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MONETARY, REAL SHOCKS AND EXCHANGE RATE VARIATIONS IN INDIA

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This article examines how a rate of the change of the exchange rate as well as how a rate of the change of the expected exchange rate are related to the unanticipated change in domestic money supply and output. Empirical analysis involves quarterly time series of the rupee/US dollar exchange rate, the narrow money M1, the broad money M3 and output in India under the market based exchange rate regime. The paper testifies exchange rate overshooting phenomenon where both unanticipated M1 and M3 cause variations and depreciation of rupee. Some evidence of the causal role of unanticipated output is observed. The rupee is found to be sensitive with both unanticipated money and output shocks where the impact of money shocks is stronger than output shocks.

Keywords: Exchange Rate Overshooting, Unanticipated Money, Unanticipated Output, Vector Autoregression, Impulse Response Function, Variance Decomposition
JEL classification: C32, E52, F31

1. INTRODUCTION

Variability of major world currencies in the post Britton Woods exchange rate era drew considerable attention to the economists, monetary authorities and market participants. Economists proceeded to provide theoretical explanations for this phenomenon. Consequently, international economics, over the last four decades, saw the growth of a plethora of economic theories on exchange rate. A number of fundamentals have been identified. A large number of empirical research studies have examined if the nominal and the real exchange rate variations are due to the real or nominal, the anticipated or unanticipated shocks in countries concerned.

India has been experiencing, since the early phase of 1970's, a spell of depreciation

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of rupee against major currencies like the U.S. dollar. The rate of depreciation, however, displayed variation over the period. Such depreciation became spectacular since the recent past when India has been initiated into the market based exchange rate regime. The exchange rate regime that India has followed since 1993 is virtually the market-based system. The phenomenon of excess variability and continuous depreciation (with some occasional breaks) of exchange rate, particularly in the market-based exchange rate regime, constitutes an issue of interest to the researchers and monetary authority of India. This is because the exchange rate is a key instrument to the monetary policy particularly in such an emerging open economy having growing global integration. Movements of exchange rate influence portfolio investment, volume of trade, cost of debt payments and even price level in India.

It has been found that macroeconomic fundamentals, sharply deteriorating merchandise trade balance, and large and growing current account deficit, speculation and central bank intervention, volatility in capital flows and forward premium are some of the important factors responsible for large depreciation and increased volatility of the Indian rupee (a more detail discussion is in Section 3: a review of related literature). The present study examines whether the variations of the Indian rupee against the US dollar that have been observed in the market-based exchange rate regime are related to the unanticipated shocks generated through money supply process and output production of India. This paper also presents a theoretical relation that variation in exchange rates is related to an unanticipated shock generated through the money supply process and output production of home country. This theoretical relation has been used as the base of the empirical analysis.

The remaining part of the paper is structured as follows: Section 2 presents theoretical exposition. A review of related literature is presented in Section 3. Section 4 deals with variables, data and methodological issues. Analysis and discussion of the results are presented in Section 5 and Section 6 concludes the article.

2. THEORETICAL EXPOSITION

Dornbusch (1976) explained how exchange rate makes a dynamic adjustment to an unanticipated monetary shock. An unanticipated increase in the domestic money supply leads a rise in the exchange rate from its initial position. Domestic currency overshoots from the long run Purchasing Power Parity line. In short, monetary expansion leads to a depreciation of the domestic currency. Following Dornbusch, monetary approach to exchange rate determination (MAER) postulates that exchange rate is negatively related to domestic money growth. According to MAER (given sufficient capital mobility and sticky price level) the asset market bears the entire (unanticipated) shock transmitted through the monetary channel. More specifically, an unanticipated increase in domestic money supply leads to fall interest rate and, as result, opportunity cost of holding money falls. Investors, therefore, sell domestic bonds and money balances and purchase foreign

bonds. Demand for foreign currency increases. Monetary expansion, therefore, leads to an immediate and large depreciation of the domestic currency.

Maitra (2010) presents a theoretical link that unanticipated shocks generated through the money supply process of domestic economy can affect variations of exchange rate. Such theoretical resolution is based on the Monetarists proposition that short-run variation of exchange rate can be managed through the introduction of monetary surprises provided that market agents would not be able to form expectations about these surprises. It means monetary surprises would be effective to manage exchange rate variations if money supply process be free from any autoregressive structure and also free from autoregressive conditional heteroscedasticity (ARCH). In other words, monetary policy may affect exchange rate volatility provided the errors transmitted through the monetary channel are white noise given that their variances are free from ARCH.

Apart from unanticipated money supply shock, this paper presents how unanticipated output shock generated from the domestic economy may affect variations in exchange rate. Foremost theoretical validation of which may come from the monetary model of exchange rate determination which advocates that an increase in domestic output leads to an appreciation of domestic currency. More specifically, an unexpected change in output production may also cause exchange rate variation. Theoretical exposition involving unanticipated money and output has been presented below. This exposition starts with two country monetary model of exchange rate determination where the demand for money function is stated in the form, known as the Cambridge quantity equation:[1]

$$m^d = kPY,\ k > 0, \tag{1}$$

where $m^d =$ the demand for money; $P =$ the price level; Y is real national income and $k =$ constant function indicating how money demand will change given a change in P or Y.

If India is the domestic country (say, *i*) and the USA is the foreign county (say, *f*), then the equations are respectively

$$m_i^d = k_i P_i Y_i,$$

and $m_f^d = k_f P_f Y_f$.

