Why Were Changes in the Federal Funds Rate Smaller in the 1990s?

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Abstract:

We identify two major changes in the dynamics of the federal funds rate in the 1990s. We model the desired rate in a two-regime setting, one when the Fed makes no change and the other when the Fed is moving the desired rate to a new level. We find that the 1990s saw longer duration in the no-change regime as well as smaller changes in the other regime. The smaller changes were neither due to a less aggressive Fed nor due to lower volatility of the fundamentals. In fact, the Fed responded more aggressively to changes in fundamentals in the 1990s.

Keywords: Federal Funds Rate, Non-Linear Policy, Taylor's Rule.

JEL Classification: E43, E52.

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1. Introduction

Movements in the monthly federal funds rate were remarkably smoother in the 1990s than in the preceding decade. This is visually apparent in Figure 1, which plots the monthly differences in the federal funds rate. The standard deviation of the first difference falls in half, from 0.331 in the 80s to 0.165 in the 90s. We use an unobserved components model to separate the desired component of the federal funds rate from noise. We then investigate the major elements that account for the increased smoothness of the funds rate.

While the federal funds rate, i_t, is directly observable, the desired funds rate, i_t^*, is not. We infer values of i_t^* by building a two-part model. First, we decompose the funds rate into two components, a desired funds rate and a white noise term. This decomposition assumes that any persistence in the funds rate must be desired. Next, we assume there are some periods in which the Fed keeps the desired rate unchanged. We use a first-order Markov switching process to model the probability that i_t^* is in this static regime. In other periods, the change in the desired rate is hit by an unobserved serially correlated shock. Thus the desired rate process obeys a nonlinear mixture model, mixing a stationary and a nonstationary process.

Next, we allow for partial observability of the desired funds rate by allowing fundamental economic pressures in the economy to affect the changes in the desired rate along with the shocks. This "partially observed" model provides for structural inferences about the changes in the conduct of in monetary policy in the 1990s. We allow for the fundamental pressures in two ways; the first is an estimated monetary policy rule with forward-looking components. In the second, we include Taylor's rule with its original weights on inflation and output gap.

We present several new results in the paper. We show the amount of noise present in the actual funds rate is quite small relative to the desired rate and the fall in the variance came mostly from the desired rate. Probing deeper, our results show that the probability of being in the static-desired-rate regime increased significantly in the 1990s. Moreover, the variance of the first difference of the desired rate in the non-static regime also dropped considerably. This means that the desired rate was less likely to change in the 1990s and that when it did change the average size of those changes was smaller. Further investigations using fundamental pressures rule out either a less aggressive behavior of the Fed in the 1990s or lower volatility of the fundamentals as explanations of the lower variance of first difference in the desired rate. In fact, the evidence points to the contrary, the Fed became more aggressive, especially with respect to forward-looking variables.

This paper also contributes to the estimation process of the monetary policy reaction function literature. We introduce a modeling technique that considers the non-linearities while estimating the coefficients of the reaction function. In our model, the coefficients are interpreted as the response of the desired rate to a unit change in the fundamentals when the desired rate did respond.

The structure of this paper is as follows: We briefly review some of the relevant theoretical and empirical literature in section 2. In section 3, we lay out our main model to estimate and all the variations in it that we will use for further structural analysis. In section 4, we present the key empirical results as well as the additional structural results. We summarize and conclude in section 5

.2. The Background: Theoretical and Empirical

A key feature of the 1990s was, as Mankiw points out (Mankiw, 2002), the remarkable stability of both real and nominal variables. The federal funds rate, the most important indicator of monetary policy in the last two decades, itself became far more stable. A number of authors have investigated the smoother dynamics of the funds rate.

The primary explanation in the literature for smooth dynamics of the federal funds rate is that the actual rate adjusts only partially to the desired rate. This phenomenon is generally labeled as 'inertia'. According to Rudebusch "The Federal Reserve as well as the financial press appears to interpret the purpose of such smoothing to be the avoidance of 'undue stress' on financial markets" (Rudebusch, 1995). Woodford argues (Woodford, 1999) that in the presence of forward-looking private agents, inertial behavior may be optimal for the central banker with a goal of output gap and inflation stabilization. It acts as a commitment device against frequent reversals in the desired rate changes.

