AN ASSESSMENT OF THE EFFECTIVENESS OF STERILIZATION OF CENTRAL BANK INTERVENTIONS: EMPIRICAL EVIDENCE FROM INDIA

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Abstract

The active participation of the central bank in exchange rate management has accelerated the growth of foreign exchange reserve in India. The massive reserve stockpiling has substantially contributed to apprehensions about excess liquidity in the domestic economy. The extent to which these concerns are justified depends on the degree to which the central bank is able to mitigate its effects on monetary aggregates. This study is an attempt to assess the magnitude of the sterilization coefficient by using quarterly data from 1996 to 2019. In order to estimate sterilization and offset coefficients, the study employed the two-stage least squares (2SLS) method under the theoretical framework of simultaneous equation modelling. The findings show that the reserve accumulation through central bank interventions puts pressure on money supply. However, the RBI sterilization policy was effective as the central bank was able to sterilize 93 percent of its interventions, while the offset coefficient was 72 percent during the period of study. The low value of the offset coefficient compared to the sterilization coefficient indicates a high degree of monetary policy independence in neutralizing the central bank's purchase interventions. Based on the findings, it can be recommended that policymakers should consider the sustainability of interventions and sterilization operations as the dual policy objectives of independent exchange rate management and monetary policy cannot be achieved in the presence of a high interest rate in an inflation-targeting regime.

Keywords: Sterilization, central bank intervention, money supply, RBI, two-stage least square, India

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1. Introduction

In the era of economic neoliberalism, foreign exchange reserve management plays a significant role in preventing vulnerabilities in emerging market economies (EMEs). Financial crises, especially the 2008 subprime crisis, demonstrated the shock-absorbing role of the international reserve. Though countries with higher levels of foreign reserve witnessed slumping growth during the crisis, its intensity was comparatively lower compared to that of countries with smaller foreign exchange reserve (Dominguez *et al*., 2012). Thus, it is important to keep sufficient foreign exchange reserves if an economy wants to maintain a stable exchange rate and independent monetary policy along with an extended and inclusive integration with the global market (Aizenman *et al*., 2010).

In the early 21st century, EMEs experienced a massive wave of foreign capital inflows tailed by extensive interventions by the respective central banks to arrest currency appreciation. If it creates more liquidity than what is necessary for a growing economy, the central bank has to use policy measures such as sterilization to neutralise its impact on domestic money supply. Theoretically, it is believed that any changes in the foreign exchange assets of central banks result in a corresponding change in the monetary base. A central bank's reserve money (monetary base) consists of circulating currency (*CC*) and commercial banks' reserve deposit (*RD*). Any changes in the foreign assets or domestic assets must be reflected in the monetary base (*MB*). $CC + RD = NFA + NDA$, $\Delta MB = \Delta NFA + \Delta NDA$. Through sterilization, the central bank tries to offset the changes in foreign exchange reserve (ΔNFA) either by changing net domestic assets (ΔNDA) or by changing the reserve deposit. While the purchase intervention is sterilized by issuing bonds, purchasing bonds from the market sterilizes the sale intervention. Sterilization is the process of neutralizing the changes in the net foreign assets (*NFA*) (which are caused by the intervention) by adjusting the net domestic assets (*NDA*) with the objective of maintaining the stability of the monetary base. As a process, sterilization neutralizes the impact of exchange market operations on domestic money supply with the help of money market instruments. Sterilization coefficients estimate the degree at which the central bank has absorbed the excess liquidity created through intervention. On the other hand, the offset coefficient measures the extend of foreign assets used for substituting the domestic asset in the monetary base.

India too witnessed a spurt of capital inflow and reserve accumulation during the early 2000s. It was crucial for a country like India which had gone through the 1991 balance of payment crisis, to amass a a huge amount of reserves as a precaution against such incidents in future. However, the presence of mercantile motive of the Reserve Bank

of India's (RBI) intervention during this period indicates that the stockpiling of the reserve exceeded the plausible precautionary levels (Rishad *et al*., 2021).

As a monetary authority, the Reserve Bank of India (RBI) used various market-friendly and non-market-friendly instruments to sterilize its intervention. However, it is difficult to manage an independent monetary policy in the presence of free capital mobility and a targeted exchange rate. This impossible trinity always raises challenges for the central bank's independent monetary policy regardless of the bank's decision to sterilize or not. For instance, absorption of the excess liquidity may cause an upward movement of the market interest rate from the desired level, which in turn attracts further capital inflow, leading to a failure of the sterilization policy. On the other hand, additional liquidity causes a fall of the market interest rate below the target level and makes the monetary policy ineffective. Unless the central bank drains the supply of domestic currency for intervention via sale of domestic assets, the money supply will increase. In the absence of complete sterilization, inflation could dampen the external competitiveness of the currency that was gained through the intervention. The size of the intervention and the extent of sterilization intensify the magnitude of the crisis. However, the RBI has taken several initiatives to counter these challenges without hindering the capital inflow. As a policy measure, the RBI introduced a market stabilisation scheme (MSS) to drain the excess liquidity caused by the asymmetric foreign exchange intervention to prevent the appreciation pressure on the rupee. In order to avoid the immediate impact of intervention on money supply, the RBI introduced forward market interventions to absorb excess liquidity from the foreign exchange market. With such a myriad of policies in place, it is difficult to coordinate the intervention activities with an independent monetary policy.

Studies about RBI sterilizations are not frequent. However, existing studies show that the RBI intervention policy was not aggressive until 2013. After this year, the RBI started aggressive interventions. However, the central bank also shifted to an inflation-targeting regime during this period. This created an instance of the RBI taking up contradictory policy measures. In this context, the present study examines the RBI's sterilization coefficient to ascertain the degree to which the central bank is able to neutralise the impact of interventions on domestic assets while pursuing an aggressive intervention policy. It also analyses the offset coefficient to measure the impact of capital inflow during the period on offsetting the effect of the RBI's sterilization policies.

This study is divided into several sections. Section 1 deals with a review of empirical literature. Sections 2 and 3 deal with the methodological framework of the study. The extent of sterilization and monetary autonomy is empirically assessed in Section 4 and concluding remarks are reported in Section 5.

