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Keywords: Markov regime switches, Monetary policy, Inflation targeting, Reserve Bank of India, Discretionary monetary policy

JEL Code: E4, E5, E6

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In this paper, we estimate regime switches in Indian monetary policy during the period 1998-2017. Prior to the adoption of an inflation targeting rule in 2016, monetary policy in India was conducted in discretionary manner. The Reserve Bank of India followed a multiple indicator approach in which the policy rate was determined based on a multitude of macroeconomic indicators. Given the absence of any well defined framework, it is possible that monetary policy experienced multiple regime shifts as a consequence of overall macroeconomic developments as well as the discretionary setting of the policy rate by various RBI Governors. We apply a multivariate Markov-switching Vector Autoregression (MS-VAR) model to uncover the time variation in a system of variables related to monetary policy, as reflected through multiple regimes. We find that the optimal number of regimes during this period was three, with one of them being relatively less persistent. Among the other two, one regime corresponds closely to the tenure of Governor Jalan and sporadically appears during the tenure of Governor Reddy whereas the other regime overlaps with the time when Governor Rajan was in office. In contrast, Governor Subbarao's tenure does not correspond to any specific regime. We also characterise the regimes by the behaviour of specific macroeconomic variables.

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1 Introduction

In advanced countries monetary policy can mostly be described by a rule that relates the short term interest rates to expected inflation and output gap.[1] This may not be the case in a large emerging economy such as India which until recently did not follow any rule-based framework. Monetary policy was instead conducted in an ad-hoc and discretionary manner. From 1998 to 2015, the Reserve Bank of India (RBI) followed a multiple indicator approach in which the policy rate was determined on the basis of a plethora of macroeconomic indicators and not just inflation and output. Given the absence of any well defined framework, it is unlikely that during this period monetary policy even implicitly followed a linear, time invariant rule. Rather it is possible that monetary policy experienced multiple regime shifts as a consequence of overall macroeconomic developments as well as the discretionary setting of the policy rate by various RBI Governors.

In this paper we attempt to uncover the regime dependent nature of a system of variables characterising monetary policy in India. We apply an empirical framework that allows time variation in the underlying monetary policy parameters in response to possible regime shifts. More specifically, we employ a multivariate Markov-switching Vector Autoregression (MS-VAR) model that endogenously separates out distinct regimes identified by regime-specific parameter sets. The model allows shifts in the intercept of the system of variables and also in the variance-covariance matrices.

India formally adopted inflation targeting (IT) in 2016. For the first time the RBI was given a specific objective to pursue in its conduct of monetary policy, that of price stability. The legal mandate from then on has been to achieve the target consumer price index (CPI) inflation of 4 percent with a band of 2 percent around it. The decision to set the short term policy rate or repo rate has been vested with a six member monetary policy committee headed by the RBI Governor.

Till the introduction of IT, RBI pursued the multiple indicator approach especially since 1998 onwards.[2] Under this approach a multitude of factors used to be taken into consideration when deciding the course of monetary policy. The levers of policy would also be more diverse than just the short term interest rates and would include quantitative instruments as well (such as the cash reserve ratio). This period saw the Governorship of Bimal Jalan (1997-2003), Y. V. Reddy (2003-2008), D. Subbarao (2008-2013) and Raghuram Rajan (2013-2016) at the RBI.

Unlike the IT regime where monetary policy gets decided by a committee, in the pre-IT era, the RBI Governor was the sole decision making authority. In absence of any systematic rule, it is possible that successive Governors responded to macroeconomic conditions in a discretionary and flexible manner. A former Deputy Governor of the RBI described this approach as follows, "*Thus the overall objective has had to be approached in a flexible and time variant manner with a continuous rebalancing of priority between growth and price stability, depending on underlying macroeconomic and financial conditions.*" (Mohan 2006; italics our own).

[1] Taylor (1993) formulated a policy rule by which the U.S. Federal Reserve adjusts the policy rate in response to past inflation and the output gap (actual less potential output). He showed that this rule described Federal Reserve policy performance quite well from 1987 to 1992. Using a quadratic loss function for the welfare objective of the central bank, Woodford (2001) provided a formal normative justification for following a Taylor-type rule under certain conditions. Many studies subsequently applied and developed this class of policy rules to examine the behavior of central banks in industrialized countries (e.g., Clarida et al. 2000).

[2] Prior to that the RBI appears to have loosely targeted the growth rate of money supply for a few years. In the pre-liberalisation era, monetary policy was mostly dominated by fiscal deficit financing and interest rates were tightly regulated.

It would be interesting to see whether the monetary policy conducted during this period was characterised by specific regimes and also analyse the extent to which the regimes uncovered in the data may have corresponded to the tenures of specific Governors. Substantial changes in the way monetary policy was conducted could have translated into regime shifts in interest rates and other associated variables.

The tenure of a Governor may have been part of a distinct regime driven by the way certain macroeconomic variables behaved during his time in office or by the way he responded to the macroeconomic conditions through his policy decisions. On the other hand, if we find that a governor's tenure did not correspond to a regime shift, it could mean that there was no substantial change in the way monetary policy was conducted irrespective of the change in leadership. Finally, if we find that the tenures of say two governors were characterised by the same regime, it could imply that their years in office were fundamentally similar, either with respect to the underlying macro-financial environment or due to their pursuit of monetary policy or both.

During the 20-year period from 1998 to 2019 India underwent significant structural changes in the macroeconomic landscape and witnessed substantial developments in financial markets and institutions (Shah, 2008). These changes were triggered by the liberalisation, privatisation and globalisation reforms of the early 1990s.

On the external side, the trade to GDP ratio increased dramatically during this period as India became progressively more integrated with the global economy. The economy experienced several episodes of surge and stops in foreign capital inflows during this period (Sengupta and Sen Gupta, 2019; Shah and Patnaik, 2007). While capital controls were largely relaxed in a gradual manner over the years, there still exist significant amount of restrictions on foreign investment unlike many other emerging economies (Sen Gupta and Sengupta, 2014; Pandey et al., 2020).

India moved towards a market determined exchange rate system in the mid 1990s. However, the RBI continued to actively intervene in the foreign exchange (FX) markets in order to stabilise the currency. From time to time the RBI also undertook interest rate defense of the Rupee in the face of sharp currency depreciations. The INR/USD exchange rate depreciated from about 31 to 66 during this two-decade period. The exchange rate itself underwent multiple regimes changes.[3].

On the domestic side, the economy experienced one major business cycle expansion from roughly 2003 to 2009, one recession from 1999 to 2002 and one prolonged phase of growth slowdown from 2010 onwards continuing for the rest of our sample period (Pandey et al., 2017). There were a couple of periods of high inflation such as 1998-99, and 2007-2010 as well as intermittent phases of relatively low inflation such as 2000-2004, and 2014-2017. Since the 1990s there has been greater flexibility in the money market interest rates in contrast to the pre-1990s when the money market was largely regulated and interest rates were essentially fixed.