Equilibrium in the money markets in both the countries requires that

[1] "The quantity theory, of which it is one version, was the orthodox approach to that we now call the demand for money until the 20th century." (Copeland, 2007, p. 130).

$$m_i^s = m_i^d ,$$

and $m_f^s = m_f^d ,$

where m_i^s and m_f^s are the money supply of the domestic and foreign country respectively. Consequently, we have

$$m_i^s = k_i P_i Y_i , \tag{2}$$

$$m_f^s = k_f P_f Y_f . \tag{3}$$

From Equation (2) and (3) we obtain:

$$\frac{m_i}{m_f} = \frac{k_i}{k_f}\frac{P_i}{P_f}\frac{Y_i}{Y_f} ,$$

$$\frac{m_i^s}{m_f^s} = \frac{k_i}{k_f} s \frac{Y_i}{Y_f} .$$

[$s = \frac{P_i}{P_f}$, assuming that purchasing power parity holds for the exchange rate].

$$\therefore s = \frac{k_f}{k_i}\frac{m_i^s}{m_f^s}\frac{Y_f}{Y_i} ,$$

where s is the home currency price of one unit of foreign currency.

Taking log on both sides, we get:

$$\log s = \log k_f - \log k_h + \log m_i^s - \log m_f^s + \log Y_f - \log Y_i .$$

Above expression, a form of monetary model of exchange rate determination (Mussa, 1976; Frenkel, 1976; Johnson, 1977; Bilson, 1979) shows that exchange rate is positively related to the domestic money supply and foreign output but negatively related to domestic output level and foreign money supply.

2.1. Effect of Money and Output Growth on Exchange Rate Variations

At a given period of time we may assume that m_t^f, Y_t^f are constant. Differentiating both sides with respect to 't', we have,

$$\frac{1}{S}\frac{ds}{dt} = \frac{1}{m_t^i}\frac{dm_t^i}{dt} + \frac{1}{Y_t^h} dY_t^i ,$$

or $\dot{S} = \dot{m}_t^i - \dot{Y}_t^i$, where $S = \log s$. (4)

Now taking expectations we have,

$$E(\dot{S}_t) = E(\dot{m}_t^i - \dot{Y}_t^i),$$
$$= E(\dot{m}_t^i) - E(\dot{Y}_t^i),$$
or $\dot{S}_t^e = \dot{m}_t^{ei} - \dot{Y}_t^{ei}$. (4a)

2.1.1. Rational Expectations with Perfect Foresight

Under rational expectations with perfect foresight (Muth, 1961; Sargent, 1975; Sargent and Wallace, 1975; Lucas, 1976),

$E(\dot{S}_t) = \dot{S}_t$, such that $E(\dot{S}_t) - \dot{S}_t = 0$, (4b)

or $E(\dot{S}_t) = \dot{S}_t^e = \dot{F}_t$, where F_t is the forward rate quoted for the period 't' at 't-1'.

Consequently,

$$E(\dot{S}_t) - \dot{S}_t = \dot{F}_t - \dot{S}_t = 0 . \quad (4c)$$

So, the rate of change in forward premium/discount $(\dot{F}_t - \dot{S}_t)$ under perfect foresight is zero. The Equation (4.c) indicates three possibilities like:

(i) the rate of change in the forward rate $(\dot{F}_t)$ equals the rate of change in spot rate $(\dot{S}_t)$ such that $\dot{F}_t = \dot{S}_t$, or

(ii) the forward premium/discount $(F_t - S_t)$ is constant over time, or

(iii) the forward premium/discount $(F_t - S_t)$ does not exist such that $(F_t = S_t)$ for all 't'.

2.1.2. Adaptive Expectations

Assuming that expectations for future exchange rate and money supply and output

growth are formed adaptively, from the definition of adaptive expectations[2] expected exchange rate can be formed as:

$$S_t^e = S_{t-1}^e + \gamma(S_{t-1} - S_{t-1}^e),$$

or $S_t^e - S_{t-1}^e = \gamma(S_{t-1} - S_{t-1}^e)$,

or $\dot{S}_t^e = \gamma S_{t-1}^u$. (5)

[$S_t^e - S_{t-1}^e = \dot{S}_t^e$, since all terms are in logarithmic forms.]

Expectations of money supply based on adaptive expectations is,

$$\log m_t^{ei} = \log m_{t-1}^{ei} + \theta_1(\log m_{t-1}^{i} - \log m_{t-1}^{ei}),$$

or, $(\log m_t^{ei} - \log m_{t-1}^{ei}) = \theta_1 \log m_{t-1}^{ui}$,

or, $\dot{m}_t^{ei} = \theta_1 m_{t-1}^{ui}$. (6)

Similarly, expectations of output growth is,

$$\log Y_t^{ei} = \log Y_{t-1}^{ei} + \theta_2(\log Y_{t-1}^{i} - \log Y_{t-1}^{ei}),$$

$$(\log Y_t^{ei} - \log Y_{t-1}^{ei}) = \theta_2(\log Y_{t-1}^{i} - \log Y_{t-1}^{ei}),$$

$$\dot{Y}_t^{ei} = \theta_2 Y_{t-1}^{ui}.$$ (7)

Equations (5), (6) and (7) indicate rate of growth of each of the three variables (namely, exchange rate, money supply and output) at any period of time is a function of unexpected growth in the previous periods of the series concerned.

Now from the Equations (4a), (6) and (7)

$$\dot{S}_t^e = \dot{m}_t^{ei} - \dot{Y}_t^{ei} = \theta_1 \dot{m}_t^{ei} - \theta_2 \dot{Y}_t^{ui},$$

[2] For details, among the writings of many authors, Chow (2011), Gertchey (2007), Pearce (1983) can be consulted.

where $\theta_1, \theta_2 > 0$.

Now, from the Equations (4) and (6), we have

$$\dot{S}_t^e = \theta_1 m_t^{ui} - \theta_2 Y_t^{ei}.$$

This theoretical analysis testifies that at any period of time, the rate of change of spot rate (under perfect foresight variety of rational expectations) and rate of change of expected spot rate (under adaptive expectations hypothesis) are: (a) positive functions of an unanticipated change in domestic money supply or an unanticipated money shocks, (b) negative function of an unanticipated change in domestic output or an unanticipated output shock. Further, the rate of change of forward premium/discount at any period is also a function of previous period unanticipated change in domestic money and output.

