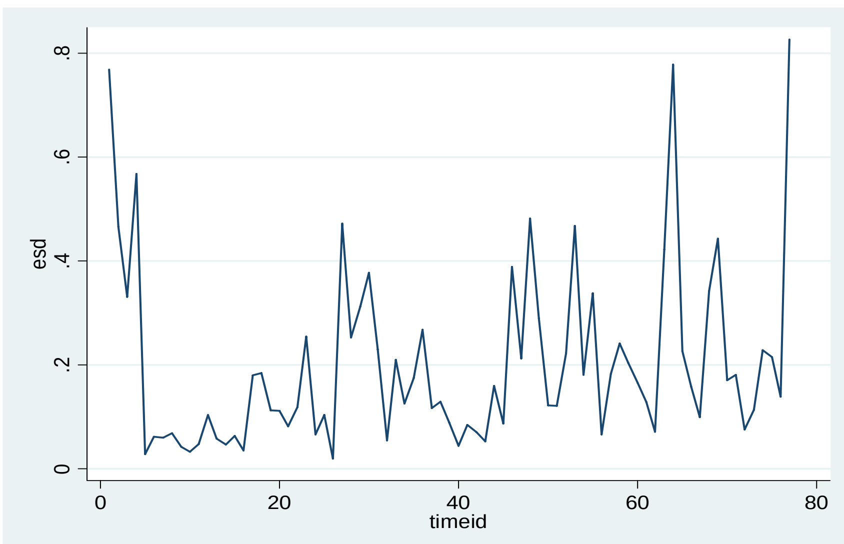

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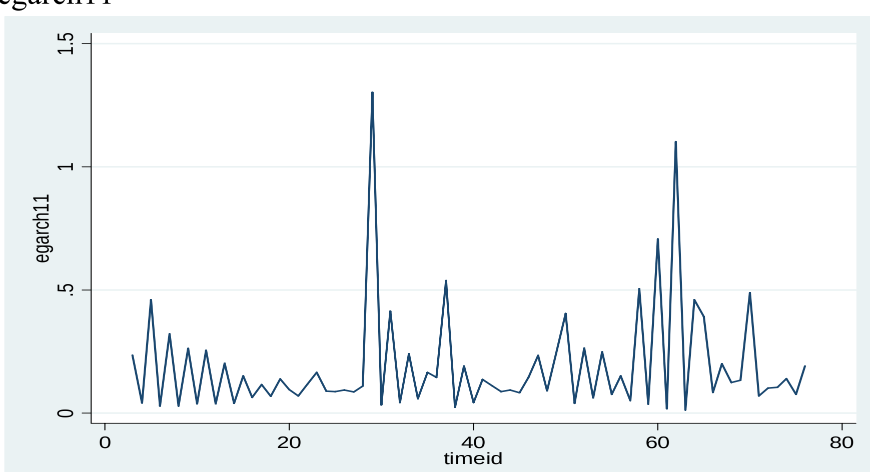

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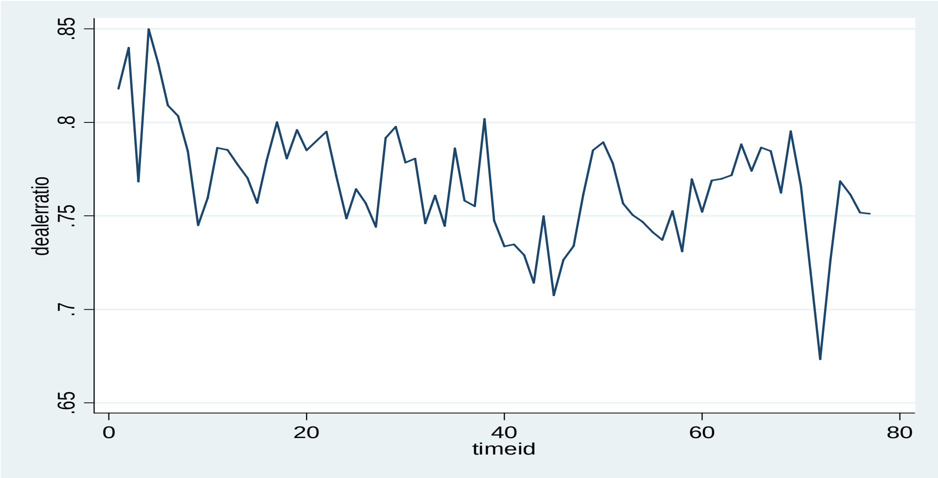