These developments potentially altered the macro-financial environment as well as the external constraints facing the RBI, and may have influenced its operating procedures as well as policy tradeoffs in the pursuit of macro-stabilisation objectives. These considerations, in turn, may have impacted the conduct of monetary policy in India. Hence it is plausible that during this 20-year period monetary policy conduct may have gone through multiple regimes as opposed to following a single, stable rule with fixed weights assigned to various targets.[4] The discretionary manner in which monetary policy

[3]See for example Patnaik (2007), Patnaik et al. (2009) and Zeileis et al. (2010)

[4]There is a sizeable literature by now that shows that the RBI has indeed switched across different policy objectives in the post-liberalisation period. Several studies have analysed these changes in context of the Impossible Trilemma

was conducted coupled with the structural transformations in the underlying macro-financial environment may have resulted in significant time variations in the joint behaviour of a system of variables that characterise Indian monetary policy.

There exists a sizeable literature that looks into regime switches in monetary policy especially in advanced countries such as the US. The pioneer work in this field was by Hamilton (1989, 1990). The MS-VAR procedure that we apply in our paper, essentially extends Hamilton's Markov-switching regime framework to VAR systems (Krolzig, 1997). Several studies have applied the MS-VAR technology to study various research questions in monetary policy and related fields. For instance, Hubert and Creel (2008) use MS-VAR to analyse whether the inflation targeting period in England, Sweden and Canada correspond to any particular regime. They find that the IT period does correspond to a specific regime switch but it is not driven by a change in the monetary policy reaction function. Ehrmann et al. (2001) estimate regime dependent impulse responses for the MS-VAR. Using the obtained impulse response functions, they conclude that oil price shocks that are more recent tend to have a less contractionary and less inflationary effect on the economy.

Bordon and Weber (2010) use a the MS-VAR model to check if the transmission mechanism in Armenia has undergone regime shifts. They find switches corresponding to the period from which inflation targeting was introduced and also corresponding to the start of the de-dollarisation program. Tillmann (2007) uses an MS-VECM model to see whether the term structure of interest rates in the US underwent regime changes corresponding to changes in monetary policy. They find significant shifts in the risk premia and interest rate volatility across regimes.

A paper related to ours is by Valente (2003) who uses an MS-VAR model to estimate regime switches in the monetary policy of six advanced countries namely France, Germany, Italy, Japan, UK and USA. He identifies significant and persistent shifts in monetary policy which affect the dynamics of the central banks' policy rates and concludes that the shifts are driven by changes in inflation targets. However the baseline monetary reaction function he estimates assumes that domestic monetary policy does not respond to external shocks. This may not be a realistic assumption especially for a country like India where the central bank actively responds to movements in the exchange rate either through foreign exchange market interventions which are bound to impact inflation and hence monetary policy or through the policy rate itself.

Other papers have used different variations of Markov switching models to address similar questions. Lo and Piger (2005) check for response of output to monetary policy using an unobserved components model with regime switching. They conclude that policy actions taken during recessions are more effective than those taken during a boom period. Debortoli and Nunes (2014) model regime switches based on changes in policymakers' behaviour and preferences. They argue that the regimes obtained provide more accurate estimates compared to using reduced form models of the interest rate rule.

Sims and Zha (2006) estimate a non linear, stochastic, dynamic, simultaneous equation model to estimate regime changes in the US monetary policy. They find that monetary targeting was active during the 1970s and also during the early 1980s. They also find that in the model that uncovers four regimes, three of the regimes roughly coincide with the years of Federal Reserve chairmanship of Paul Volcker, Alan Greenspan, and Arthur Burns. Their thorough and detailed study motivated our analysis of whether the regimes endogenously uncovered by the model correspond to the years in office of specific RBI Governors.

objectives and related policy trade offs (Aizenman and Sengupta, 2013; Hutchison et al., 2012; Sen Gupta and Sengupta, 2014; Sengupta and Sen Gupta, 2019). Hutchison et al. (2013) have explicitly estimated regime switches in the Taylor Rule so as to uncover changes in the underlying policy preferences.

Several studies have documented the history and evolution of monetary policy in India and also estimated the monetary policy reaction function of the RBI.[5] To the best of our knowledge, only two papers estimate regime changes in RBI's monetary policy reaction function. Hutchison et al. (2013) use a time varying Taylor rule to study regime changes based on the focus RBI puts on inflation, vis-a-vis output gap and exchange rate. They find that for the period 1987-2008, the 'Dove' regime was predominant with the RBI being relatively less responsive towards inflation and more focused on the output gap and the exchange rate. Kumawat and Bhanumurthy (2016) use a smooth transition autoregressive (STAR) model to study changes in the monetary policy response function. They find that regime shifts are driven mostly by changes in the inflation gap and the exchange rate for the period 1996-2015.

Analysing shifts in the monetary policy reaction function conveys only one part of the picture. In reality it is highly plausible that the policy rate is set in response to multiple factors which in turn interact with each other in complex ways and the processes generating this system of variables itself could be undergoing shifts over a period of time. In other words, if these macroeconomic variables jointly behave in a certain way for some period of time and then in a different way for some other period of time, then this may qualify as a regime shift in context of monetary policy. Estimating regime changes in the Taylor Rule and imposing a two-regime structure may not capture these complexities. Regime switches in a simple rule-based reaction function generally do not capture multiple shifts in variance and identification of such functions is also usually weak (Sims and Zha, 2006).

To this end, our objective in this paper is to improve upon the existing studies and contribute to the literature by exploring the possibility of there being multiple regimes in a system of macroeconomic variables that describe the monetary policy stance and strategy of the RBI. Apart from adopting a more generalised and dynamic approach, the other contribution of our work is that we do not impose the number of regimes while doing the estimation. We let the data and the model endogenously determine the optimal number of regimes for our sample period.

Thus when estimating the regimes, we do not start with any prior hypothesis. The way we have conducted our analysis is that we find out the number of regimes first. Then, we study the smoothed probabilities to see the time period of our regimes. Finally, we characterise these regimes in terms of macroeconomic variables and check if they correspond to the tenures of specific governors.

We find that the optimal number of regimes is 3. The tenure of Governor Jalan matches with the entire duration of a regime, and another specific regime occurs with high probability during Governor Rajan's tenure. In the baseline model where we allow both the intercept and error terms to vary, the regime that characterises Jalan's tenure recurs sporadically during the early part of Governor Reddy's tenure. In the model where only the error term varies, the regime that characterises Rajan's tenure also appears during the years when Reddy was in office.

This implies that there was something about Jalan's and Rajan's tenures which separates these periods out as specific regimes and that there were similarities across tenures of Jalan, Reddy and Rajan in general, either in the underlying macro-financial conditions or in the manner in which they conducted monetary policy or both. Governor Subbarao's tenure on the other hand does not correspond to any specific regime and is in fact a mix of two or more regimes.

In terms of macroeconomic variables, Jalan's tenure saw both the highest and lowest levels of CPI inflation. Subbarao lowered interest rates to the lowest levels in our sample period, in the aftermath

[5] See for example Hutchison et al. (2010), Mohan (2006), Mohanty (2013a,b), Mohanty and Klau (2005), Ray (2014), Mohan and Ray (2017), Bhattacharyya and Ray (2007) among others.

of the 2008 global financial crisis. Rajan's tenure witnessed the highest interest rates even though inflation was not very high during this time. This was an interest rate defense of the Rupee that the RBI initiated in response to the taper tantrum shock of 2013. Also the exchange rate was more or less stable during Jalan's tenure and the early years of Reddy implying active FX intervention by the RBI. The same phenomenon is found to occur during Rajan's tenure when once again the exchange rate depreciated within a narrow band. The flexibility of the rate appears much higher during Subbarao's tenure.