2. Literature Review

Empirical literature reflects broadly three approaches to analysing the magnitude of the central bank's sterilization policy. The first group of studies employs ordinary least squares (OLS) to estimate the central bank's monetary reaction function (see Aizenman and Glick, 2009; Cavoli and Rajan, 2006; Takagi and Esaka, 2013). However, these studies failed to capture the contemporaneous relationship between domestic and foreign assets, which makes the coefficients biased and inconsistent. Aizenman and Glick's (2009) study on Asian and Latin American countries from 1984 to 2007 found that the sterilization coefficient ranges from −0.6 to −1.4. This study had a significant impact in the literature as it developed a strong theoretical fou*NDA*tion for central bank reaction function and evidence-based justification for sterilization coefficient below −1. They argued that in the presence of strong anti-inflationary policy action, sterilization coefficient can fall below the theoretical threshold limit of −1. Altınkemer´s (2005) study on the Central Bank of Turkey (CBT) from 1990 to 1997 found a sterilization coefficient between −0.82 to 0.91. It can be noted that the interest rate differentials played a significant role in the sterilization behaviour of the central bank in the post currency crisis 1994. The findings of Siklos (2000) on the Central Bank of Hungary (NBH) using the OLS method indicate a complete sterilization to keep an independent monetary policy.

The second group of studies used a Vector Autoregressive model (VAR), (see Christensen, 2004; He *et al*., 2005; Moreno, 1996; Waheed, 2007) by incorporating macroeconomic variables in the basic model. Moreno (1996) argued that Korea and Taiwan managed an independent monetary policy along with complete sterilization policy and presence of capital control helped Korea to maintain the policy effectively. He *et al*. (2005) also discovered perfect sterilization in China. By exploring the sterilization coefficient of the Czech Republic from 1993 to 1996, Christensen (2004) found an initial success of sterilization policy. However, the capital inflow induced by the high interest rate differential caused high costs of sterilization and gradually the policy became ineffective. Contrary to that, Waheed (2007) discovered a sterilization coefficient of −0.50 with significantly low offset coefficient (−0.16) for Pakistan during the period 2000 to 2006. It shows the use of intervention for monetary expansion. Patnaik (2004) examined RBI intervention during the period 1993 to 2003 to suggest a large but incomplete sterilization with a sizable offset coefficient (−0.8). Though the VAR model has been used extensively in the literature because of its ability to capture time-induced shocks, symmetrically endogenous assumption of variables has made it weaker as the model cannot estimate the coexisting relationship of variables.

The third group of studies overcame these issues by developing a set of simultaneous equations to estimate the relationship between net domestic assets (*NDA*) and net foreign assets (*NFA*). As a forerunner, Brissimis *et al*. (2002) developed a set of simultaneous equations under the basic framework of the central bank loss minimisation function. Their study on the German central bank shows a high sterilization coefficient (−0.74) with a lower offset coefficient (−0.22), showing the effectiveness of sterilization with an independent monetary policy. Because of the theoretical dominance of this study, later studies (*e.g*., Chang *et al*., 2015; Li *et al*., 2017; Ouyang *et al*., 2010; Ouyang and Rajan, 2011; Zhang, 2012) followed the same framework for estimating sterilization and offset coefficients in the case of Asian countries. Examining the Turkish sterilization between 1990 to 1996, Denizer *et al*. (1999) found that the sterilization was incomplete (−0.37) by contradicting the findings of Altinkemer (1998). Emir *et al*. (2000) also supported a low level of sterilization and offset coefficients for the same period.

EMEs have been using intervention policy extensively to maintain external competitiveness and to attract more capital since they shifted towards neoliberal policies. This prevalent use of intervention and sterilization in EMEs have inspired several studies about the sterilization coefficient in these economies. However, the question of independent monetary policy in the presence of free capital mobility in the EMEs is a hot topic among academic researchers. It is observed that some of the Asian EMEs have crossed the threshold limit of the sterilization coefficient (*i.e.*, −1) prescribed by the theoretical frameworks to maintain independent monetary policy. For instance, Ouyang (2007) found that the sterilization coefficient in five East-Asian economies ranged from −1.04 to −1.23 during the 1990s and 2000s. In China, this was between −1.02 to −1.23 during the 2000s. On the contrary, the sterilization coefficient in China was −0.79 from 1986 to 2007 (Aizenman and Glick, 2009) and −0.96 in the period 1999–2009 (Wang, 2010). The Korean central bank had successfully been practising complete sterilization up to the capital inflow surge in the early 1990s. In the early 1980s, central banks were forced to follow an over-sterilization policy in Korea to minimise the vulnerability arising from declining foreign exchange reserves (Kim, 1995). In the early 2000s, Asian economies used sterilization policy as a substitute for monetary expansion (see Table 1). It created a situation of complete sterilization in the short run but partial sterilization in the long run (Choi, 1995).

Table 1: Sterilization and offset coefficients in Asian economies

Author	Country	Methodology	Period of study	Sterilization	Offset
Ouyang *et al*. (2010)	China	TSLS	June 2000 to September 2008	1 to –1.02	0.52 to –0.54
		3SLS		1.210 to –1.234	0.70 to –0.72
Hamed (2011)	Iran	Ordinary Least Square	1971 to 2008	up to –0.1	–0.12
Lin (2012)	Thailand	error correction model (ECM), OLS	January 2004 and December 2010	0.97 to –1.06	0.91 to –0.98
	Korea			0.77 to –0.90	0.77 to –1
	Indonesia			0.181 to –0.87	0.152 to –0.53
	Malaysia			1.03 to –1.45	0.48 to –0.78
Ouyang *et al*. (2008)	India	Panel data with random effects (2SLS)	1990 to 1997	0.966 to –1.046	0.796 to –0.838
	Indonesia				
	Korea				
	Malaysia				
	Philippines		1998 to 2005	0.846 to –1.265	0.514 to –0.601
	Singapore				
	Taiwan				
	Thailand				
Kwack (2001)	Indonesia	OLS	1985 to 1996	–0.99	
	Korea			–0.97	
	Malaysia			–0.99	
	Philippines			–0.94	
	Singapore			–0.99	
	Thailand			–0.81	
	Taiwan			–0.94	

Source: Authors' own elaboration

This study contributes to the literature in two ways. Firstly, most of the Indian studies which have examined the sterilization practices of the RBI have had certain methodological constraints. For instance, Gupta and Sengupta (2013), Patnaik (2004) and RBI (2004) used OLS and VAR frameworks to estimate the sterilization and offset

coefficients. Due to the methodological limitations of these approaches in capturing the contemporaneous relationship between domestic and foreign assets, the coefficients were biased and inconsistent. Moreover, the symmetrically endogenous assumption of variables in the VAR model also made the coefficients weaker as the model cannot estimate the coexisting relationship of variables. The present study seeks to address this limitation in the existing literature using a simultaneous equation modelling under the 2SLS framework.