Empirical evidence on inertial behavior in the federal funds rate is very robust across different studies. Studies based on quarterly data typically report an estimate of inertia in the range of 50-80 percent[1]. The monthly study by Clarida, Gali and Gertler reports inertial estimates of over 90 percent for the US (Clarida *et al*., 1998). At a higher frequency level, Rudebusch provides evidence of significant partial adjustment in the funds rate on a daily basis (Rudebusch, 1995). All of these high values of inertia imply a high degree of persistence in the federal funds rate dynamics. Using a longer time series, Watson also found a very high degree of persistence in the funds rate process (Watson, 1999).

[1] For example, see Clarida, Gali and Gertler (Clarida *et al*., 2000), Judd and Rudebusch (Judd and Rudebusch, 1998).

Overall, the evidence in favor of strong inertia in the federal funds rate dynamics is very consistent across different samples and frequencies.

The second explanation for smooth dynamics of the federal funds rate can be traced back to Brainard (Brainard, 1967). He argued that in the presence of significant multiplicative parametric uncertainty, the monetary authority should respond in a highly cautious fashion to changes in the macroeconomic fundamentals. This results in sluggish movements in the desired rate itself rather than sluggish adjustments towards a desired rate. Sack provides some support in favor of this hypothesis as an explanation of smoothness in the federal funds rate (Sack, 2000). He used the variance-covariance matrix of estimated parameters as a measure of parametric uncertainty to show multiplicative parametric uncertainty results in significantly reduced volatility of the desired rates. Sack and Wieland provides (Sack and Wieland, 1999) a good summary of the empirical evidence on interest rate smoothing.

The above literature investigates linear models of persistence. However, a salient feature of monetary policy is that in many periods the Open Market Committee explicitly holds constant the target funds rate. In addition, there is an important technical issue about the degree of persistence of the shocks to the funds rate, i.e., is the federal funds rate process stationary but very persistent or is it non-stationary? An overwhelming majority of the literature fails to reject a unit root. However, in practice, both stationary processes and non-stationary processes are used for empirical modeling of the federal funds rate[2]. The Markov-switching model we introduce in the next section directly models the 'sometimes

[2] For example, see Watson (Watson, 1999) and Mehra (Mehra, 1998).

constant' behavior of the Open Market Committee by allowing for periods of both stationary and non-stationary behavior of the actual federal funds rate.

3. The Models

3.1 The basic unobserved desired rate model

Our model decomposes the actual federal funds rate into two components, a persistent desired rate part and a white noise component. The 'white' part of noise implies that the Fed does not make any persistent mistake in hitting its desired rate. Our measurement equation is:

$$\begin{aligned} i_t &= i_t^* + \varepsilon_t \\ \varepsilon_t &\sim iid\, N(0, \sigma_\varepsilon^2) \end{aligned} \tag{1}$$

We assume the desired rate evolves according to one of the two regimes. In the first regime, the desired rate is static:

$$i_t^* = i_{t-1}^* \tag{2}$$

This specification implies that the actual federal funds rate is stationary in this regime in the absence of any shock to the desired rate. In the second regime, we allow the desired rate to be non-stationary:

$$\begin{aligned} i_t^* &= i_{t-1}^* + u_t \\ u_t &= \phi u_{t-1} + \nu_t \end{aligned} \tag{3}$$

The change in the desired rate is hit by a serially correlated shock, u_t, assumed to follow an AR (1) process[3]. We assume $|\phi| < 1$ and $\nu_t \sim N(0, \sigma_\nu^2)$. We call this the 'dynamic' regime.

[3] Several diagnostic checks suggest an AR (1) specification is sufficient.

Letting $\mathrm{S_t} = 0$ when the static model applies and $\mathrm{S_t} = 1$ when the desired funds rate is hit by the correlated shock, the two regimes can be nested in our basic non-linear model for the federal funds rate:

$$\begin{aligned} i_t &= i_t^* + \varepsilon_t \\ i_t^* &= (1 - S_t) i_{t-1}^* + S_t [i_{t-1}^* + u_t] \\ u_t &= \phi u_{t-1} + \nu_t \\ S_t &= 0, 1. \end{aligned} \qquad \text{(Model 1)}$$

We assume that S_t follows a first order Markov process. Specifically, the transition probabilities are as follows:

$$\Pr(S_t = 0 \mid S_{t-1} = 0) = p$$
$$\Pr(S_t = 1 \mid S_t = 1) = q$$

In the empirical implementation, we let every parameter of the model take on different values in the early and late periods.