3. A REVIEW OF RELATED LITERATURE

Large number of empirical studies has examined the effect of monetary and other shocks in the variations of exchange rates in the post Bretton Woods floating exchange rate era. Among these studies, Lastrapes (1992) analyzes the sources of real and nominal exchange rate fluctuations in the United States, Germany, United Kingdom, Japan, Italy, and Canada over the period 1973 to 1989, using monthly data. The dynamic effects of real and nominal shocks and their relative importance with regards to exchange rates are studied. The study presents the evidence that real shocks account for the major part of fluctuations in both the nominal and the real exchange rates over short and long frequencies. Clarida and Gali (1994) sought to identify the sources of real exchange rate fluctuations in Japan, Germany, Britain and Canada for the post Bretton Woods floating period 1973 to 1992. They find that, in case of Japan and Germany, nominal shocks accounts for a substantial amount of the variations in dollar/deutsche mark and dollar/yen real exchange rates. However, in case of Britain and Canada, the evidence is weak. Chadha and Prasad (1997) examine the relationship between the exchange rate and the business cycle in Japan during the post-Bretton Woods floating exchange rate period. Applying a structural vector-autoregression model they attempt to identify the macroeconomic shocks like supply, real demand, and nominal shocks and their impact on output and exchange rate. They find that relative nominal and real demand shocks are the main determinants of the variation in real exchange rate changes. Further, based on a historical decomposition they reported that the sharp appreciations of Yen in 1993 and 1995 and its subsequent depreciations can be attributed primarily to relative nominal shocks.

Thomas (1997) studies the determinants of movements of real exchange rate in Sweden over the period 1979:1 to 1995:4. Involving a structural vector autoregression representation of Mundell-Fleming model the study finds that real shocks accounts for

over 60 per cent of the forecast error variance of the real exchange rate. Further, demand shocks account for a significantly higher fraction of real shocks in Sweden than the other core EMU countries. Bhundia and Gollschalk (2003) investigate the sources of fluctuations of South African rand/dollar exchange rate from first quarter of 1998 to second quarter of 2002. The study identifies aggregate supply, aggregate demand, and nominal disturbances as possible sources of exchange rate fluctuations. Nominal disturbances emerge as the major factor behind the depreciation of rand. Wang (2005) has studied the relative importance of different types of macroeconomic shocks for fluctuations in real exchange rate in China between 1985 and 2003 with a structural vector autoregression model. Empirical analysis establishes the real relative demand shocks constitute the most important source of fluctuations in real exchange rate. Further, the study reveals that supply shocks are equally important source of variations in real exchange rate. Estimating unrestricted VAR model, Maitra (2010) examines how unanticipated monetary shocks account for variations in Sri Lankan currency against the US dollar under the independent float regime of exchange rate. The study gains evidence that unanticipated monetary shocks assume significant role in generating variations in Sri Lankan rupee/dollar exchange rate. Similarly, Maitra and Mukhopadhyay (2011) find that unanticipated money shocks cause variations in rupee/US dollar exchange rate in India in the recent float.

Few other studies attempt to identify the determinants and causes of exchange rate variability in India. Moore and Pentecost (2006) enquire into the contributions of real and nominal shocks to the variations in nominal and real exchange rates of the Indian rupee against the US dollar over the period March, 1993 to January, 2004. Applying the structural VAR technique, they find the evidence that in the variations of both real and nominal exchange rates, real shocks are more significant. Same conclusion derives by Pattnaik, Kapur and Dhal (2003) for Indian rupee/dollar exchange rate over the period April 1993 to December 2001.Inoue and Hamori (2009) examine the sources of variations in nominal and real exchange rates in India over the period January 1999 to February 2009. They report that, real shocks are the prominent factors behind the variations in both the real and nominal exchange rates. Maitra and Mukhopadhyay (2010) have found a bi-directional causal relation between money supply and exchange rate in the basket peg exchange rate regime and a unidirectional causal relation running from money supply to exchange rate in the market determination exchange rate regime in India. They have viewed that these findings are in conformity with the proposition of Mundell-Fleming model of open economy macroeconomics.

Bhanumurthy (2006) examines the relative importance of macro vis-à-vis micro variables in determining the exchange rate movements over different time horizons with the help of primary information collected from the Indian foreign exchange dealers. The study found that speculation and central bank intervention are the major determinants of the intraday movements in the exchange rate. Economic fundamentals, on the other hand, played a major role in the variation in exchange rate in the medium run and long run. Kohli (2003) analyses the effect of capital flows on exchange rate variations in Indian

context and finds that inflow of foreign capital results in a real appreciation of the exchange rate. Dua and Sen (2009) find that an increase in capital inflows and their volatility lead to an appreciation of the exchange rate in India. Net capital inflows and their volatility explain a large part of the variations in exchange rate. Dua and Ranjan (2011) attempt to forecast the exchange rate of Indian rupee in terms of the US dollar under managed floating exchange rate regime. The study extended the monetary model of exchange rate through the inclusion of forward premium, capital inflows, volatility of capital flows, order flows and central bank intervention. Based on the empirical analysis, they viewed that monetary model outperforms the naïve model. The forecast accuracy of exchange rate can be improved by extending the monetary model, particularly including forward premium, volatility of capital inflows and order flow. The study also reports that the Bayesian vector autoregressive models outperform their corresponding VAR variants.

It is clear from the above discussion that papers studied the determinants and movements of exchange rate in India involve a number of fundamentals, data pertinent to different frequencies and also have used different methodologies. Probably for these reasons findings of the papers are not uniform, and have no clear consensus about the causes of variations of Indian rupee. In this backdrop, this paper presents how a rate of change of spot rate under perfect foresight variety of rational expectations as well as a rate of change of expected spot rate under adaptive expectations hypotheses are related to unanticipated change in domestic money supply and output. These theoretical propositions are examined empirically involving quarterly time series in India under market based exchange rate regime. It is expected that the paper would confirm the dynamic movements of exchange rate due to money and output shocks and would also substantiate their relative role.