Unlike the previous studies, this study examined an updated dataset on RBI sterilization which spans across a period that reflects several policy changes from RBI and various economic scenarios at the global level. The period analysed by the present study also witnessed a major shift in the sterilization instrument when RBI introduced more market friendly instruments starting from early 2000s.

Due to some methodological limitations, past studies on central bank intervention in India did not examine the monetary autonomy of RBI. The present study used simultaneous equation modelling under the international capital flow framework to estimate offset coefficient to measure the monetary autonomy of the RBI. Further, it examines the effectiveness of RBI sterilization in the post-floating period and the episodic behaviour of sterilization and monetary independence for the study period.

3. Theoretical Framework

The empirical model for estimating the impact of intervention on money supply and monetary policy efficiency is derived as a combined theoretical framework of monetary policy reaction function developed by Cumby and Obstfeld (1982) and international capital flow model developed by Kouri and Porter (1974). Cumby and Obstfeld (1982) argued that central banks neutralise the impact of reserve accumulation by adjusting the *NDA*. On the other hand, the capital flow model justifies the linkage between capital inflows and monetary policy measures.

As *NDA* and *NFA* exhibit a mutually inverse relationship, any intervention activity in the foreign exchange market will reflect on *NDA* immediately. If central banks systematically sterilise its interventions, the variation in *NDA* will be correlated with the error term in the capital flow equation which makes the OLS estimates inconsistent (Jan *et al*., 2005). Concurrent impact of intervention on domestic and foreign assets demands simultaneous equation modelling as the OLS framework will give biased and inconsistent results (Kouri and Porter, 1974; Obstfeld, 1983). Using Instrumental Variable models like 2SLS will help to overcome the potential endogeneity problem of *NDA* (Brissimis *et al*., 2002; Denizer *et al*., 1999; Kamas, 1986; Kouri and Porter, 1974). Following these arguments, the study used a 2SLS model for estimating the monetary reaction function.

Simultaneous equation model suggested by Kouri and Porter (1974) clearly explains the central bank's sterilization mechanism as shown below:

$$\Delta NDA_t = a_1 + a_2 \Delta NFA_t + a_3 X_t + u_t \quad (1)$$

$$\Delta NFA_t = b_1 + b_2 \Delta NDA_t + b_3 Y_t + \upsilon_t. \quad (2)$$

X and Y are the factors influencing ΔNDA and ΔNFA. u_t and v_t are the IID error terms. The coefficient a_2 explains the extent to which the central bank sterilised their intervention. Similarly, b_2 describes the offset coefficient.

A purchase intervention by the central bank expands the reserve money and the sterilization drains the excess money from the market so that the net change in reserve money will be zero. If a_2 is exactly equal to −1, it indicates a complete sterilization of intervention. On the contrary, sterilization coefficient near zero indicates the absence of sterilization on the market ($\Delta MB \neq 0$; $\Delta NDA < \Delta NFA$). If a central bank reduces the reserve money by following a contractionary monetary policy, it results in over-sterilization which is reflected as a sterilization coefficient above −1 ($a_2 > -1$). Such policies are practised to prevent the expected inflationary pressure. ($a_2 \geq 0$), specifies that when the monetary expansion policy is employed to reduce the credit crunch or to manage the external imbalances, the sterilization coefficient will be greater than or equal to zero.

Similarly, if $b_2 = 0$, it shows perfect capital control (*i.e.*, changes in the reserve money do not influence capital flow). Conversely, when $b_2 = -1$, it is the evidence of perfect capital mobility (*i.e.*, a decrease in *NDA* is balanced by an equivalent increase in *NFA* without altering the monetary base and vice versa). In such cases, the sterilization is ineffective because the amount of decline in domestic assets is substituted by supplementary foreign capital. It raises the amount of foreign reserve or *NFA*. Sterilizing this additional reserve generates a "vicious circle of sterilization" (Christensen, 2004). In the presence of high monetary independence, the absolute value of sterilization coefficient will be high and that of offset coefficient will be low. Complete sterilization can be observed if $\Delta MB = \Delta NDA + \Delta NFA = 0$, hence an excess (or deficit) value of ΔMB can be inferred as unsterilized capital inflow (or outflow).

4. Empirical Model

This study follows a modified form of the model developed by Brissimis *et al*. (2002) after incorporating the required modifications suggested by Ouyang *et al*. (2008). These models are adopted because of their theoretical orientation towards the narrow approach of sterilization as the RBI uses Open Market Operation (OMO) as the primary sterilization instrument. Moreover, the assumptions and components of the central bank loss function

in these models are suitable for the Indian scenario as RBI's monetary policy aims to achieve multiple subsidiary objectives such as economic growth, exchange rate and interest rate stabilisation apart from the main objective of price level control. Hence this study incorporated these four variables along with other macroeconomic variables influencing *NDA* and *NFA* in the empirical model.

$$\begin{aligned}\Delta NDA_t = \ & \propto_0 + \sum_{i=0}^{n} \propto_{1i} \Delta NFA_{t-i} + \sum_{i=0}^{n} \alpha_{2i} \Delta MM_{t-i} + \sum_{i=1}^{n} \alpha_{3i} \Delta CPI_{t-1} + \sum_{i=1}^{n} \alpha_{4i} \Delta GAP_{t-1} \\ & + \sum_{i=0}^{n} \alpha_{5i} \Delta FD_{t-1} + \sum_{i=1}^{n} \alpha_{6i} \Delta REER_{t-1} + \sum_{i=0}^{n} \alpha_{7i} \Delta \left(r_{t-1} + E_t e_{t+1-i} \right) \\ & + \sum_{i=1}^{n} \alpha_{8i} \left(d_1 - 1 \right) \sigma r_{t-1}^{f} + \varepsilon_t \ . \end{aligned} \tag{3}$$

$$\begin{aligned}\Delta NFA_t = \ & \beta_0 + \sum_{i=0}^{n} \beta_{1i} \Delta NDA_{t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta MM_{t-i} + \sum_{i=1}^{n} \beta_{3i} \Delta CPI_{t-1} + \sum_{i=1}^{n} \beta_{4i} \Delta GAP_{t-1} \\ & + \sum_{i=0}^{n} \beta_{5i} \Delta FD_{t-1} + \sum_{i=1}^{n} \beta_{6i} \Delta REER_{t-1} + \sum_{i=0}^{n} \beta_{7i} \Delta \left(r_{t-1} + E_t e_{t+1-i} \right) \\ & + \sum_{i=1}^{n} \beta_{8i} \left(d_2 - 1 \right) \sigma e_{t-i} + \varepsilon_t \ . \end{aligned} \tag{4}$$

A description of the variables used in this study is given in Table 2.