3.2 The models with fundamental economic pressures

Both the level and the change in the desired funds rate are treated as unobserved in the above model. This eliminates the need to make an assumption about the Fed's stabilization goals, but at the cost of discarding potential valuable information available from those variables. In this section, we modify the above model in the dynamic regime to allow for change in the desired rate to be partially observable and driven by changes in - the indicators containing information about the Fed's stabilization goals.

In our first variant, we assume the first difference in the desired rate is driven by changes in components of a monetary policy rule with both forward-looking and backward looking features:

$$\begin{aligned} i_t^* &= i_{t-1}^* + \beta_\pi \Delta\pi_{t-1} + \beta_{\pi^e}\Delta\pi_{t-1}^e + \beta_x \Delta x_{t-1} + \beta_R \Delta R_{t-1} + u_t \\ u_t &= \phi u_{t-1} + \nu_t \end{aligned} \qquad (4)$$

As in the previous model, we allow the changes in the desired rate to be hit by an unobserved AR (1) shock, u_t, which makes the changes in the desired rate only partially observed. The terms $\Delta(.)$ indicate first differences in the variable concerned. The variable π denotes inflation rate, π^e stands for expected inflation, x is the output gap and R represents the financial market spread that predicts future recessions and inflations[4]. We assume these variables give information about the current and future output gaps and inflation conditions and therefore changes in these variables should influence Fed's decision about changing the desired rate. We specify lagged changes to insure that the driving variables are in fact in the Fed's information set. Our estimating model after allowing the parameters to change is given by:

$$\begin{aligned} i_t &= i_t^* + \varepsilon_t \\ i_t^* &= (1-S_t)i_{t-1}^* + S_t[\beta_{\pi,j}\Delta\pi_{t-1} + \beta_{\pi^e,j}\Delta\pi_{t-1}^e + \beta_{x,j}\Delta x_{t-1} + \beta_{R,j}\Delta R_{t-1} + i_{t-1}^* + u_t] \\ u_t &= \phi_j u_{t-1} + \nu_t \\ S_t &= 0, 1. \\ j &= 1980s, 1990s. \end{aligned} \qquad \text{(Model 2)}$$

It is useful to separate the relative reliance the Fed places on current versus forward-looking indicators. Because the independent variables in Model 2 are lagged, there is a possibility that the forward-looking components are proxying for omitted information about the economic condition of the current period as well as future periods. To control for this possible effect, we substitute for the current period variables a target rate computed from Taylor's rule using Taylor's original weights (Taylor, 1993) on inflation and output gap and a real interest rate target of 2 percent[5]. We restrict the changes in the desired rate to be the sum of the changes in the Taylor rule's target rate, the effect of changes in the lagged forward looking variables and an AR (1) shock. If the target rates computed from Taylor's rule at time *t* are denoted by i_t^T , then the dynamic regime of our second variant is:

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\begin{aligned}
i_t^* &= \Delta i_t^T + \beta_{\pi^e,j} \Delta \pi_{t-1}^e + \beta_{R,j} \Delta R_{t-1} + i_{t-1}^* + u_t \\
i_t^T &= 2 + 1.5\pi_t + 0.5x_t \qquad (5) \\
u_t &= \phi u_{t-1} + \nu_t
\end{aligned}
$$

After allowing all the parameters to change values from 1991:04, our complete model can be written as:

$$
\begin{aligned}
i_t &= i_t^* + \varepsilon_t \\
i_t^* &= (1 - S_t) i_{t-1}^* + S_t [\Delta i_t^T + \beta_{\pi^e,j} \Delta \pi_{t-1}^e + \beta_{R,j} \Delta R_{t-1} + i_{t-1}^* + u_t] \\
u_t &= \phi_j u_{t-1} + \nu_t \qquad \text{(Model 3)} \\
S_t &= 0, 1. \\
j &= 1980s, 1990s.
\end{aligned}
$$