4. VARIABLES, DATA AND METHODOLOGICAL ISSUES

The study involves quarterly series of rupees/US dollar nominal exchange rate, money supply and output in India for the period first quarter 1996-97 to fourth quarter 2012-13 (Q1:1996-97 to Q4: 2012-13). Prior to this period, the quarterly series of output is not available. Both the narrow money supply M1 and the broad money supply M3 are chosen. Gross domestic product (GDP) at factor cost is taken as a measure of output. The dataset is taken from Reserve Bank of India, handbook of statistics in Indian economy. Money supply and output dataset is converted into real terms (by the consumer price index, 2005=100). Very strong seasonal variations are associated with the output series. Applying Census X-12 quarterly seasonal adjustment method,[3]seasonally

[3] This approach of seasonal adjustment method is based on the United States Bureau's X12 seasonal adjustment program. A more detailed discussion of the X12 procedures can be found from the Census Bureau

adjusted output series is generated. Money supply series are also seasonally adjusted by this method.

Empirical analysis requires unanticipated exchange rate, unanticipated money supply and unanticipated output which need to be generated from the actual series of the variables concerned. However, there is no definite procedure of generating such series. Empirical research often involve structural model or univariate forecast model where forecast series represent anticipated component while the forecast residual series is the measure of unanticipated component of the variable concerned. Among the structural and univariate forecast models, the former requires a set of variables, having causal relation with the actual variable under study. For example, the computation of anticipated and unanticipated exchange rate involving structural model requires use of exchange rate fundamentals in model estimation. Application of this model in case of money supply series necessitates estimation of money demand function. Similarly, estimation of unanticipated output under a structural model requires identification of determinants of output which is difficult and lengthy too. Inappropriate selection of determinant variables results in misspecification bias with deceptive series of anticipated and unanticipated components.

On the other hand, univariate forecasting procedure such as autoregressive integrated moving average (ARIMA) or autoregressive conditional heteroscedasticity (ARCH)/generalized autoregressive conditional heteroscedasticity (GARCH) based ARIMA, despite of their inherent limitations, is comparatively simple, and does not require any additional variables like structural model. Under this forecasting procedure, adequate care is taken to generate efficient forecast where white noise forecast residual should not bear any information about the actual series. However, the forecast residual or unanticipated realization of the series may explain the variance of other variables. Further, if we use these unanticipated variables in the estimation of VAR model, innovations found from the estimated model represent a more accurate measure of unanticipated variable. This is because; a part of the variance of dependent variable (unanticipated variable) may be explained by the other unanticipated variables.

This paper, therefore, has used the univariate forecasting model. Applying Box-Jenkins methodology (Box and Jenkins 1970, 1976), minimum mean squared error anticipated (forecast) series of exchange rate, money supply and output are generated. Corresponding forecast residual series or unanticipated series are also generated. A summary of univariate forecasting models of the selected series is presented in Table 1 shows that the exchange rate series follows ARIMA [(1, 4, 6) 1, 0] stochastic process. That is, the order of integration of the series is 1 and the integrated series has three AR terms (at lag 1, lag 4 and lag 6)[4] but has no MA term. On the other hand, seasonally

documentation and the web page (https://www.census.gov/srd/www/winx12/winx12_down.html) can be visited.

[4]In time series data, particularly in case of high frequency time series more than one AR term is a general

adjusted monetary aggregates M1 and M3 exhibit GARCH (2,1) based ARIMA [(1,6) 1, 0] and GARCH (1,1) based ARIMA [(1,6) 1, 0] processes respectively. The seasonally adjusted output series exhibits ARIMA [(4,5) 1, 0] stochastic process. A more detail results of the forecasting models are presented in Tables A1 and A2 (appendix). From the estimated models, the unanticipated part of the series has been generated. A summary of relevant variables for empirical analysis is presented in Table 2.

Table 1. Univariate Forecasting Models of Selected Series

Series	Stochastic Process	Complete Model
Exchange Rate	AR(p) structure: 1,4,6 Order of integration(d): 1 MA(q) structure: 0	ARIMA [(1, 4, 6) 1, 0]
M1 Money Supply	GARCH order: (2,1) AR(p) structure: 1,6 Order of integration(d): 1 MA(q) structure: 0	GARCH (2,1) based ARIMA [(1, 6),1,0
M3 Money Supply	GARCH order: (1,1) AR(p) structure: 1,6 Order of integration(d): 1 MA(q) structure: 0	GARCH (1,1) based ARIMA [(1, 6),1,0
Output	AR(p) structure: 4,5 Order of integration(d): 1 MA(q) structure: 0	ARIMA [(4, 5) 1, 0]

The empirical analysis, as per the objective of the article, has been carried involving battery of time series econometric techniques. Augmented Dickey-Fuller unit-root test is used for the confirmation of stationarity and the order of integration of the variables (Dickey and Fuller, 1981). To study the exchange rate dynamics as well as the causal relation, the vector autoregression (VAR) model is used. How such dynamics are affected by the endogenous innovations of the VAR model has been assessed involving impulse response functions. In addition to this, variance decomposition analysis is used identifying the relative strengths of innovations affecting exchange rate dynamics. The paper refrain methodological explanations because these are popular and commonly used in time series data analysis. However, only an estimable form of VAR model involving selected variables is specified.

phenomenon.