The main objective of the study is to find sterilization coefficient (α_1) and the offset coefficient β_{1i}. The monetary policy reaction function (Equation 3) was developed by incorporating the most important determinants. The central bank follows a contractionary monetary policy to curtail the inflation because a rise in inflation and the resulting economic instability may encourage a capital flight. The money multiplier will also cause an equivalent effect by increasing the money supply and causing an instability in the domestic economy. Similarly, an expected depreciation of the domestic currency may also force the central bank to follow tight monetary policy actions. Thus, the coefficients are expected to be negative in such a scenario. If the central bank follows a countercyclical monetary policy to minimise the money creation impact of an economic boom (*i.e.*, *GDP* growth rate above the trend) or to manage an expansionary fiscal deficit, it will also cause a negative coefficient in the equation α_4. However, the economic slowdown may force the policy makers to follow expansionary monetary and fiscal policies together to recover the economy. This situation yields a positive coefficient in the monetary policy reaction function.

Table 2: Description of variables

Variables	Definition	Measured as	Sources
ΔNFA_t^A	Revaluation excludes net foreign assets scaled in GDP Net foreign assets are defined as foreign assets minus foreign liabilities of central bank	$\left[NFA_t + NFA_{t-1}\left(\frac{e_t}{e_{t-1}}\right)\right] / GDP_t^N$ *NFA* –Net Foreign Assets, e_t – Nominal exchange rate at the end of the month. GDP_t^N – Nominal Gross Domestic Products.	Reserve Bank of India
ΔNDA_t^A	Revaluation Adjusted Net Domestic Asset scaled in GDP	$\left[\Delta NDA_t + NFA_{t-1}\left(\frac{e_t}{e_{t-1}}-1\right)\right] / GDP_t^N$ *NDA* – Net Domestic Assets, Δ – first difference operator.	Reserve Bank of India
ΔMM_t	Changes in money multiplier for *M*2	$\log\left(\frac{M2_t}{MB_t}\right) - \log\left(\frac{M2_{t-1}}{MB_{t-1}}\right)$ *M*2 is money supply, *MB* is monetary Base.	Reserve Bank of India. CECID database
ΔCPI_t	Changes in Consumer price index 2010 = 100	log (CPI_t) – log (CPI_{t-1})	Reserve Bank of India Federal Reserve
ΔFD_t	Changes in government's fiscal deficit scaled in GDP	FD_t / GDP_t^N *FD* is Government's Fiscal Deficit.	Reserve Bank of India
ΔGAP_t	Difference between real GDP and potential GDP calculated using Hodrick-Prescott (HP filter) with smoothing parameter of 1,600.	log (GDP_t^R) – log (GDP_t^P) GDP_t^R is real *GDP* and GDP_t^P is the potential *GDP* calculated using Hodrick-Prescott (HP filter) with smoothing parameter of 1,600.	Reserve Bank of India Federal Reserve
$\Delta REER_t$	Changes in Real Exchange Rate 2010 = 100	log ($REER_t$) – log ($REER_{t-1}$) *REER* is Real Effective Exchange Rate.	Reserve Bank of India Bank for International Settlement
$\Delta (r_t^f + E_t e_{t+1})$	Exchange rate adjusted foreign interest rate. Foreign interest rate is defined as the 3-month US Treasury bill rate.	Δ [r_t^f + log (e_{t+1})] r_t^f is the foreign interest rate, e_{t+1} is average nominal exchange rate of INR/USD at time t + 1.	Reserve Bank of India Federal Reserve
σe_t	Standard deviation of exchange rate	Standard deviation of within quarter variation in rupee exchange rate.	Reserve Bank of India Federal Reserve
σr_t	Standard deviation of domestic interest rate.	Standard deviation of within quarter variation in domestic interest rate.	Reserve Bank of India CEICD database
d_1	Dummy variable	d_1 = 2, if $\Delta NDA_t < 0$, otherwise 0	
d_2	Dummy variable	d_2 = 2, if $\Delta NFA_t < 0$, otherwise 0	

Source: Authors' own elaboration

Equation 4 shows the balance of payment function which consists of six "push" and "pull" factors that stimulate capital flow into the concerned economy. It also shows the capital flow reaction to monetary policy. It is expected that an increase in the money multiplier will result in an increase in money supply and will bring down the interest rate. This will cause a drop in the foreign capital inflow. Higher inflation causes a depreciation of the nominal exchange rate which will negatively affect the reserve accumulation practices of the central bank. Thus, the coefficients are expected to be negative. The appreciation of the *REER* dampens the external competitiveness of the domestic currency. To prevent this, the central bank usually expands the monetary base which causes a negative impact on the *NDA*. The output gap may exacerbate the current account deficit because of the income effect and may prevent the central bank from accumulating reserves. However, the growth of output will lead to accelerated capital inflow. Therefore, it can be said that a domination of capital inflow over current account offers a positive coefficient and it will be negative otherwise. It is substantiated that reserve accumulation and capital inflow causes appreciation of the *REER* and economic growth. Undervaluation of the *REER* (depreciation of the nominal exchange rate) and a drop-in foreign interest rate may increase the reserve accumulation.