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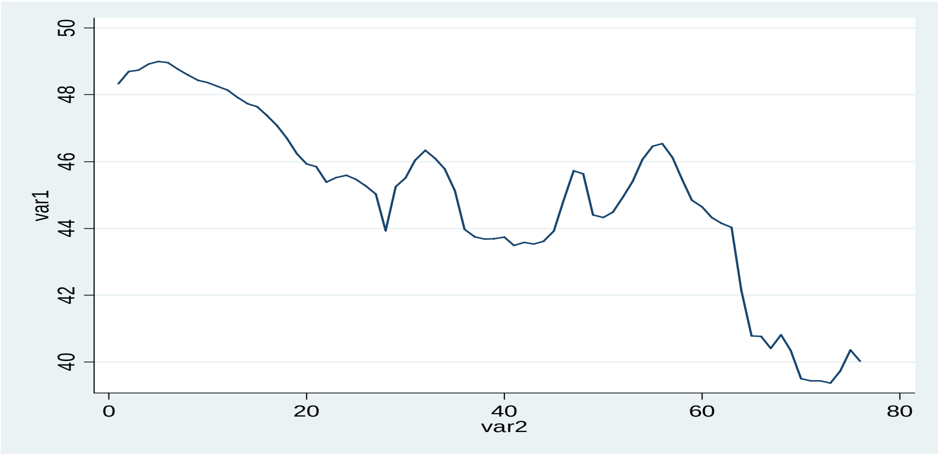