The rest of the paper paper is divided into the following sections. In section 2, we outline the theoretical framework for the estimation of regimes. In section 3, we explain the data and conduct a preliminary analysis before we discuss our results in section 4. In section 5, we conduct multiple robustness checks to ensure the validity of our analysis and finally we conclude in section 6 concludes.

2 Theoretical framework

We use a Markov Switching Vector Auto Regression(MS-VAR) model to estimate the regime changes in India's monetary policy. Switching regressions were first used in econometrics in Quandt (1958). The Markov switch is a certain class of switching regressions, introduced to econometrics in Goldfeld (1973) and subsequently popularised by Hamilton (1989) who proposed the application of unobservable Markov chains as regime generating processes.[6]

The Markov switch became popular after there arose a need to identify regime shifts endogenously from the data. We use the discrete first order Markov process, where the model assumes that for a given number (k) of states, the probability of the economy being in a particular state only depends on the state it was in the previous period. More formally, if we have P (s_t = j) as the probability of the economy being in an unobserved state j in period t, the Markov process states that

$$P(s_t = j | s_{t-1} = i) = p_{ij} \text{ with } \sum_{j=1}^{k} p_{ij} = 1, \text{ for i= 1,...,k}$$

where s_t is the unobserved state variable in time t.

In a single equation Markov switch process, one could accordingly define the coefficients in a way such that they differ between the regimes. Instead of a single equation estimation, we use a VAR framework. This is a generalisation of the single equation model since the VAR would incorporate all the equations with the variables as dependent variables.[7]

If we have the vector of sample observations $Y = (Y_1, Y_2, ...Y_T)$, $Y_t \in R^n$, where n is the number of variables in the VAR model, then the most general form of the MSVAR model would be :-

$$Y_t = 1_n.\alpha_{S_t} + (Y_{t-1}Y_{t-2}\cdots Y_{t-p})\beta_{S_t} + \epsilon_t,$$

where

[6] Other kinds of switching regressions include the mixture of normal distributions model, the self-exciting threshold autoregressive model and the smooth transition autoregressive model, etc.

[7] If we constrained the number of regimes to be one, then the system would collapse to the single equation model which in our case would be some version of the monetary policy reaction function as defined by the Taylor Rule

$\beta_k = (\beta_1 \beta_2 \cdots \beta_p)'$,

$\epsilon_t \sim N(0, \Omega_{S_t})$,

where p is the number of lags in the VAR model, and k is the number of regimes in the economy, that is S_t = (1, 2, ...k). It is assumed that the probability of the economy being in a state follows a first order Markov process, i.e.:

$P(s_t = j | s_{t-1} = i) = p_{ij}$ with $\sum_{j=1}^{k} p_{ij} = 1$, for i= 1,...,k

These probabilities are called the transition probabilities. For k states, there are k^2 transition probabilities given by the transition matrix :-

The MS-VAR specified above is the most general form, where the intercept, the autoregressive (AR) coefficients and the variance-covariance matrix, are all dependent on the state of the economy.

Krolzig (1997) broadly defines three types of MS-VAR models namely the MSI-VAR, the MSH-VAR and the MSA-VAR. In the MSI-VAR class of models, a change in only the intercept vector drives a change in regimes. For the MSH-VAR models, the variance-covariance matrix is regime-dependent. For the MSA models, a change in all the AR parameters drives the regime changes. Including their combinations, there are 7 distinct possibilities that decide what drives regime shifts. For our analysis, we have relied on Droumaguet (2012) which uses 6 model types- MSI, MSH, MSIA, MSIH, MSAH and MSIAH. To decide the optimal model specification, as discussed in the next section, we have used the AIC, BIC and HQ criteria set by Droumaguet (2012).

It is important to mention that in this paper we primarily concern ourselves with the transition probability matrix and the smoothed probabilities, i.e, the probability of the economy being in a certain regime given all our sample observations. However, we also want to find the estimated parameters of the MS-VAR in order to suitably characterise the regimes. Hamilton (1989) proposes a filter to obtain the smoothed probabilities. It accepts as input

$P(S_{t-1} = s_{t-1}, S_{t-2} = s_{t-2}, \cdots S_{t-r} = s_{t-r} | y_{t-1}, \cdots y_{-r+1})$

and through some algebra, we get

$P(S_t = s_t, S_{t-1} = s_{t-1}, \cdots S_{t-r+1} = s_{t-r+1} | y_t, y_{t-1}, \cdots y_{-r+1})$.

From the last expression we get the filtered probability

$$P(S_t = s_t | y_t, y_{t-1}, \cdots y_{-r+1}) = \sum_{S_{t-1}=0}^{1} \sum_{S_{t-2}=0}^{1} \cdots \sum_{S_{t-r+1}=0}^{1} P(S_t = s_t, S_{t-1} = s_{t-1}, \cdots S_{t-r+1} = s_{t-r+1} | y_t, y_{t-1}, \cdots y_{-r+1})$$

and the smoothed probability

$$P(S_{t-r} = s_{t-r} | y_t, y_{t-1}, \cdots y_{-r+1}) = \sum_{S_t=0}^{1} \sum_{S_{t-1}=0}^{1} \cdots \sum_{S_{t-r+1}=0}^{1} P(S_t = s_t, S_{t-1} = s_{t-1}, \cdots S_{t-r} = s_{t-r} | y_t, y_{t-1}, \cdots y_{-r+1}).$$

As a by-product,we also obtain the conditional log likelihood
$logf(y_T, y_{T-1}, \cdots, y_1 | y_0, y_{-1}, \cdots y_{-r+1})$

For a single equation case, the conditional log likelihood could be maximised with respect to the all the parameters (i.e. intercept terms, AR coefficients, variance-covariance matrices and the transition probabilities) to obtain the estimated value of the parameters. For the vector case, this exercise become difficult due to the computational difficulty of an ill-behaved likelihood surface. Moreover, analytically computing the derivatives becomes a tedious job. Hence we use the expectation-maximisation algorithm (EM) for maximum likelihood estimation to obtain the parameter estimates (Hamilton, 1990; Kim et al., 1999). Instead of calculating the derivatives recursively, the EM algorithm makes use of the following three equations:-

$$p_{ij}^{l+1} = \frac{\sum_{t=m+1}^{T} p(s_t=j, s_{t-1}=i|\boldsymbol{Y};\boldsymbol{\lambda_l})}{\sum_{t=m+1}^{T} p(s_{t-1}=i|\boldsymbol{Y};\boldsymbol{\lambda_l})}, \quad i,j = 1, \cdots, K \tag{1}$$

$$\sum_{t=m+1}^{T} \sum_{s_t=1}^{K} \cdots \sum_{s_{t-m}=1}^{K} \frac{\partial log p(\boldsymbol{y_t}|\boldsymbol{z_t};\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} . p(s_t, \cdots, s_{t-m}|\boldsymbol{Y};\boldsymbol{\lambda_l}) = \mathbf{0} \tag{2}$$

$$\rho_{i_m, i_{m-1}, \cdots, i_1}^{l+1} = p(s_m = i_m, s_{m-1} = i_{m-1}, \cdots, s_1 = i_1 | \boldsymbol{Y};\boldsymbol{\lambda_l}),$$

$$i_1, \cdots, i_m = 1, \cdots, K \tag{3}$$

where p_{ij}^{l+1} is an element in the transition matrix at stage l+1.