σ_r represents the standard deviation of the within quarter variations in the monthly interest rates. The dummy variable (d_1) takes a value of 2 if the domestic money market is in a surplus condition ($\Delta NDA < 0$), and it takes a value of 0 otherwise (*i.e.*, if $\Delta NDA > 0$). The central bank injects (or withdraws) money to manage interest rate volatility. A higher interest rate volatility stimulates greater money market intervention. An interest rate hike (σ_r) makes a positive change in *NDA*, hence, the coefficient will be negative (as a rise in *NDA* reduces volatility).

σ_e is the standard deviation of the within quarter variation in the nominal bilateral exchange rate. The dummy variable (d_2) takes a value of 2 if there is an excess demand ($\Delta NFA < 0$). In such a case, the central bank depletes the reserves. During an episode of excess supply ($\Delta NFA > 0$), it takes a value of 0 as the central bank replenishes the foreign exchange reserve. During a period of excess demand (or excess supply) of foreign reserves, central banks go for sales (or purchase) intervention to stabilise the exchange rate. A positive change in *NFA* decreases the exchange rate volatility; hence the coefficient will be negative.

The study uses quarterly data from the first quarter of 1996 to the last quarter of 2019. The choice of this particular period is based on the exchange rate policy shifts and the consequential current and capital account policies. The period has witnessed major economic events such as radical shifts in foreign exchange intervention policies, liberalisation of capital inflow, introduction of MSS and depreciation of the rupee.

A gradual deterioration of the dominance of non-market friendly instruments resulting from the introduction of market friendly instruments also occurred during this period. All the data were collected from various publications of the RBI, IMF and Federal Reserve Bank of St. Louis.

4.1 Adjustment of valuation effect

The change in the foreign exchange reserve was used as a proxy for intervention as it reflects the instances of both direct and indirect intervention operations. The official intervention data only show the RBI's direct interventions through its trading platform. However, if it is using commercial banks for interventions, it will only be reflected in the balance sheet. Since reserve changes are influenced by several factors including interventions, using it as a proxy for interventions may lead to wrong conclusions. These transactions will not alter the currency value of the monetary base but will be captured in the capital account. Hence, it should be adjusted in both *NFA* and *NDA*. In order to remove the revaluation effect caused by the foreign exchange volatility, the study employes the following equation.

$$NFA_t = \left(R_t \times e_t\right) - FL_t \tag{5}$$

$$Revaluation\,effect = NFA_{t-1}\left(\frac{e_t}{e_{t-1}} - 1\right), \tag{6}$$

$$\text{so, adjusted: } NFA = NFA_t^A = NFA_t - NFA_{t-1}\left(\frac{e_t}{e_{t-1}} - 1\right) \tag{7}$$

$$\text{so, adjusted: } NDA = NDA_t^A = NDA_t + NFA_{t-1}\left(\frac{e_t}{e_{t-1}} - 1\right). \tag{8}$$

R_t is the foreign exchange reserve, denominated in foreign currency. The exact data on composition of the foreign exchange reserve are not available, so it is assumed that the RBI invests its reserve in USD denominated assets. e_t is the domestic currency per unit of foreign currency and FL_t is the the central bank foreign liabilities.

5. Estimated Results

In order to ensure the stationarity of the variables under study, we employed Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The results show that all variables are stationary at the 10% level of significance. This permitted us to estimate the simultaneous equation under the 2SLS framework (Equations 3 and 4). Table 3 and 4 summarizes the results of the sterilization equation and offset equation. It can be observed that the sterilization and offset coefficients are negative and statistically significant at the 1%

level. It shows that a 1% increase in foreign exchange reserve (intervention) decreases the domestic assets by 0.93%, reflecting that the intervention was almost completely sterilized. Similarly, a 1% decrease in domestic assets is offset by an additional flow of foreign assets by 0.76%. It denotes that there is a restriction on the capital mobility in the economy even after the development of the financial market and the sterilization is effective.

Table 3: Sterilization coefficient

	Coefficient	Std. error	*t*-statistic	Prob.
Constant	0.016698	0.003214	5.194676	0.0000
ΔNFA_t^A	−0.929305	0.036032	−24.99577	0.0000
ΔMM_t	−0.585052	0.088684	−6.597048	0.0000
ΔCPI_t	−0.119134	0.120613	−0.987736	0.3263
ΔFD_t	−0.042741	1.694096	−0.025230	0.9799
ΔGAP_t	0.355006	0.126328	2.810191	0.0063
$\Delta REER_t$	0.065992	0.070946	0.930171	0.3552
$\Delta (r_t^f + E_t e_{t+1})$	0.002765	0.003519	0.785823	0.4344
d_1	−0.005360	0.008136	−0.658780	0.5120

Source: Authors' own calculation

The findings of this study are substantiated by similar studies from emerging economies (Cavoli and Rajan, 2015; Ouyang and Rajan, 2011; Takagi and Esaka, 2013; Wang, 2010; Yang, 2016). Scholars such as Oyung *et al*. (2008) had previously discovered a sterilization coeffect below −1 for RBI intervention, but the period was before the 2008 crisis. It indicates the use of sterilization for administering a contractionary monetary policy. The post-crisis period witnessed a massive capital inflow. The resulting intervention created monetary growth in the economy. This was one of the reasons for high inflation during the period between 2009–2010 to 2013–2014. Gupta and Sengupta (2013) found a sterilization coefficient between (−0.21) to (−0.61) in this period (1990–2010). However, Rajan's regime witnessed a sharp decline in inflation rate though the intervention reached its historical peak. It may be because of the active use of innovative sterilization instruments such as Monetary Stabilisation Bonds (MSBs) to manage the liquidity position. A comparison of the present results with those of previous studies shows that the magnitude of sterilization has decreased. This study covered a period of aggressive

and persistent intervention (*i.e.*, 2014–15 to 2018–19) when the RBI wanted to prevent the appreciation pressure from the positive Interest Rate Differentials (IRDs). Thus, the RBI was following an expansionary monetary policy along with economic growth. Adoption of inflation targeting also forced the RBI to manage money supply to support the economic policies.

A statistically significant negative coefficient of the money multiplier shows that an increase in the money multiplier enhances the growth of money supply and reduces the interest rate, which leads to capital outflow (or trimming down of capital inflow) and enhances the depreciation pressure on the rupee. This may be the reason why the RBI follows a tight monetary policy even during a period of high capital inflow. This confirms the active anti-inflationary actions of monetary policy as the faster growth of money contracts the *NDA*. This interpretation is further substantiated by a negative coefficient of the domestic interest rate (β_7) for the period. This indicates that the RBI has opted for intensive sterilization to reduce the net domestic assets in order to manage the impact of capital inflow induced by a higher interest rate.