Note that instead of estimating the coefficient of Δi_t^T, we restrict it to one. This has the implication that monetary authority *knows* the current economic condition and acts *fully* according to the weights of Taylor's rule. Therefore, the effect of lagged changes in the forward-looking variables will capture only additional forward-looking concerns of Fed

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[4] See Mishkin (Mishkin, 1990) and Estrella & Hardouvelis (Estrella and Hardouvelis, 1991) for discussions on these issues.

while setting the desired rate. This experiment allows us to distinguish between the current period forecast component of the forward-looking variables as against their forecast of the future. This does have the drawback of forcing the weights Fed would assign on current inflation and output gap, but that is necessary to avoid the endogeneity issue involved to estimate the effect.

4. Empirical Results

4.1 A look at the data and basic estimation results

Most of our data is taken from the Federal Reserve Economic Database (FRED). The dataset is monthly US time series from 1982:11 to 2000:12. The observed federal funds rate is the monthly average rate for all the models[6]. For Models 2 and 3, we compute the output gap by quadratically detrending the log of real GDP interpolated[7] to monthly series. Annual inflation was calculated by interpolating the seasonally adjusted GDP deflator series (chained index in 1996 dollars) to a monthly frequency. These calculations make the computed Taylor's rule consistent with Taylor's original work. The monthly spread was calculated by taking the difference of the monthly average of 10-year Treasury note rate and the monthly average of 3-month T-bill rate. These data were also taken from FRED.

The second and third models include a monetary policy rule based in part on inflationary expectations. We interpret this variable as being part of the Federal Reserve's

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[5] We computed the rule with a zero percent inflation target as against Taylor's 2 percent.

[6] Using monthly average data makes it easy to compare the results with the standard literature on monetary policy. Finally, the data on other variables were available only at monthly frequency. We do not use the end of the month data because some of them are on 'clearance Wednesdays' and add extra noise to the data.

[7] All the interpolations have been computed using the cubic spline method and "interp1" command in MATLAB.

forward looking data, so we want a measure that directly estimates expectations about future inflation. We measure inflationary expectations by taking the Survey of Professional Forecasters (SPF) data and interpolating to a monthly series. The SPF forecasts the GDP deflator, which is consistent with our measure of inflation. In addition, Croushore argues (Crueshore, 1998) that the SPF is the best of the available survey-based data.

We treat the Federal Reserve's desired funds rate as unobservable, but some data does exist on the Federal Reserve's announced targets. We chose to treat the desired rate as unobservable for two reasons. First, as a matter of principle we prefer to let the data identify policymaker intentions rather than impose a priori that announced targets are real targets. Second, there are several significant data issues in using announced targets. The Fed has announced target rates only from the 1990s, although earlier target rates can be derived from the minutes of FOMC meetings. Further, target rates are generally set at six-week intervals, which is an awkward match for the calendar month frequency usually used for monetary policy analysis.

Whatever the advantages in principle of treating the desired rate as unobservable, it is nonetheless interesting to look at announced target data. We took data for the Federal Reserve's announced targets from 1989:06 onwards from Haver Analytics while the earlier data is from the Economagic web site.[8]Announced target rate data, along with the estimated desired rate from our first model, is plotted in Figure 3. As a practical matter announced targets and the estimated desired rate are essentially indistinguishable, including during the periods in the 1990s when the Fed held the announced target rate fixed.

Our data runs from the end of monetary base targeting through the last available data, 1982:11-2000:12. The dating of the breakpoint is treated as known and certain, but the actual date chosen is at once somewhat arbitrary and not too important. We assume a known breakpoint at 1991:04 since the NBER announced trough of the 1990-91 depression was on 1991:03. After that date, the US economy did not experience any other recessions or significant inflationary periods during the data sample. This breakpoint also conveniently divides our sample roughly in half. Thus, "1980s" is the shorthand for 1982:11-1991:03 and "1990s" is the shorthand for 1991:04-2000:12.