$\boldsymbol{\lambda_l}$ is the parameter set $(p_l, \boldsymbol{\theta_l}, \rho_l)$.

$\boldsymbol{\theta_l}$ contains all other parameters apart form the transition probabilities. ρ_l contains the probabilities of the initial unobserved states, i.e., before the EM algorithm starts. These probabilities do not follow the Markov process. Instead they follow an entirely separate distribution which does not have any of the parameters from the original system of equations.

It is to be noted that we do not actually calculate the derivative of the log-likelihood in equation (2). Instead equation (2) usually boils down to a simple weighted average of the sample observations. Thus instead of analytically calculating the derivatives, we first calculate the smoothed probabilities based on an initial arbitrary λ_0. Then equations (1)-(3) are solved to get λ_1. We then calculate the smoothed probabilities and update λ_l each time till we reach a convergence criterion. Other than its computational simplicity, the EM algorithm always finds an interior solution and does not get stuck on local maxima due to the irregular surface of the likelihood function.

3 Data and Preliminary Analysis

We use monthly data from January 1998 to March 2017.[8] We have used 5 variables that are of key interest in Indian monetary policy. These include an index for inflation, a proxy for domestic demand, exchange rate, interest rate and the price of oil. We do not include any measure of unemployment rate since the labour market in India is highly fragmented and it is relatively difficult to find an accurate measure for unemployment.[9]

We use data on the year on year Consumer Price Index (CPI) Inflation. Nominal CPI is the anchor which is used for the purpose of inflation targeting and being a retail measure of inflation this is also what matters for the average Indian consumer.[10] An exogenous shock in the CPI inflation or a change in the coefficients related to the CPI could be an important indicator of a regime shift. This differs from Hutchison et al. (2013) who use the Wholesale Price Index (WPI) as the metric for inflation.

As a proxy of domestic demand, we use the Index of Industrial Production (IIP), due to its availability at a monthly level.[11] For the interest rate, we have used the 91-day Treasury Bill yields since this captures any changes in the monetary policy stance and strategy of the RBI which may not be limited to changes in the policy rate.[12] We use data on the nominal rupee dollar bilateral exchange rate.[13]

We have sourced the data for all the macroeconomic variables from the Centre for Monitoring Indian Economy (CMIE). India is an important importer of oil and oil price has been known to be a critical driver of domestic inflation. We use the West Texas Intermediate price sourced from the US Energy Information Administration with the units in dollars per barrel. We checked for seasonality and deseasonalised the necessary variables using Census X-13 ARIMA.[14]

Figures 1-4 respectively show the evolution of the 91-day T-bill yields, the CPI inflation, the INR/USD nominal exchange rate and the IIP during our sample period, across the tenures of 4 RBI Governors.[15]

[8] The RBI used to follow monetary targeting which was abandoned in April 1998. Thus, for our sample period, we do not consider monetary aggregate and start the sample from the time when the multiple indicator approach was formally adopted. This also reduces one equation in the VAR as well as the number of coefficients to estimate. In April 1998, RBI released its Monetary and Credit Policy for the First Half of 1998-99. In the report, they said that financial innovations had increased in India and worldwide and that there was a need for monetary policy to step up and hence made the case for adoption of the MIA approach.

[9] All the studies that have used MS-VAR and that we have cited in this paper use some metric of domestic inflation, aggregate demand and interest rate in their VAR. Extensions if any, usually include exchange rate, a monetary aggregate, unemployment rate or an additional variable for commodity prices.

[10] We have also done a robustness check replacing CPI with wholesale price index inflation.

[11] As a robustness check, we use monthly imports growth instead of IIP, as an indicator of domestic demand. The data has been sourced from the RBI's Handbook of Statistics on the Indian Economy. The results are the same for the 3 regime case

[12] Unlike some studies, we do not use the weighted average call money rate since it is highly volatile. As Kumawat and Bhanumurthy (2016) point out, the correlation between the time series of the call money rate and the 91 day T-bill is fairly high and the treasury bill rate is much less volatile, thus justifying its use. As a robustness check, we also carry out our analysis using the Weighted Average Call Money Rate instead of the 91 day T-bill rate. For the MSIH(3)-VAR(2) model, results are the same.

[13] In 1993 Indian transitioned to a market determined exchange rate regime from the pegged regime of the previous years. However from time to time the RBI has actively intervened in the foreign exchange market to either stabilise currency fluctuations or to maintain the exchange rate within a particular range (Patnaik, 2007; Patnaik et al., 2009; Shah, 2008).

[14] In addition, we also checked for seasonality based on a periodogram derived from the Fast fourier transform of each individual time series.

[15] It helps to use the Governor tenures as distinct sub-periods to understand the movement of these variables because it throws light on the factors that may have played a critical role in their conduct of monetary policy while in office and also the effects thereof on the relevant macro indicators that we look at.

We see that Governor Jalan's time in office was characterised by an initial phase of high interest rates. This was presumably a policy response to the steep rise in CPI inflation which almost touched 20 percent, as seen in figure 2 and perhaps also to prevent currency depreciation in the aftermath of the East Asian Crisis of 1997. Average inflation between May 1998 and May 1999 was 13 percent. Thereafter inflation fell to very low levels and eventually stabilised. Average inflation during 2002-2003 period was down to 4 percent. The initial period of high interest rate was followed by a prolonged phase of monetary expansion during which interest rates came down dramatically. Jalan's tenure witnessed the highest as well as the lowest levels of CPI inflation in our sample period.

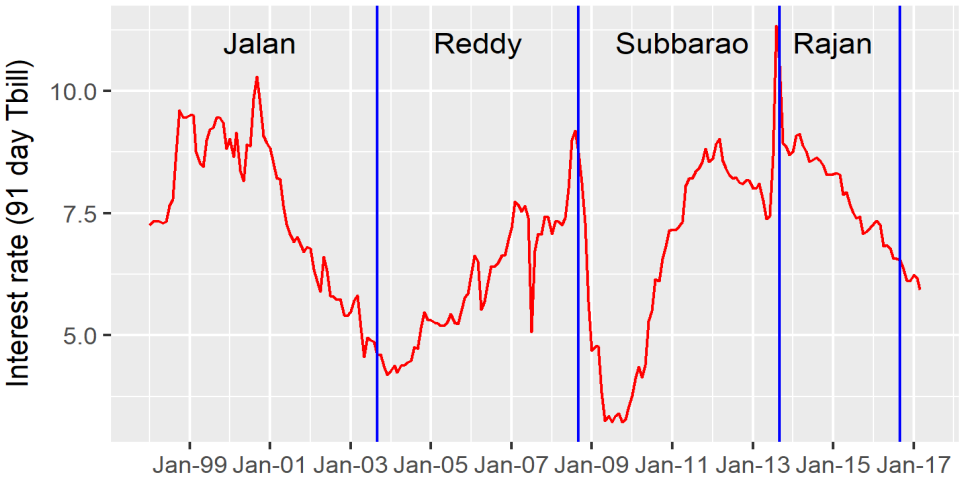

Figure 1: Time path of Interest Rate

In contrast, Governor Reddy's tenure on average witnessed a near doubling of interest rates (from 4.5 percent to about 9 percent) though there were intermittent periods of interest rate reductions. The period saw high market liquidity due to a substantial rise in domestic credit growth and foreign capital inflows. High inflation was thus a primary concern during this time. Reddy's stance was to increase key policy rates steadily. While inflation remained low and more or less stable during the initial years of his tenure, towards the end however inflation started rising well above the average level of 5 percent. By the time he left office in August 2008, CPI inflation was as high as 9 percent. This may explain the steady increase in interest rates during this period. Interest rates went up from 5 percent in July, 2007 to 9 percent in August, 2008.