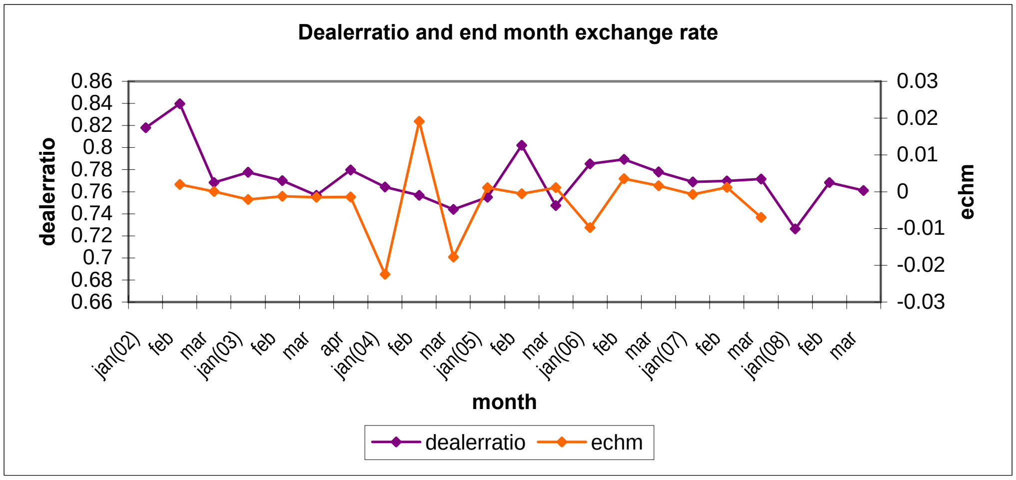

Charts 4: Daily data graphs

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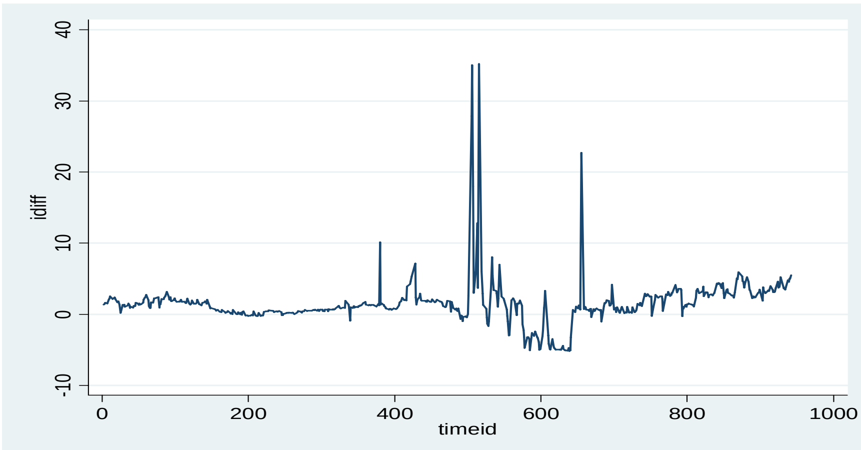

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400=5th Dec 06
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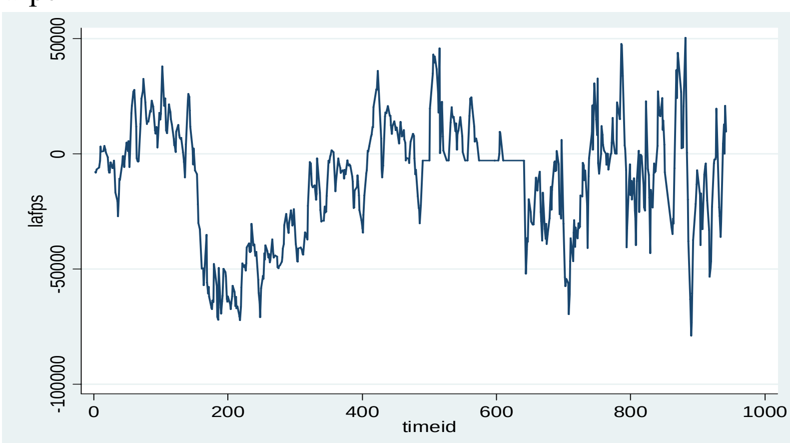
800=9th Jan 08
943= 31st May 08

lafps



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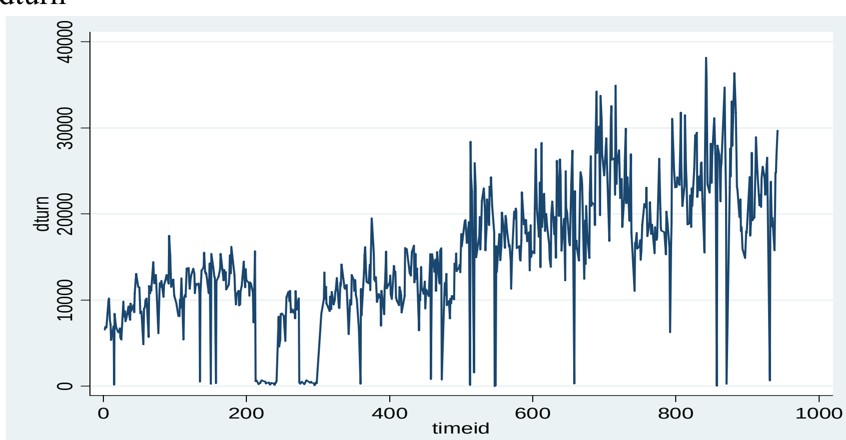