Similarly, the exchange rate coefficient is negative and significant too, which shows that depreciation of the rupee causes massive flow of foreign capital. In such a situation, the RBI intervenes on the foreign exchange market with the dual objective of mitigating exchange rate volatility and preventing appreciation pressure on the rupee. This situation forces the RBI to sterilize the intervention with extreme caution. This scenario is mentioned in several policy documents of the RBI, especially during the post-Rajan regime (after 2014) when the higher costs of sterilization severely affected the central bank's balance sheet. As a solution to such a scenario, the RBI started active use of MSS instruments to ensure automatic sterilization of the interventions without severe impact on the normal interest rate.

Despite the high degree of sterilization, the inflationary pressure was also significantly high during the initial period of the floating regime. It touched two digits in the period after the subprime crisis. For instance, inflation was 8.35% in 2008–2009, but increased to 11.99% in 2010–2011. The situation was more or less the same until 2014–2015, when it dropped to 6.65%. This indicates that sterilization was ineffective on money supply, which explains the price level movement. The low degree of the inflation coefficient indicates that the RBI policies were ineffective to control the inflationary pressure. There is a possibility that irrespective of the high inflation pressure, the central bank was forced to continue its expansionary monetary policy to achieve the economic growth objective planned by the government. The under-utilisation of MSS instruments for the sterilization from 2009–2010 to 2015–2016 further substantiates this argument. MSS instruments do not create any liability to the central bank balance

sheet because they are issued exclusively for sterilization and their costs are borne by the government.

During this period, trade-weighted and export-weighted *REER* (2015–16 = 100) were undervalued. However, shifting to the flexible inflation targeting (FIT) regime by the RBI in 2016 with a target level of 4% (+/− 2 tolerance band) drastically reduced the inflation though the central bank increased its intervention in foreign exchange market. Similar situations are reported in China (Ouyang *et al*., 2010). The Chinese central bank was partially sterilizing its intervention to undervalue the domestic currency to increase the capital inflow.

Table 4: Offset coefficient

	Coefficient	Std. error	*t*-statistic	Prob.
Constant	0.019981	0.006258	3.193060	0.0020
ΔNDA_t^A	−0.763828	0.137551	−5.553037	0.0000
ΔMM_t	−0.475180	0.080322	−5.915965	0.0000
ΔCPI_t	−0.227525	0.113700	−2.001096	0.0489
ΔFD_t	0.793691	2.141611	0.370605	0.7119
ΔGAP_t	0.326272	0.178702	1.825786	0.0717
$\Delta REER_t$	−0.160623	0.694451	−0.231295	0.8177
$\Delta (r_t^f + E_t e_{t+1})$	−0.002425	0.009405	−0.257791	0.7972
d_2	−0.004744	0.004756	−0.997588	0.3216

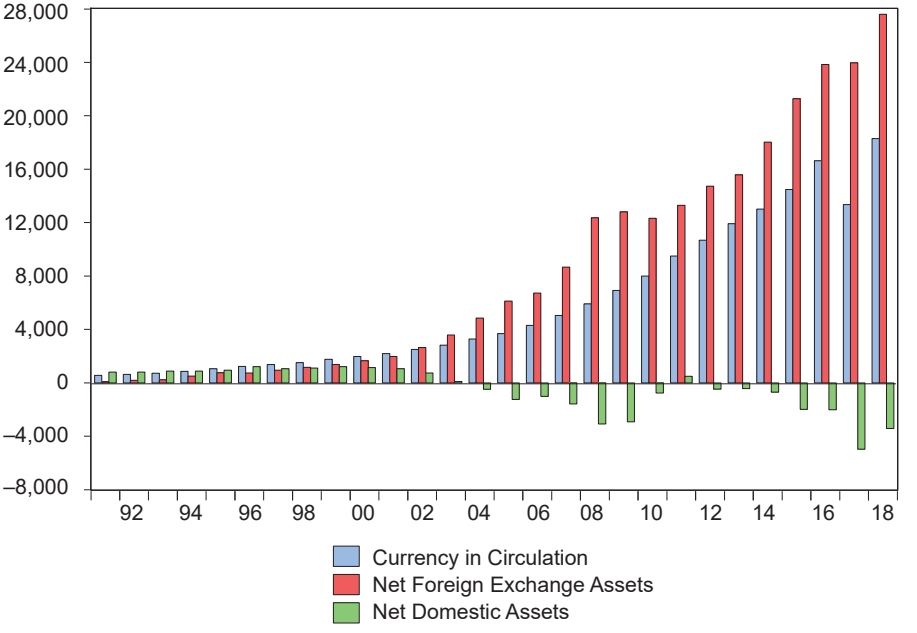
Source: Authors' own calculation

The low value of the offset coefficient compared to the sterilization coefficient indicates a high degree of monetary policy independence in neutralizing the central bank's purchase intervention (Ouyang *et al*., 2007). As expected, other independent variables in the equation are also capable of influencing the capital inflow. The negative coefficient of the money multiplier is substantiated by the theoretical argument that a higher level of MM will enhance the liquid assets and will cause a negative impact on the interest rate. This will ultimately lead to a decline in foreign capital inflow. The exchange rate coefficients reflect the intervention policy of the RBI. If the RBI relies on interventions to ensure a stable exchange rate, the rapid depreciation of the rupee will force the RBI to sell foreign exchange, which will lead to a reduction in *NFA*. On the other hand, preventing appreciation through purchase interventions will increase the foreign assets. The offset

coefficient estimated by Pattanaik (1997) was less than −0.33, which is lower compared to the findings of this study. The increased offset coefficient is an outcome of the initiative taken by the government to lift the restrictions on Foreign Portfolio Investment (FPI), allowing foreign investors to participate on the government and corporate securities market. It is a strong step towards a less restricted capital account though it enhances exposure of the economy to short-term debt. The positive interest rate difference during the period after the subprime crisis also favoured India to enhance the offset coefficient over this period.