Governor Subbarao came to office in the wake of the 2008 Global Financial Crisis. During this time the RBI embarked on a brief period of monetary expansion in order to provide stimulus to the economy in the aftermath of the global crisis. Interest rates during this time (2008-09) are seen to have reached the lowest levels in our sample period. During the period April 2009 to January 2010, average interest rate was 3.4 percent. However, CPI inflation continued to rise. Thus Subbarao lowered interest rates even as inflation was inching upwards. By January 2010, CPI inflation had reached 16 percent, the second highest level in our sample period.

To fight this persistent inflation, Subbarao initiated monetary tightening from early 2010 onwards, for almost two years, till about March 2012, as seen in figure 1. Inflation gradually started coming down. Towards the end of his tenure he put an end to the monetary tightening and started lowering the rates from April 2012 onwards.

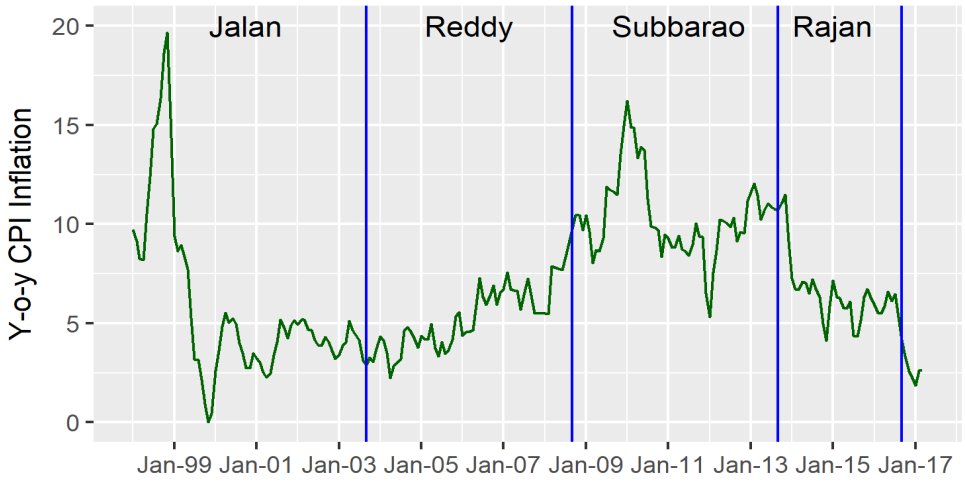

Figure 2: Time path of CPI Inflation

In the summer of 2013, India experienced the Taper Tantrum shock when Federal Reserve Chairman Ben Bernanke announced that the Fed would put an end to the quantitative easing that had been initiated in the aftermath of the 2008 crisis. In response to the shock, RBI mounted an interest rate defense of the Rupee primarily under the Governorship of Raghuram Rajan. The interest rate was sharply increased and then gradually brought down. During Rajan's tenure CPI inflation came down further from 10.7 percent in September 2013 to 5.3 percent in August, 2016, amidst low global oil prices.

If we look at the overall 20 year period, it appears that inflation was on an upward trajectory from Governor Reddy's tenure onwards, peaking in 2010. There have been two periods of inflation decline followed by price stability: from the middle of Governor Jalan's tenure to the end of his time in office (roughly 1999-early 2003) and from the middle of Governor Subbarao's tenure to the end of Rajan's time in office (roughly 2012 to 2016).

Figure 3 shows the time path of the INR/USD exchange rate during the period under study. We see that the exchange rate was more or less stable during the time that Governors Jalan and Reddy were in office. It depreciated roughly from 40 to 50 between 1998 and 2002 and then came back to 40 again by early 2008. This was the period when the Rupee was pegged first to the US dollar and then to a basket of currencies. The stability was maintained by active interventions in the FX market by the RBI which in turn would have impacted domestic inflation depending upon the extent to which the interventions were sterilised. Thus, during 1998-2007, exchange rate potentially played an important role in influencing monetary policy. This is consistent with the findings in Hutchison et al. (2013).

During Subbarao's tenure the exchange rate steadily depreciated from about 46 to 65 in the aftermath of the 2008 global crisis and was mostly in a flexible regime with very limited FX interventions by the RBI. During Governor Rajan's time in office the Rupee depreciated within a narrow band, from 65 to 67 thereby implying that RBI once again intervened heavily in the FX market.

Figure 4 shows that the IIP steadily increased from 1998 till about 2011 and thereafter its growth rate slowed down significantly. This was the start of a general economic slowdown which continued

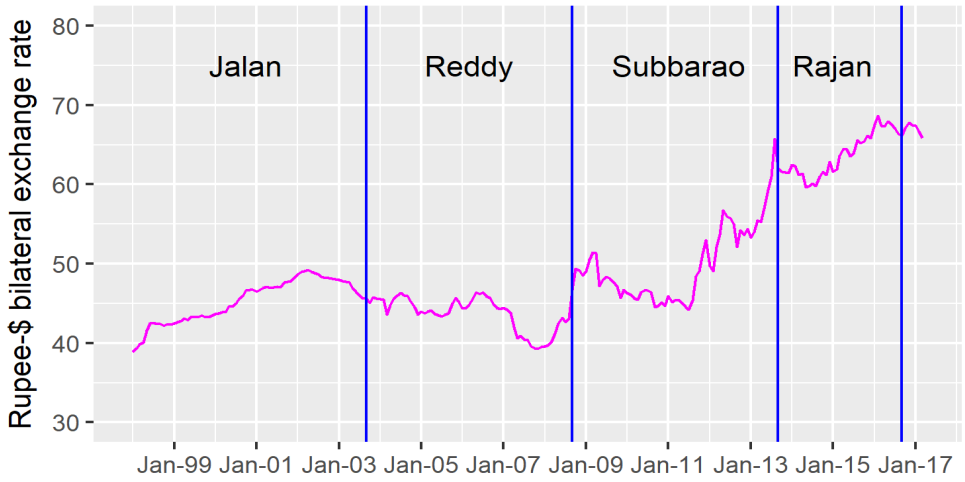

Figure 3: Time path of Exchange Rate

almost till the end of our sample period.

Since our underlying time series model is a VAR, it is necessary that all the variables included are stationary. We conduct the Dickey-Fuller test to check for stationarity and find except for the CPI inflation term, all the variables are non-stationary and integrated of the order 1. Accordingly, we take the log difference of these variables.[16] Other than making the variables stationary, the log difference of the variables has an added interpretation as their growth rate.