Our results are – mostly – robust to the choice of breakpoint. Moving the breakpoint forward up to 24 months while re-estimating Model 1 produces log likelihood values that are not significantly different from the results based on 1991:04, and in fact are almost always lower. Similarly, moving the breakpoint backward up to 7 months gives no significant differences in the log likelihood. Moving the breakpoint earlier does sometimes give higher values of the log likelihood function, but the model for the "1980s" begins to break down as estimated transition probabilities go to the boundary of the parameter space. At the same time, the substantive conclusions are the same as from the use of our preferred breakpoint. For example, Hamilton and Jorda mention (Hamilton and Jorda, 2002) 1989:12 as the starting point of the Fed's shift in operating procedure. As a comparison we re-estimated our results for Model 1, given in Table 4A, using 1989:12 as the breakpoint and present the results in Table 4B. The estimates of the model and the results are essentially the same as that of Table 4A except that the estimate of p in the 1980s hits the zero

[8] The sites are http://www.economagic.com/em-cgi/data.exe/rba/fooirusfftrmx and http://www.economagic.com/em-cgi/data.exe/rba/fooirusfftrmn. Some of the months have a range between

boundary. Note in particular that the standard deviation of the first difference of the federal funds rate in the 1980s is approximately 1.94 times that of the same estimate in the 1990s, differing inconsequentially from the 2.06 ratio using 1991:4 as the breakpoint.

We begin the data analysis proper by conducting the standard unit root test on the federal funds rate. In Table 2, we provide the ADF-Statistic for the full sample and the two sub-samples. It is not possible to reject the presence of unit root at 10 percent level of significance in any of the samples, which suggests that the presence of unit root in the series is a possibility. In Table 3, we report the KPSS test results for the null of level stationarity. Results for the full sample show we can reject level stationarity at 5 percent level of significance. The KPSS test result for the first half sample is not significant. However, the second half sample rejects the null of level stationarity at the 5 percent level. Taken together, - this evidence does offer some support for the presence of a unit root in the funds rate series and provide the basis for including a non-stationary regime in the switching model.

4.2 Estimation results and hypothesis testing in the unobserved desired rate model

We present the estimation results for the unobserved desired rate model in Table 4-A[9]. Parameter estimates are given separately for the 1980s and 1990s. The standard deviation of the noise element, σ_ε, drops by about a third in the 1990s. The standard deviation of the shocks to the desired rate, σ_v, in the 1990s is less than half its 1980s value.

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minimum and maximum intended rate and in those cases; the average of the two has been used as data.

[9] All the following estimations have been done using the approximate maximum likelihood method outlined in Kim and Nelson (Kim and Nelson, 1999). Calculations were done using the BFGS algorithm in GAUSS.

Both parameters are tightly estimated. The estimates also show a rise in the persistence of the AR (1) shock, u_t.

The increased persistence increases the variance of u_t while the drop in σ_v decreases it. The net effect on $\sigma_u^2 = \frac{\sigma_v^2}{1-\phi^2}$ is a drop in the variance of the shock to the desired rate from 0.114 to 0.048. We used a nonlinear Wald test to check the hypothesis that the variance of u_t remained same across the break point. A test statistic value of 4.42 implies that the null hypothesis is rejected at 5 percent level of significance. Finally *p,* the probability of remaining in the static regime, rose and *q,* the probability of remaining in the non-static regime, fell. The estimated steady-state probability of being in regime 1, $\frac{1-q}{(1-p)+(1-q)}$ increased from 10 percent to 49 percent. A Wald statistic of 7.45 against the null of an unchanged steady-state probability implies we can reject the null at the 1 percent level of significance.

The point estimates in Table 4–A indicate that there was a greatly increased tendency in the 1990s for the Fed to keep the desired federal funds rate fixed. Another way to look at this dramatic change is presented in Figure 2, which shows the smoothed probabilities of being in the static regime[10]. High probabilities of the static regime occurrence are much more frequent after 1991:04 than before. The second Wald test in Table 4-A shows that the size of change in monthly average desired rate also dropped significantly. In fact, when in the dynamic state, the average size of change in monthly

[10] The two-sided estimates of the filtered probability were computed using Kim's smoothing algorithm outlined in Kim and Nelson (Kim and Nelson, 1999).

desired rate has dropped from 34 basis points in the 1980s to 22 basis points in the 1990s. Estimated values of the desired rate are shown in Figure 3. In Table 5, we use the estimates of model 1 to decompose the decrease in the variance of the change in the funds rate into its various components. We first divide the reduction into two parts; the part due to reduction in the variance of the desired rate change and the part due to reduction in the variance of the white noise term. The variance of the change in the desired rate is the variance of u_t conditional on being in the dynamic state. The figures in Table 5 show that essentially all the change in the variance, 95 percent, can be attributed to reduction in the variance of changes in the desired rate.