Table 2. Variables and Representations

Variable	Description	Notation
Exchange Rate	Rupee/US dollar rate	S_t
	Rate of change of rupee/US dollar exchange rate	$\Delta S_t (= \dot{S}_t)$
	Unanticipated rupee/US dollar rate	S_t^u
Money Supply	M1 money (seasonally adjusted)	m_{1t}
	First difference of m_{1t}	Δm_{1t}
	Unanticipated M1 money	m_{1t}^u
	M3 money (seasonally adjusted)	m_{3t}
	First difference of m_{3t}	Δm_{3t}
	Unanticipated M3 money	m_{3t}^u
Output	GDP at factor cost (seasonally adjusted)	Y_t
	First difference of Y_t	ΔY_t
	Unanticipated output	Y_t^u

To enquire if the rate of change of exchange rateis caused by unanticipated M1 money and unanticipated output, a VAR model is estimated where the relevant VAR equation is

$$\dot{S}_t = \alpha + \sum_{i=1}^{k} \beta_i \dot{S}_{t-i} + \sum_{i=1}^{k} \gamma_i m_{1t-i}^u + \sum_{i=1}^{k} \delta_i Y_{t-i}^u + \varepsilon_i . \tag{8}$$

Similarly, for enquiring if unanticipated change in exchange rate is caused by unanticipated M1 money and unanticipated output, estimable form of the VAR equation is:

$$S_t^u = \alpha + \sum_{i=1}^{k} \beta_i \dot{S}_{t-i} + \sum_{i=1}^{k} \gamma_i m_{1t-i}^u + \sum_{i=1}^{k} \delta_i Y_{t-i}^u + \in_i . \tag{9}$$

In the above equations, $\dot{S}_{t-i}$, S_{t-i}^u, m_{1t-i}^u and Y_{t-i}^u ($i = 1,2,...,k$) represent lagged series of rate of change of exchange rate, unanticipated variations of exchange rate, unanticipated M1 money and unanticipated output respectively. ε_i and $\in_i$are vectors of innovations that may be contemporaneously correlated but are uncorrelated with their own lagged values and with all of the right-hand-side variables. Variable 'k' is the optimum lag length which can be determined by the lag selection criteria. In these equations if we replace unanticipated M1 money by the unanticipated M3 money, the

effect of unanticipated component of M3 money supply and output on rate of change of exchange rate as well as on unanticipated variation in exchange rate can be studied.

5. ANALYSIS AND DISCUSSION

The analysis of the article begins with the study of stationarity of variables, which has been done by the Augmented Dickey-Fuller (ADF henceforth) unit-root test (Dickey and Fuller, 1981). Results of the tests, summarized in Table 2, have revealed that the null hypothesis of unit-root is rejected even at 1 percent level for each of the series. These series, therefore, testified as stationary series and their order of integration is I(0). Nevertheless, lag length '0' as selected by the Akaike Information Criterion (AIC) in each of the series is an indication of absence of serial correlation in the residual series of ADF test equations. In such a case the Dickey-Fuller unit-root test is equivalent to the ADF test (Dickey and Fuller, 1979).

Table 3. Results of ADF Tests

H0: the series has unit-root				
Series	Deterministic Component	Lag length (based on AIC)	ADF Statistic	Probability
$\dot{S}_t$	intercept	0	-5.062	0.00
S_t^u	intercept	0	-7.243	0.00
m_{1t}^u	intercept	0	-7.204	0.00
m_{3t}^u	intercept	0	-8.612	0.00
Y_t^u	intercept	0	-7.520	0.00

Having identified that stationarity, the causal relation as well as underlying dynamics of exchange rate, maintained with unanticipated money and output has been studied through the estimation of VAR models as stated by Equation (8) and (9). Table 4 presents estimated VAR Equation (8) involving two sets of variables namely, $\dot{S}_t$, m_{1t}^u, Y_t^u and $\dot{S}_t$, m_{3t}^u, Y_t^u. For simple understanding these are denoted by VAR Model-I and II respectively. On the other hand, in Table 5 estimated Equation (9) of the VAR model involving sets of variables namely, S_t^u, m_{1t}^u, y_t^u and S_t^u, m_{3t}^u, y_t^u is presented and denoted by VAR Model-III and IV respectively. In these estimations optimum lag length is determined based on Akaike Information Criterion (AIC).

The VAR Model-I revealed that the estimate of two quarter lagged unanticipated M1 money is positive and significant implying that unanticipated M1 money directly affects

exchange rate; more specifically, it provokes depreciation of the Indian rupee. The estimates of (lagged) unanticipated output are statistically insignificant even at 10 percent level which implies that unanticipated variations in domestic output assures no significant role in the variations in exchange rate.

Table 4. Rate of Change of Exchange Rate due to Unanticipated Money and Output Shocks

VAR Model-I Dependent variable: $\dot{S}_t$ Endogenous variables: $\dot{S}_t$, m^u_{1t}, y^u_t Sample (adjusted): (1998Q2-2012Q4) Lag Order: 2				VAR Model-II Dependent variable: $\dot{S}_t$ Endogenous variables: $\dot{S}_t$, m^u_{3t}, y^u_t Sample (adjusted): (1998Q4-2012Q4) Lag Order: 4			
Estimated Model-I				Estimated Model-II			
parameters	Estimates	t-ratio	Probability	parameters	Estimates	t-ratio	Probability
c	0.002	0.563	0.57	c	0.003	0.984	0.33
$\dot{S}_{t-1}$	**0.355**	**2.652**	**0.01**	$\dot{S}_{t-1}$	**0.486**	**3.689**	**0.00**
$\dot{S}_{t-2}$	0.044	0.344	0.73	$\dot{S}_{t-2}$	0.153	1.128	0.26
$\dot{S}_{t-3}$	-	-	-	$\dot{S}_{t-3}$	-0.157	-1.154	0.25
$\dot{S}_{t-4}$	-	-	-	$\dot{S}_{t-4}$	-0.241	-1.942	0.05
m^u_{1t-1}	0.135	0.677	0.50	m^u_{3t-1}	0.068	0.252	0.80
m^u_{1t-2}	**0.521**	**2.482**	**0.01**	m^u_{3t-2}	**0.639**	2.359	**0.02**
m^u_{1t-3}	-	-	-	m^u_{3t-3}	**-0.662**	-2.390	**0.02**
m^u_{1t-4}	-	-	-	m^u_{3t-4}	0.121	0.456	0.65
y^u_{t-1}	-0.122	-0.565	0.57	y^u_{t-1}	-0.116	-0.532	0.59
y^u_{t-2}	0.034	0.163	0.87	y^u_{t-2}	0.188	0.891	0.37
y^u_{t-3}	-	-	-	y^u_{t-3}	0.287	1.348	0.18
y^u_{t-4}	-	-	-	y^u_{t-4}	**-0.408**	-1.922	**0.06**
Diagnostic statistics	R^2=0.271, $\overline{R}^2$=0.187,log likelihood=138.3, AIC=-4.45, F-statistic=3.230, DW=1.998			Diagnostic statistics	R^2=0.493, $\overline{R}^2$=0.11, log likelihood=143.8, AIC=-4.59, F-statistic=3.58, DW=1.98		