Selecting the optimal number of regimes is more challenging. Except for Sims and Zha (2006), the literature does not use any objective method to select the number of regimes. The selection of regimes is usually taken as three, allowing for two distinct, persistent regimes and one regime that is usually transitory. Droumaguet (2012) introduces an AIC, BIC and HQ criteria to decide the number of regimes, as well as to select the optimal MS-VAR model. We have applied the same. Table 1 reports the results from the model selection exercise for each MS-VAR specification based on the AIC, BIC and the HQC criteria.

We run checks for M=2,3,4 regimes. For each run, the algorithm returns the optimal lag length p as defined by each of the 3 criteria. MSH is a Markov-switching-heteroskedastic VAR model and MSIH is a Markov-switching-intercept-heteroskedastic VAR model. Thus the MSH corresponds to a model where only the variance of the error terms differ across regimes. In the MSIH model, the intercept and the variance both differ across regimes. The check runs as follows: If we run it for the MSH model and say for M=2, the information criterion mentions the optimal number of lags that the VAR should have. In this case, the optimal number of lags is 4 for the AIC criterion, 1 for the BIC and 1 for HQC. The optimal number of lags are listed below the criteria values in the table.

Next, if we compare the AIC criterion across all 5 x 3= 15 models, the models marked with a $*$ are the most optimal. For the BIC, they are marked with a # and for HQC with a †.

[16] These variables are also non-stationary when taken in logs

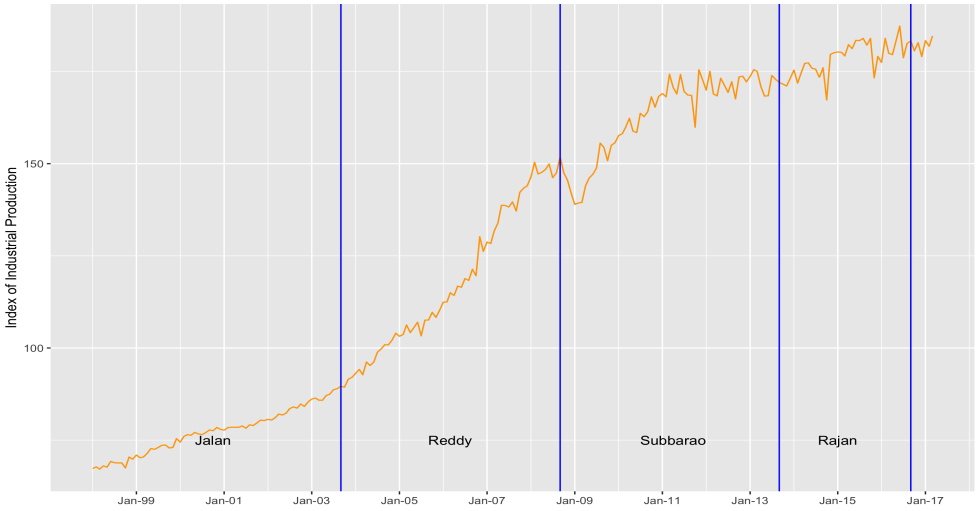

Figure 4: Time path of IIP-Levels

No. of regimes	M=2			M=3			M=4		
	AIC	BIC	HQC	AIC	BIC	HQC	AIC	BIC	HQC
MSH	-13.06231	-12.06485$^{\#}$	-12.62625†	-13.22375*	-11.96911$^{\#}$	-12.70256†	-14.12076*	-11.81299$^{\#}$	-13.18933†
p	4	1	1	3	1	1	3	3	3
MSI	-12.30236	-11.466584	-11.93744	-12.46050	-11.372040	-11.93351	-12.51857	-11.228953	-11.92418
p	2	1	1	2	1	2	2	1	2
MSIAH	-12.83007	-11.429710	-12.26276	-13.04029	-10.899533	-12.17627	-13.03384	-10.057189	-11.795726
p	2	1	1	1	1	1	2	1	1
MSIA	-12.60613	-11.298022	-11.99525	-12.27216	-10.586880	-11.591971	-12.43122	-10.199364	-11.530431
p	3	1	1	1	1	1	1	1	1
MSIH	-12.80896	-11.76389	-12.37057	-13.25995*	-11.78217$^{\#}$	-12.60616†	-13.15797*	-11.381602	-12.44102
p	3	1	1	3	1	1	1	1	1

Table 1: Optimal number of lags in the MSVAR.

There are 3 potential models: these are MSH with M=3,4 and MSIH with M=3. The main distinction between these models is the state varying Variance-Covariance matrix. We select a specification of the MS-VAR that allows for regime shifts in the intercept of the system of variables as well as in the error term or the variance-covariance matrix to get a more comprehensive picture. The finding is in line with Valente (2003). Thus, we go with the MSIH model with M=3 as our baseline case. The optimal number of lags is 3 by the AIC and 1 by the BIC and HQC. We take the optimal number of lags here as 1. Thus our optimal model is MSIH(3)-VAR(1). We also report results for the MSH(3)-VAR(1) model.

In terms of variables, our MS-VAR model is of the form:-

$$\begin{pmatrix} \Delta ln(OilPrice_t) \\ \Delta ln(IIP_t) \\ \Delta ln(ExchRate_t) \\ (CPIInflation)_t \\ \Delta ln(IntRate_t) \end{pmatrix} = \begin{pmatrix} \alpha_{1_{St}} \\ \alpha_{2_{St}} \\ \alpha_{3_{St}} \\ \alpha_{4_{St}} \\ \alpha_{5_{St}} \end{pmatrix} + \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} & \beta_{15} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} & \beta_{25} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} & \beta_{35} \\ \beta_{41} & \beta_{42} & \beta_{43} & \beta_{44} & \beta_{45} \\ \beta_{51} & \beta_{52} & \beta_{53} & \beta_{54} & \beta_{55} \end{pmatrix} \begin{pmatrix} \Delta ln(OilPrice_{t-1}) \\ \Delta ln(IIP_{t-1}) \\ \Delta ln(ExchRate_{t-1}) \\ (CPIInflation)_{t-1} \\ \Delta ln(IntRate_{t-1}) \end{pmatrix} + \begin{pmatrix} \epsilon_{1_{St}} \\ \epsilon_{2_{St}} \\ \epsilon_{3_{St}} \\ \epsilon_{4_{St}} \\ \epsilon_{5_{St}} \end{pmatrix}$$

where, $Var(\begin{pmatrix}\epsilon_{1St} & \epsilon_{2St} & \epsilon_{3St} & \epsilon_{4St} & \epsilon_{5St}\end{pmatrix}') = \Omega_{5x5}^{S_t}$

The only difference with respect to a traditional VAR is the subscript S_t for all the coefficients. In a non-switching VAR, the coefficients do not change from one state to another.