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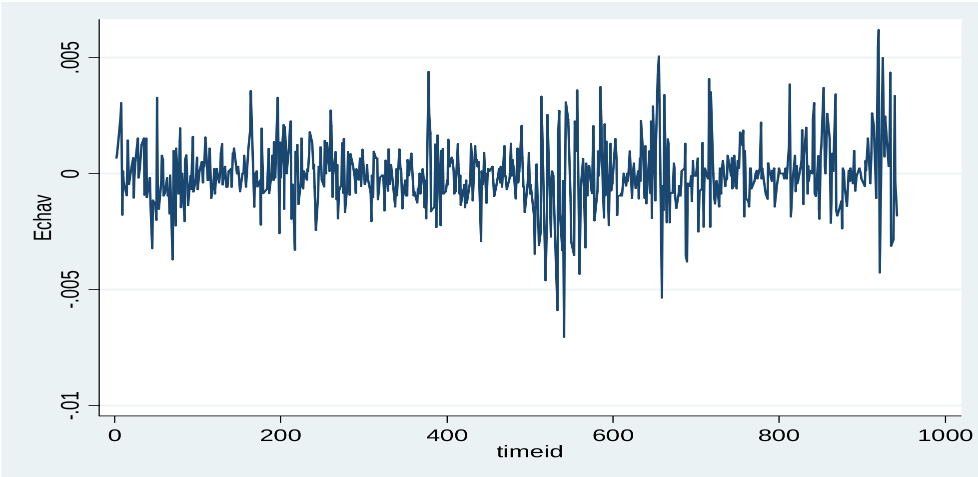

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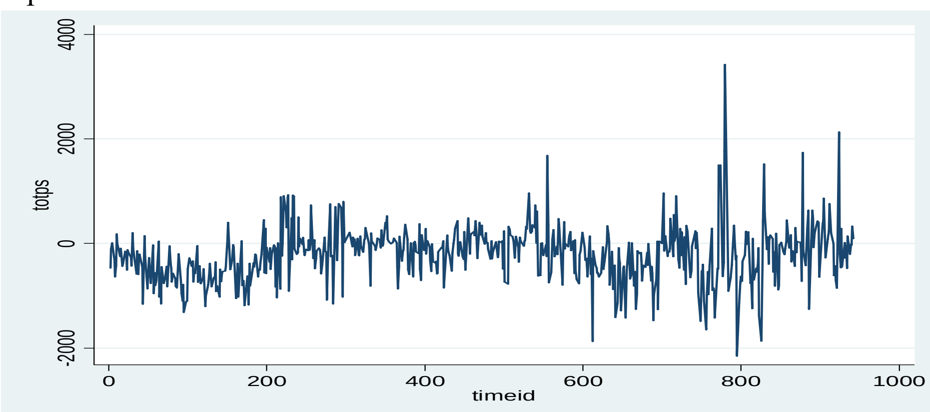

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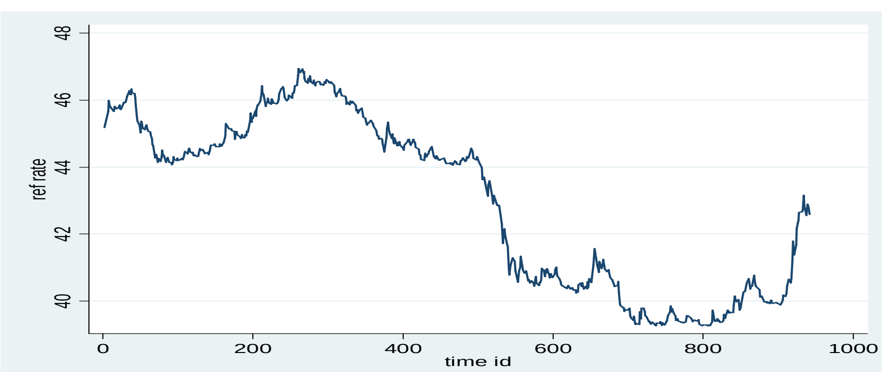

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