Table 5. Unanticipated Variation in Exchange Rate due to Unanticipated Money and Output Shocks

VAR Model-III				VAR Model-IV			
Dependent variable: S_t^u				Dependent variable: S_t^u			
Endogenous variables: S_t^u, m_{1t}^u, y_t^u				Endogenous variables: S_t^u, m_{3t}^u, y_t^u			
Sample (adjusted): (1998Q2-2012Q4)				Sample (adjusted): (1998Q4-2012Q4)			
Lag Order: 2				Lag Order: 4			
Estimated Model-III				Estimated Model-IV			
parameters	Estimates	t-ratio	Probability	parameters	Estimates	t-ratio	Probability
c	-0.001	-0.325	0.74	c	-0.001	-0.483	0.63
S_{t-1}^u	0.030	0.212	0.83	S_{t-1}^u	0.252	1.742	0.08
S_{t-2}^u	-0.038	-0.285	0.77	S_{t-2}^u	0.129	0.942	0.35
S_{t-3}^u	-	-	-	S_{t-3}^u	-0.055	-0.395	0.69
S_{t-4}^u	-	-	-	S_{t-4}^u	-0.104	-0.781	0.43
m_{1t-1}^u	0.133	0.712	0.48	m_{3t-1}^u	0.158	0.595	0.55
m_{1t-2}^u	**0.480**	**2.387**	**0.02**	m_{3t-2}^u	**0.568**	**2.161**	**0.03**
m_{1t-3}^u	-	-	-	m_{3t-3}^u	**-0.654**	**-2.448**	**0.01**
m_{1t-4}^u	-	-	-	m_{3t-4}^u	0.301	1.164	0.25
y_{t-1}^u	-0.163	-0.778	0.44	y_{t-1}^u	-0.117	-0.561	0.57
y_{t-2}^u	-0.075	-0.380	0.71	y_{t-2}^u	0.117	0.569	0.57
y_{t-3}^u	-	-	-	y_{t-3}^u	0.188	0.916	0.36
y_{t-4}^u	-	-	-	y_{t-4}^u	**-0.446**	**-2.173**	**0.03**
Diagnostic statistics	R^2=0.271, $\overline{R}^2$=0.187, log likelihood=138.3, AIC=-4.57, F-statistic=3.230, DW=1.87			Diagnostic statistics	R^2=0.299, $\overline{R}^2$=0.108, log likelihood=145.4, AIC=-4.64, F-statistic=2.56, DW=1.97		

In VAR Model-II, estimates of unanticipated M3 money at the 2nd and the 3rd lags are found statistically significant. Among these two estimates, the sign of the estimate at lag 2 is positive and that at the lag 3 is negative. It means that two quarter lagged unanticipated M3 money causes a raise in exchange rate or depreciation of rupee in terms of the US dollar; whereas three quarter lagged unanticipated M3 money causes fall exchange rate or helps appreciation of the rupee. This may be due to the fact that the estimated VAR equation embodies dynamics adjustment of exchange rate due to unanticipated money and output over time. This dynamics is captured by the short, medium and the long-run effects of unanticipated money on exchange rate. If prices remain sticky in the short run but flexible in the long run, a rise in money supply in any

period, leading to a rise in price with a passage of time. Consequently, real money balances may fall and causes an appreciation of exchange rate over time. Such appreciation is captured by the negative coefficient of 3rd lag of unanticipated M3 money.This phenomenon is popularly known as 'exchange rate overshooting' as explained by Dornbusch (1976). Another fact is that, the estimates of unanticipated money supply (M1 and M3 both) at the lag one in estimated VAR Model-I and II are statistically insignificant which may be due to the reason that money supply needs a passage of time (at least one quarter) before being active in affecting exchange rate. Moreover, statistically significant estimates of one period lagged rate of change of exchange rate $(\dot{S}_{t-1})$ on its current value $(\dot{S}_t)$ in the VAR Model-I and II may be an indication of exchange rate hysteresis.

On the other hand, unlike the VAR Model-I, estimates of the four quarter lagged unanticipated output is found negative and significant at 6 percent level. So, in this case, a causal role of unanticipated output in the variation in exchange rate is established. Negative sign of the estimate indicates unanticipated output causes a fall in rupee/US dollar rate or appreciation in rupee. This finding is in conformity with the proposition of the two country monetary model of exchange rate that an increase in domestic output causes appreciation of domestic currency. Similar evidence is found from the VAR Model-III and IV as reported in Table 5. In short, VAR Model-III has shown that unanticipated M1 money supply also cause depreciation and variation of Indian rupee. However, in the VAR Model-IV, role of both unanticipated M3 money and output is established. Here, the phenomenon of 'exchange rate overshooting' is also established. Further, the significant role of unanticipated output promoting appreciation of rupee is found.