4 Results

The transition probability matrix has been defined earlier. Since there are 3 states in our model, the matrix will be of dimension (3 X 3) and is given by the following:-

	$s_t = 1$	$s_t = 2$	$s_t = 3$
$s_{t-1} = 1$	0.849	0.039	0.112
$s_{t-1} = 2$	0.377	0.623	0.000
$s_{t-1} = 3$	0.089	0.069	0.841

Table 2: $Pr(s_t|s_{t-1})$

Each row of the transition probability matrix sums upto 1. From row 1, it is seen that the first regime is fairly persistent as there is a 0.849 probability that given the economy was in regime 1 in the previous period, it is more likely to stay the same in the current period. Regime 3 is fairly persistent as well with a corresponding probability of 0.841. Regime 2 on the other hand is relatively less persistent. If the economy was in regime 2 the previous period, there is approximately a probability of 0.4 for a switch to regime 1 in the current period. Thus regime 2 is relatively a more unstable regime.

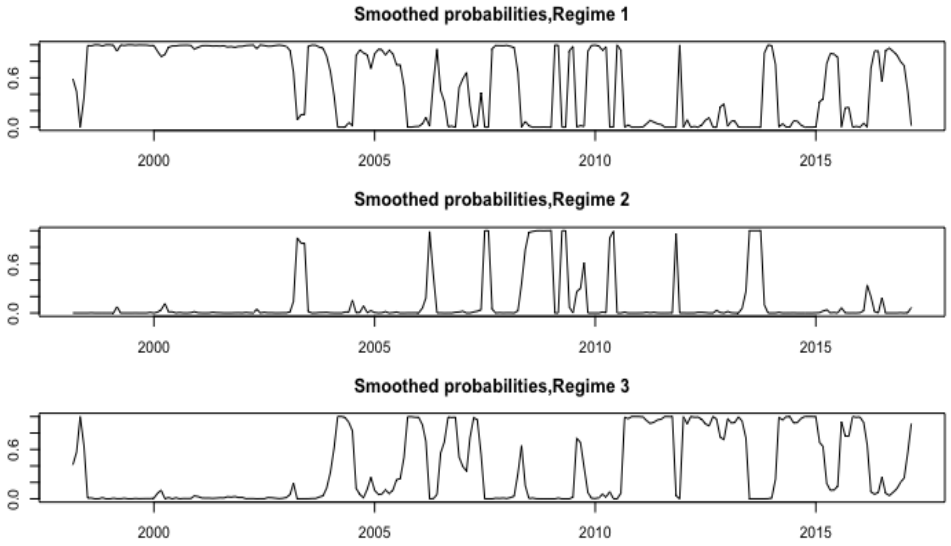

Figure 5: Regime switches for the MSIH(3)-VAR(1) model

Figure 5 presents the conditional (smoothed) probabilities of all 3 regimes for our MSIH (3)-VAR (1) model.[17] We see that regime 2 exists only for a few sporadic intervals and there appears to be a gradual shift over time from regime 1 to regime 3. The probability of the economy being in regime 1 is the highest for the years 1998-2003, a period which almost entirely corresponds to Governor Jalan's tenure. It reappears sporadically between 2004 and 2010, especially during the first part of Governor Reddy's time in office. It then appear even more infrequently between 2014 and 2017. Thus regime 1 appears to the most dominant one during our sample period.

Regime 3 is the next most common occurring most frequently from 2011 onwards. It is relatively more sporadic between 2011 and 2013 and is the more dominant regime from 2013 to 2016. This mostly coincides with Governor Rajan's tenure.

	Intercept term			Lag: 1				
	Regime 1	Regime 2	Regime 3	Oil Price	IIP	Exch. Rate	CPI	Int Rate
Oil Price	0.025	-0.007	-0.007	0.108	0.065	-0.466	-0.001	-0.006
	(0.037)	(0.032)	(0.023)					
IIP	0.005	0.003	0.004	0.020	-0.398	-0.115	0	0.014
	(0.006)	(0.006)	(0.004)					
Exchange Rate	-0.001	0.002	0	0.014	-0.041	0.157	0	-0.077
	(0.009)	(0.006)	(0.006)					
CPI Inflation	0.094	0.617	0.424	1.760	-2.196	2.052	0.955	-1.385
	(1.172)	(1.12)	(0.831)					
Interest Rate	-0.015	-0.043*	-0.012	0.056	0.235	-0.092	0.002	0.125
	(0.018)	(0.021)	(0.018)					

Note: Bootstrapped standard errors in parantheses

Table 3: Coefficients of MSIH(3)-VAR(1) model

From this, it appears that monetary policy in India roughly went through two main regimes during the period when RBI was following a multiple indicator approach. One lasted from 1998 to 2003 and then off and on from 2004 to 2011 while the other regime mostly prevailed from 2011 to 2016. In terms of governors, it seems that Governor Jalan's tenure can be described by a distinct regime which also prevailed during the first part of Governor Reddy's tenure. The other regime seems to coincide with Governor Rajan's time in office.

The MS-VAR model endogenously separates distinct regimes characterised by regime-specific parameter sets Tillmann (2007). The estimated parameters of each regime for the MSIH(3)-VAR(1) model are shown in table 3.[18] From the fourth equation, it is seen that regime 1 has the lowest inflation. From the fifth equation it is also seen that interest rate[19] is high for the first regime. This is consistent with the strong correspondence of regime 1 to Governor Jalan's tenure, as described in section 3. For regime 3, the regime that corresponds largely to Governor Rajan's period in office, the interest rate is the highest. Although the interest rate is comparable to regime 1, CPI inflation for regime 3 is much higher than the inflation rate in regime 1.

We also report the results for the MSH model for the sake of completion. Both M=3 and M=4 models

[17] This means a 3 regime model and a VAR system with 1 lag.

[18] Since the model is MSIH, both the intercepts and the variance-covariance matrices vary according to the regimes. Here, we analyse only the changes in the intercepts

[19] Since we have taken the log difference of all variables except inflation, the variables are effectively their growth rates instead of levels. We use the terms 'interest rate' and the 'growth rate of interest rate' here interchangeably.

are almost equally optimal. We only report the results for the M=3 case with the optimal number of lags selected as 1.

MSH(3)-VAR(1) model:

	$s_t = 1$	$s_t = 2$	$s_t = 3$
$s_{t-1} = 1$	0.942	0.058	0.000
$s_{t-1} = 2$	0.020	0.931	0.049
$s_{t-1} = 3$	0.025	0.119	0.856

Table 4: $Pr(s_t|s_{t-1}) : MSH(3) - VAR(1)$

Here we see that regimes 1 and 2 are the relatively persistent ones with regime 3 being more unstable. The near perfect correspondence of regime 1 with Governor Jalan's tenure (1998-2003) is even more evident now. On the other hand regime 2 which is more sporadic than regime 1 but still with a high transition probability (0.931) seems to start with Governor Reddy's time in office. It pretty much covers his entire tenure and appears infrequently during Governorr Subbarao's tenure. Most remarkably it coincides almost entirely with Governor Rajan's tenure.