The fiscal deficit coefficient shows the positive impact of deficit on foreign capital inflow *i.e.*, growth of *NFA*. It shows the existence of a countercyclical monetary policy during the period of growing government debt. This confirms the use of external borrowing for fiscal expansion. At the same time, the RBI accumulated foreign exchange reserves by expanding the monetary base. It gave scope for managing the economy during the episodes of slow economic growth and limited foreign capital inflow. It may be one reason for the significantly lesser impact of the subprime crisis on the RBI's balance sheet.

Figure 1: Variation in *NDA* and *NFA*

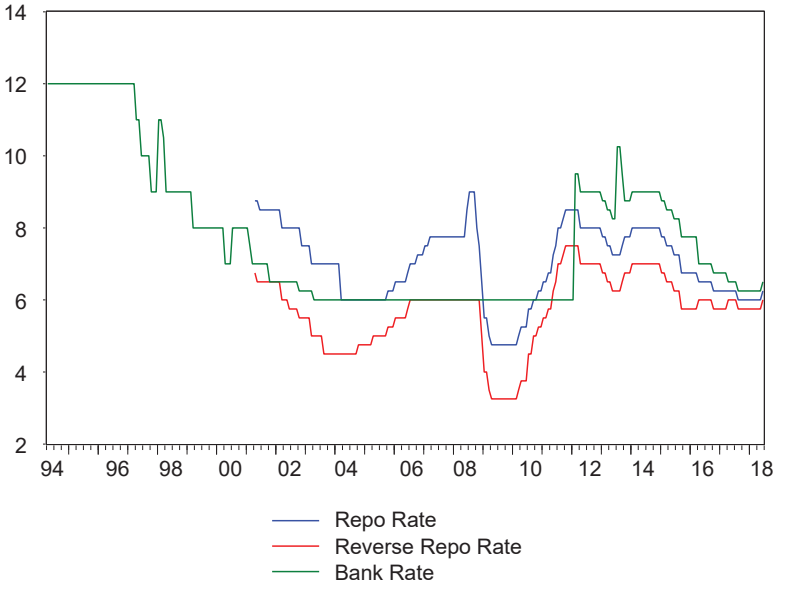


Data source: RBI (https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications)

Source: Authors' own elaboration

It can be observed that in the initial stage of the floating regime, the intervention was more of a game of adjustment between *NDA* and currency in circulation (*CC*). After the Asian crisis, the intensity of the sterilization operations increased. As a result of preventing appreciation of the Indian rupee (INR), the *NFA* growth level accelerated while the *NDA* level plunged to a negative value. Until this point, *CC* had been on par or above the *NFA* historically. However, during this period, *CC* also increased but this growth was not proportionate to that of the *NFA*. Such a unique combination of assets and liabilities in the central bank's balance sheet shows evidence of imperfect sterilization of the RBI intervention (Figure 1). This argument can be further validated by analysing the changes in major policy rates of the RBI during the period presented in Figure 2. In the introductory stage of adopting the floating regime, policy rates were used for both exchange rate and monetary policy operations. The policy rates plummeted during the period after the Asian crisis. However, the "bank rate" continued its stable position until the period of higher inflation after the subprime crisis. The repo and reverse repo rates were at a historic low during this period. The development of innovative and market-friendly instruments after the Asian crisis helped the RBI maintain its monetary autonomy to an extent.

Figure 2: Major policy rates



Data source: RBI (https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications)
Source: Authors' own elaboration

Figure 2 gives a clear idea about the RBI's policy preferences. In the presence of a high positive interest rate differential, the RBI accumulates foreign exchange reserves instead of reducing the interest rate to bring down the impact on inflation. It specifies that the foreign interest rate fluctuation (US T-bill rate) does not have a consistent and significant impact on capital flow and money supply. This may be one of the reasons behind the RBI's "fear of appreciation" policy. The insignificant behaviour of these variables may be because of two reasons. Firstly, the investors could be more concerned with expected rate of return (premium for risky assets) than the interest rate differential (Choi and Park, 2008; Verma and Prakash, 2011). Otherwise, it could be because the RBI uses the US interest rate as a yardstick for deciding the policy interest rate.

The exchange rate coefficient in the monetary reaction function shows that an increase in the *REER* (*i.e.*, depreciation of the INR) may create an inflationary pressure on the market; thus, the RBI tightens the monetary policy. Similarly, the coefficient is positive but not significant. It exemplifies the typical character of EMEs where an increase in the *REER* (*i.e.*, depreciation of domestic currency) stimulates more capital inflow. The result shows that the RBI sells foreign reserves to stabilise volatility and to prevent the depreciation pressure (by reducing net foreign assets). Appreciation of the rupee forces the RBI to intervene by purchasing foreign currency reserves, which adds to its balance sheet.

Considering the domestic and international economic conditions, it can be argued that the estimated sterilization and offset coefficients indicate a laudable management of the scenario by the central bank. Factors such as economic reforms, oil price shocks, external debt, higher inflation, considerable trade deficit and the growth of global liquidity in the post-subprime crisis period forced RBI to perform a tightrope walk during the period. It was crucial for the country to acquire sufficient foreign assets to prevent the crisis situation it faced in 1991. But at the same time, it is essential to manage the price level to ensure economic competitiveness. This situation might have restrained RBI to opt for a complete sterilization. This is substantiated by the findings of Ouyang *et al*. (2007) who argued that effectiveness of sterilization policy highly depends on the macroeconomic objectives of the central bank. Compared to other EMEs, India gradually liberalised its short-term capital flow to the secondary market. It may turn future sterilization s less successful. It will be very difficult for the central bank to sterilise the intervention due to the "vicious circle of sterilization" during these periods (Christensen, 2004). Ouyang *et al*. (2010), Zhang (2011) and Chung *et al*. (2014) highlighted a similar situation in China despite a sterilization coefficient over −0.8. In such a scenario, the sterilization of intervention driven from the IRDs will be successful because such restrictions will prevent additional capital flow. Factors such as economic reforms, oil price shocks, external debt, higher

inflation, considerable trade deficit and the growth of global liquidity in the period after the subprime crisis forced the RBI to perform a tightrope walk during the period. It was crucial for the country to acquire sufficient foreign assets to prevent the crisis situation it faced in 1991. However, at the same time, it is essential to manage the price level to ensure economic competitiveness. This situation might have restrained the RBI to opt for a complete sterilization. This is substantiated by the findings of Ouyang *et al*. (2007), who argued that the effectiveness of sterilization policy highly depends on the macroeconomic objectives of the central bank. Compared to other EMEs, India gradually liberalized its short-term capital flow to the secondary market. This may make future sterilizations less successful. It will be very difficult for the central bank to sterilize the interventions due to the "vicious circle of sterilization" during these periods (Christensen, 2004). Ouyang *et al*. (2010), Zhang (2011) and Chung *et al*. (2014) highlighted a similar situation in China despite a sterilization coefficient over −0.8. In such a scenario, the sterilization of interventions driven from the IRDs will be successful because such restrictions will prevent additional capital flow.