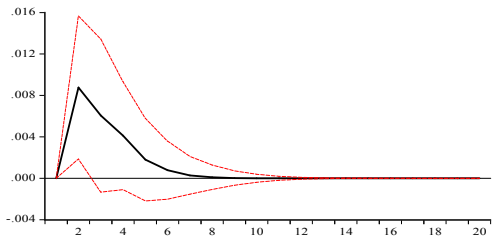

Figure 1a. Response of $\dot{S}_t$ to one S.D. Innovation of Unanticipated M1 Money

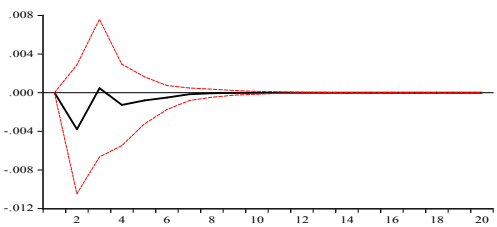

Figure 1b. Response of $\dot{S}_t$ to one S.D. Innovation of Unanticipated Output

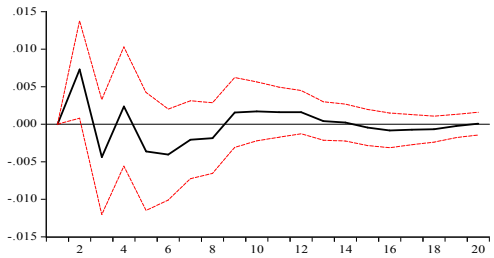

Figure 2a. Response of $\dot{S}_t$ to one S.D. Innovation of Unanticipated M3 Money

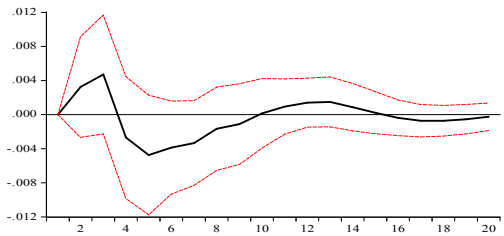

Figure 2b. Response of $\dot{S}_t$ to one S.D. Innovation of Unanticipated Output

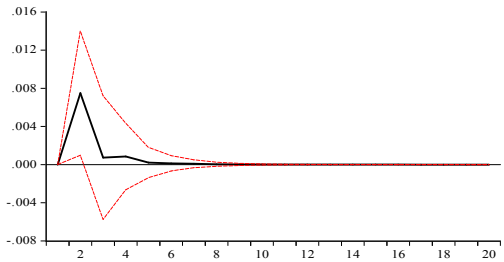

Figure3a. Response of S_t^u to one S.D. Innovation of Unanticipated M1 Money

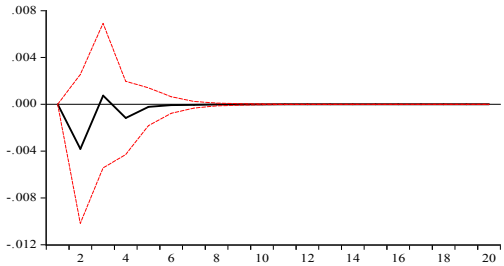

Figure 3b. Response of S_t^u to one S.D. Innovation of Unanticipated Output

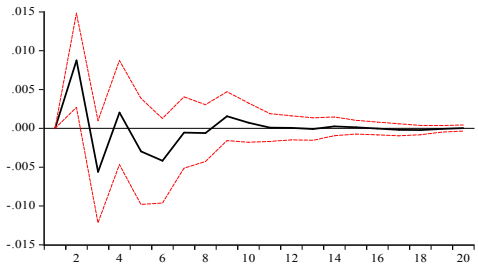

Figure 4a. Response of S_t^u to one S.D. Innovation of Unanticipated M3 Money

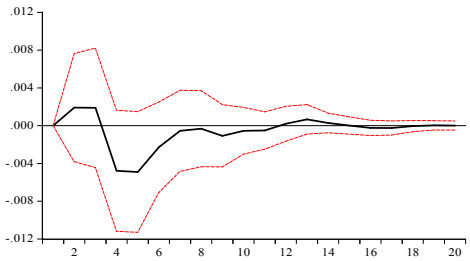

Figure 4b. Response of S_t^u to one S.D. Innovation of Unanticipated Output

Having identified causal relation, an impulse response analysis has been carried out. It is expected that impulse response functions may provide a clear portrait about the dynamic impact of the endogenous innovations in the variations of rate of change of exchange rate and the unanticipated variations in exchange rate. Figures 1a, 1b, 2a, and 2b present relevant impulse response functions (where the response of the variables is presented in the vertical axis against the time period measured horizontally) of the generated from the VAR Model-I and II respectively. On the other hand, impulse response functions generated from the VAR Model-III and IV are presented in Figures 3a, 3b, 4a, and 4b respectively. In Figure 1a and 3a, a positive unanticipated M1 money innovation (presented in the vertical axis) raises rate of change in exchange rate as well as unanticipated exchange rate. The value of rupee depreciates sharply. However, with the passage of time, rupee returns back to initial level (base line in Figures). Therefore, a positive impulse transmitted through unanticipated M1 money channel ushers depreciation of rupee in the short run which is further indication of 'exchange rate overshooting'. The impact of unanticipated M3 money innovation as shown in Figure 2a and 4a is slightly different. A positive M3 money innovation causes 'exchange rate overshooting' and exchange rate fluctuation around its initial level (base line) for a long time. Impact of unanticipated output innovation in this regard is found contradictory. A positive unanticipated output innovation as shown in Figures 1b and 3b causes exchange rate to a fall or rupee to appreciate. However the impact of unanticipated output innovation as shown in Figures 2b and 4b shows that instead of mere appreciation, the

value of rupee fluctuates.