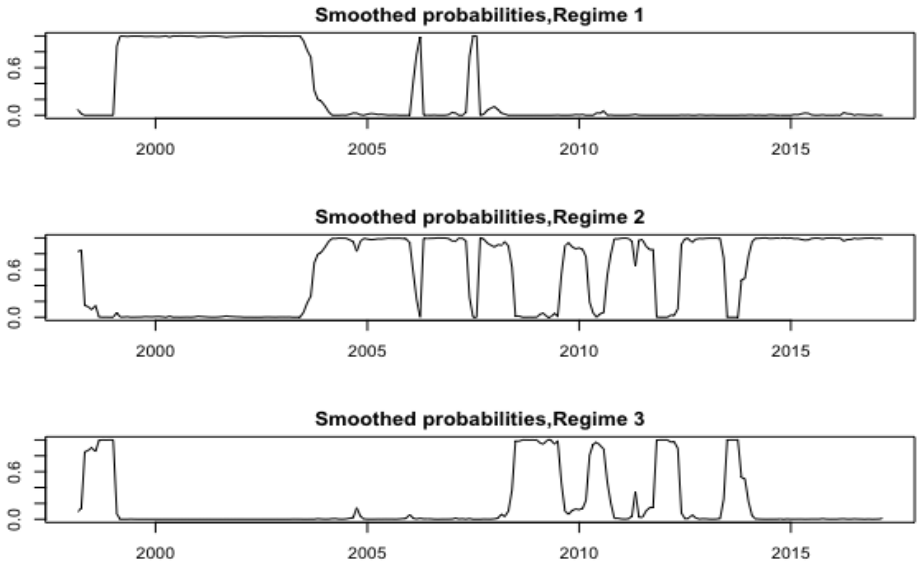

Figure 6: Regime switches for the MSH(3)-VAR(1) model

The MS-VAR models thus seem to suggest that specific regimes identified in the data overlap with the years when Governors Jalan, and Rajan were in office. Governor Subbarao's tenure is at best a mix of multiple regimes. The Jalan regime (apparent in both the MSIH (3) and MSH (3) models) seems to have been associated with the lowest rate of inflation and among the highest rates of interest. There also appear to be some similarities across the tenures of Governors Reddy and Rajan as in one specification these belonged to the same regime, despite being years apart.

	Lag: 1					
	Intercept	Oil Price	IIP	Exch. Rate	CPI	Int Rate
Oil Price	0.014	0.169	-0.029	-0.515	-0.001	-0.118
IIP	0.007	0.023	-0.396	-0.156	0.000	0.019
Exchange Rate	0.000	0.000	0.006	0.120	0.000	-0.020
CPI Inflation	0.078	0.840	1.755	4.866	0.976	-2.456
Interest Rate	-0.014	0.066	0.376	0.137	0.002	0.157

Table 5: Coefficients of MSH(3)-VAR(1) model

5 Robustness

We undertake three main robustness checks and report and analyse the results of the MSIH(3)-VAR(1) model for all our robustness checks.

With WPI instead of CPI: It maybe argued that CPI has been used relatively recently by the RBI as a metric to measure inflation. Previous governors had incorporated the WPI more frequently into their policy rule. To check if our results hold irrespective of the measure of inflation, we run our baseline models using WPI inflation instead of CPI inflation. Data for WPI Inflation has been sourced from the website for the Office of the Economic Adviser, Government of India. The transition probabilities for the 3 regime case is given by the following:-

	$s_t = 1$	$s_t = 2$	$s_t = 3$
$s_{t-1} = 1$	0.944	0.000	0.056
$s_{t-1} = 2$	0.089	0.764	0.147
$s_{t-1} = 3$	0.028	0.077	0.895

Table 6: $Pr(s_t|s_{t-1}) : MSIH(3) - VAR(1)$ with WPI

It is seen that the second regime is most unstable, similar to the baseline MSIH(3) model. Figure 7 shows the smoothed probabilities for the MSVAR with WPI.Once again, there is a transition in regimes from regime 1 to regime 3 over time. Regime 1 clearly corresponds to Governor Jalan's tenure (1999-2003) as well as early part of Governor Reddy's tenure. Regime 3 coincides almos entirely with Governor Rajan's time in office and also the later part of Governor Subbarao's tenure. The results are thus similar to the baseline model.

We conducted more robustness checks dropping the oil price from the model as Indian oil prices are regulated, incorporating the Federal Funds rate as a proxy for foreign interest rate and dropping 2017 from the sample as Governor Rajan's tenure ended in 2016 which is when inflation targeting was officially implemented. We find that the results are more or less robust to these changes.

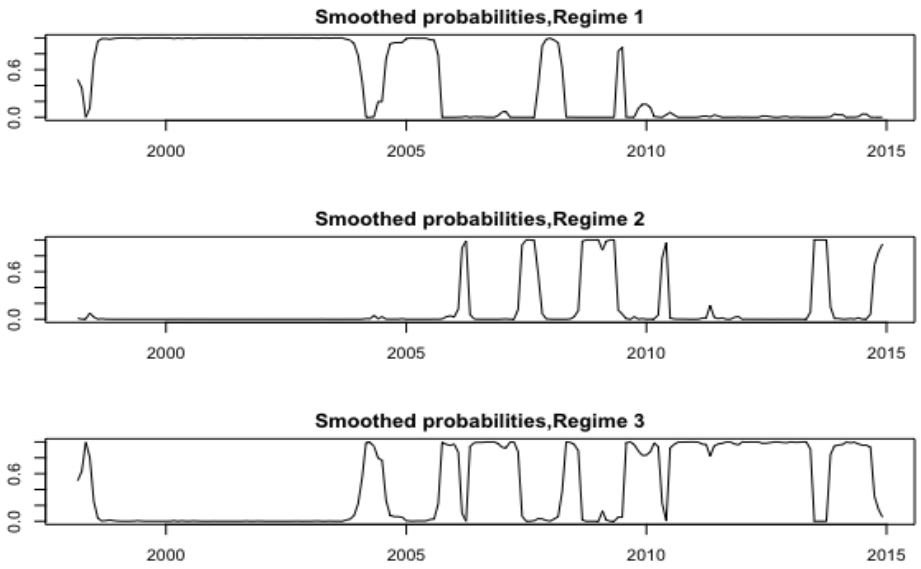

Figure 7: Regime switches for the MSIH(3)-VAR(1) model with WPI

6 Conclusion

Monetary policy in India was conducted in an ad-hoc and discretionary manner in the pre-inflation targeting era when the Reserve Bank of India pursued a multiple indicator approach. Different Governors would take into consideration a multitude of factors while setting the policy interest rate. Hence it maybe argued that monetary policy was largely dependent on the individual decision-making of the governors. Using a multivariate MS-VAR model we estimate regime switches in monetary policy during the period 1998-2017 and also comment on the extent to which specific regimes correspond to the tenures of successive RBI Governors.

We find that by and large the period under study witnessed two main regimes, one of which had a very close correspondence with the tenure of Governor Jalan and the other more or less matched the tenure of Governor Rajan. In the baseline model specification where we allow for both the intercept and the error term to vary, we find that the regime that characterised Jalan's time in office also occurred sporadically during the early part of Governor Reddy's time in office thereby hinting at similarities across these two sub-periods. In the model specification where we only allow the error term to vary, we find that the regime that roughly characterises Rajan's tenure also appears during Reddy's tenure. Governor Subbarao's tenure corresponds the least to any specific regime across all specifications.

This hints at similarities across the Governorships of Jalan, Reddy and Rajan in the way monetary policy was conducted or in the behaviour of underlying macro-financial variables or both. Our results may help understand the kind of discretionary approach applied by successive RBI Governors in their pursuit of monetary policy, in the run-up to a more rule-bound, inflation targeting framework.

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