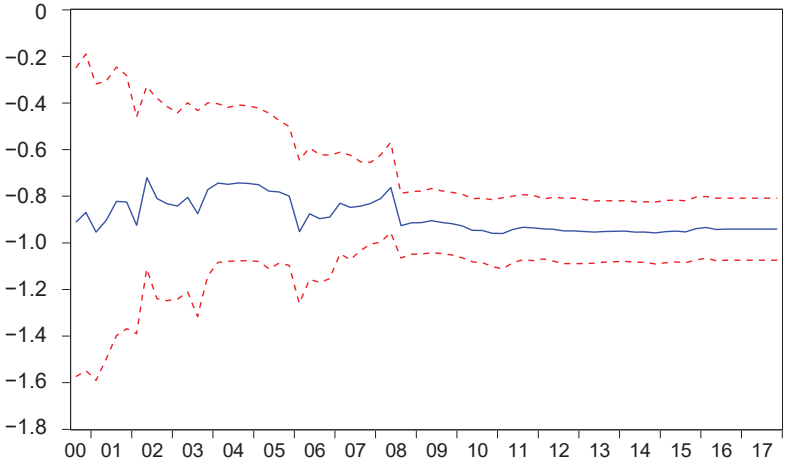
5.1 Recursive estimation

For estimating the time-variant sterilization and offset coefficients, a rolling recursive estimation on quarterly data was used. Following Ouyang *et al*. (2010), the recursive estimation is done by generating initial estimates by using a sample from 1996Q1 to 1999Q4. The next episode was constituted by including the next data point (*i.e.*, after 1999Q4) and deleting the first data point (*i.e.*, after 1996Q1). This was repeated each time until the last observation in the model was estimated. Therefore, each estimation in the model employs an equal number of observations.

Figure 3 shows the recursive estimation results. The sterilization coefficient during the period of study lies between −0.72 to −0.96 and it was unstable up to the second quarter of 2009. Thereafter, the sterilization coefficient was stable and always above −0.90. It shows the outcome of a rapid institutional and instrumental development which facilitated the RBI's sterilization activities. During the period of dot-com bubble in 2002, the sterilization coefficient was at its lowest point (−0.72). The scarcity of market-friendly instruments in the early 2000s created unstable sterilization s. The use of non-market friendly instruments (such as reserve requirements) was very high during this period. Because of external disturbances, this phenomenon continued even after the introduction of MSS. An excessive capital inflow during the subprime crisis period reduced the sterilization coefficient from −0.95 in 2006 Q1 to −0.75 in 2008 Q2. Thereafter, the sterilization was always above 90% and in 2011 it was at its maximum (−0.96). This period witnessed

a tremendous growth in the use of market-based sterilization instruments and reduced the reserve requirements for liquidity adjustment. The RBI intervention statistics shows a strong asymmetric intervention and highly positive interest rate differentials in these periods. The low sterilization coefficient during the initial period shows the use of sterilization for monetary expansion.

Figure 3: Recursive estimation of sterilization coefficient



Source: Authors' own calculation

Figure 4: Recursive estimation of offset coefficient

Source: Authors' own calculation

The recursive estimation of the offset coefficient was unstable during the major episodes of our study (Figure 4). In the mid-1990s, it was less than −0.20, which shows high restriction on capital mobility. It gradually increased with liberalisation of the capital restriction and opening of the sectoral investment schemes. Despite the low offset coefficient, the results show that India had slowly been cutting down the capital account limitations until 2005 without stepping towards capital account convertibility. In the end of 2006, it reached its peak (with a coefficient value of −0.91 and continued the trend with little variation during the subprime crisis. Thereafter, the magnitude of instability of the offset coefficient was reduced and its movement was stable after 2014. It can be concluded that the RBI maintained its autonomy in the intervention and sterilization policy. However, the impact of the financial crisis spillover effect has largely influenced the nature and character of the intervention (due to capital inflow) and sterilization policies (at both the instrumental and institutional levels).

6. Conclusion

The study found that the RBI's sterilization policies were in line with the requirements of a rapidly growing economy. The values of the sterilization coefficients reveal that irrespective of intensive and persistent intervention, the sterilization aimed to keep the market interest rate in line with the targeted monetary policy position of the central bank. Thus, the RBI has always stuck to the real exchange rate valuation instead of the nominal one. It may be one of the reasons for a stable sterilization coefficient after the subprime crisis too. The high value of the estimated offset coefficient shows the impact of the challenge raised by the "vicious circle of sterilization", caused by the impossible trinity. The coefficients of the money multiplier, inflation, exchange rate and interest rate also indicate the sensitivity of the macroeconomic variables towards capital inflow and monetary policy. Hence, the RBI can increase the use of derivative instruments for intervention to reduce impact on money supply. Periodic reviews of intervention policies and liquidity conditions are required to prevent the negative impact of liquidity injection into the market.

Since the RBI follows a policy to primarily prevent the appreciation pressure, it will definitely stockpile foreign exchange reserves by crossing the conventional precautionary levels. In this scenario, the RBI should try to follow complete sterilization to minimise the potential vulnerabilities caused by the liquidity injection. It is more crucial as the RBI follows an inflation-targeting policy while the government follows a fiscal expansion policy. As an emerging economy, India cannot tolerate fiscal and monetary expansion policies as the inflation is already high. It can be argued that such policies create a threat

to the inflation-targeting policy of the central bank, forcing it to continuously revise the inflation target rates. The central bank should develop more market-friendly instruments to sterilize the acquisition of foreign assets. Use of non-market-friendly instruments such as reserve requirements may create a severe crisis in the banking industry. Moreover, the central bank should try to keep its autonomy from the political institutions while framing and implementing policies.

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