Table 6. Variance Decomposition Analysis

Period ahead	variance of $\dot{S}_t$ accounted by			variance of $\dot{S}_t$ accounted by		
	$\dot{S}_t$	m_{1t}^u	Y_t^u	$\dot{S}_t$	m_{3t}^u	Y_t^u
1	100.0	0.00	0.00	100.0	0.00	0.00
2	99.02	0.51	0.48	99.52	0.04	0.44
3	88.77	10.78	0.46	90.68	8.55	0.77
4	86.70	11.97	1.33	87.86	9.45	2.69
5	85.64	12.53	1.83	86.04	10.03	3.93
6	85.59	12.51	1.91	85.75	10.36	3.89
7	85.57	12.52	1.91	85.10	11.16	3.74
8	85.53	12.55	1.92	85.17	11.10	3.73
9	85.51	12.57	1.92	84.74	11.56	3.70
10	85.51	12.57	1.93	85.55	11.58	3.87
11	85.50	12.57	1.93	84.62	11.54	3.84
12	85.50	12.57	1.93	84.65	11.54	3.81
Period ahead	variance of S_t^u accounted by			variance of S_t^u accounted by		
	S_t^u	m_{1t}^u	Y_t^u	S_t^u	m_{3t}^u	Y_t^u
1	100.0	0.00	0.00	100.0	0.00	0.00
2	98.40	0.56	1.04	98.99	0.51	0.50
3	89.25	9.45	1.29	90.19	9.20	0.61
4	88.80	9.40	1.80	85.44	13.38	1.18
5	88.71	9.40	1.89	80.22	15.36	4.42
6	88.67	9.44	1.89	79.32	16.24	4.44
7	88.67	9.44	1.89	78.99	16.56	4.45
8	88.66	9.44	1.90	78.99	16.56	4.45
9	88.66	9.44	1.90	78.79	16.76	4.45
10	88.66	9.44	1.90	78.45	16.96	4.59
11	88.66	9.44	1.90	78.46	16.94	4.60
12	88.66	9.44	1.90	78.46	16.94	4.60

Finally, to examine the relative strengths of money and output innovations, variance decomposition analysis has been used. The percentile decomposition of variance of rate of change in exchange and unanticipated variations in exchange rate representing contribution of shocks transmitted through the channels of unanticipated money and output is given by Table 6. In the decomposition of forecast error variance of rate of change in exchange rate and unanticipated variations in exchange rate, money

innovations dominate the output innovation. Specifically, more than 12 percent and 10 percent variance of rate of change of exchange rate (at the 6 forecast period ahead and after) are explained by the unanticipated M1 and M3 innovations respectively. Unanticipated output innovation, in this regard, accounts less than 4 percent of such variance. Further, the M3 money innovation explains more than 16 percent variation of the unanticipated exchange rate (at and after the 6 forecast period ahead) where the unanticipated output accounts for less than 5 percent of such variations. Monetary shocks, therefore, dominates over the output shock. Short run variations in exchange rate in India are to a larger extent a monetary phenomenon.

6. CONCLUDING REMARKS

This article examines if the variations in Indian rupee against the US dollar that have been observed in the market-based exchange rate regime in India are related to unanticipated shocks generated through domestic money supply process and output production. Quarterly series of rupee/US dollar exchange rate, domestic money supply M1, M3and GDP are being considered for empirical investigations. GARCH based minimum mean squared error ARIMA forecast give forth the series for unanticipated realization of the variables and Gaussian normal white noise series free from autoregressive conditional heteroscadaticity. Estimated VAR model followed by the impulse response analysis testify the fact that lagged unanticipated money supply cause variations in the exchange rate. These analyses also confirm the exchange rate overshooting phenomenon. Some evidence of causal role of unanticipated output in the exchange rate variations is established where unanticipated output also provokes fluctuation of the Indian rupee. Finally, variance decomposition analysis found that money innovations may have stronger role than output innovation in the variations of Indian rupee in the period ahead.

This article has some policy implications. As the exchange rate is sensitive to the unanticipated money, it could be possible to stabilize exchange rate to an extent, through the appropriate monetary administration. More specifically, the monetary authority may effectively control exchange rate through judicious and direct introduction of surprises in the money supply process. Performance of real sector of the economy is also important for this stabilization. Comprehensive macroeconomic policy which could stabilize real sector of the economy in general and exchange rate in particular is, therefore, essential. Apart from this, the impact of sectoral output in the variation in exchange rate may promote further insights. This article, therefore, has a scope for extension by examining the role of primary, secondary and service sector output in the variation of exchange rate. Further study may be undertaken in this direction.

APPENDIX

Table A1. Estimated ARIMA Models of Exchange Rate and Output (seasonally adjusted)

Dependent Variable: ΔS_t				Dependent Variable: ΔY_t			
Parameters	Estimates	'z'-statistic	Prob.	Parameters	Estimates	'z'-statistic	Prob.
α	0.006	1.781	0.08	α	0.014	4.484	0.54
ΔS_{t-1}	0.358	3.048	0.00	ΔY_{t-4}	-2.238	-1.909	0.06
ΔS_{t-4}	-0.204	-1.739	0.08	ΔY_{t-5}	0.219	1.786	0.07
ΔS_{t-6}	-0.242	-1.974	0.05	-	-	-	-

Table A2. Estimated GARCH based ARIMA Models of Money Supply M1 and M3
Estimation Method: Maximum-Likelihood ARCH

Dependent Variable: Δm_{1t}				Dependent Variable: Δm_{3t}			
Parameters	Estimates	'z'-statistic	Prob.	Parameters	Estimates	'z'-statistic	Prob.
α	0.0017	0.598	0.54	α	0.0017	0.598	0.54
Δm_{1t-1}	0.251	2.137	0.03	Δm_{3t-1}	0.251	2.137	0.03
Δm_{1t-6}	0.580	4.356	0.00	Δm_{3t-6}	0.580	4.356	0.00
Variance Equation				Variance Equation			
β	$9.55(10)^{-6}$	0.108	0.91	β	$1.08(10)^{-5}$	2.504	0.01
ε_{t-1}^2	-0.132	-2.554	0.01	ε_{t-1}^2	-0.143	-5.324	0.00
γ_{t-1}^2	0.195	0.756	0.44	γ_{t-1}^2	1.056	19.312	0.00
γ_{t-2}^2	0.891	3.183	0.00				

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