Since this component is the biggest portion of the fall in the variance, we further decompose it into three parts. (Details of the calculation are given in the Appendix.) The first part is the part due to reduction in the variance of u_t, keeping the steady-state probabilities of each state at the 1980s level. (The figures in Table 5 are given as a percentage of the reduction in the desired rate variance, so the denominator for the last three rows is the numerator from row two.) The second part is due to the change in steady-state probabilities only, keeping the variance of change in the desired rate at the 1980's level. The third part is the interaction term between the above two types of change. They account for 76 percent, 57 percent and –33 percent of the final change in the mean value of variance of change the desired rate respectively.

4.3 Estimation results and hypothesis testing in the extended models

In this subsection, we investigate two potential explanations for the smaller average size of changes in the desired rate. Can less forceful reaction of the Fed to the changing economic pressures form an explanation to the phenomenon or is the lower volatilities of the economic pressures in the 1990s a better answer? The answer is a surprising 'neither'. To examine, we add to the unobserved desired rate model a monetary policy rule with forward and backward looking components. Using the estimated monetary policy rule leaves the parameter estimates (in Table 6) of p, q and σ_ε essentially unchanged from the previous model. In particular, we find that the steady-state probability of being in the static regime rose from 11.6 percent in the 1980s to 47 percent in the 1990s, the change being significant at the 5 percent level.

Parameter estimates of the coefficients on inflation, inflationary expectations, and the spread indicate that the Fed reacted more aggressively in the 1990s than it had in the 1980s. Point estimates of the coefficient of inflation and inflationary expectations went up by three times, the spread coefficient went from insignificantly negative to significantly positive. Only the point estimate of the coefficient of the output gap decreased, but insignificantly so. The increased response to inflation in the 1990s confirms the findings by Mankiw (Mankiw, 2002).

Just how significant were these increases in estimates? Using a formal Wald test we can reject the joint null hypothesis that the four parameters remained the same across periods at the 5 percent level of significance[11], as a whole they became more aggressive. However, when we subdivide the four explanatory variables into forward-looking (inflationary expectation and spread) and backward-looking (inflation and output gap) variables and do Wald tests on each group separately, the test statistic value for the forward-looking variables was significant at 5 percent level but the test statistic value for backward-looking variables was not (though significant at 10 percent level). This suggests that even though there was a general rise in aggressiveness of Fed in the 1990s, it was more pronounced with respect to the forward-looking variables.

How should this increase in forward-looking behavior be interpreted? We know that the 1990s was a more stable decade than the 1980s. Our results on increased forward-looking behavior of the Fed in the 1990s is at least suggestive that this changed policy behavior contributed to the added stability.

Having ruled out a less aggressive Fed as an explanation for smaller variance, we then ask how much of monetary policy (changes in desired rate) is a reaction to the explanatory variables? A comparison of the variances of u_t from model 1 and model 2 helps us to identify how much of the variation in change of desired rate can be explained by the four explanatory variables. Only 20.6 percent of the variation in change of desired rate can be explained by these four variables in the first half sample whereas 59.4 percent can be explained in the second half. This suggests that the Fed is sticking closer to an interest rate rule-like behavior than before.

In Table 7, we decompose the components of variation of the change in the desired rate into forward-looking and backward-looking parts and examine how that changed between the two decades. The variances of all explanatory variables are given and they

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[11] Rejection of the null hypothesis of four restrictions is primarily driven by change in the inflationary expectation and the spread coefficients. A similar result is also reported in Hamilton and Jorda (Hamilton and

confirm Mankiw's (Mankiw, 2002) results - the 1990s was indeed a more stable decade compared to 1980s[12]. But, the total explained variation by the four explanatory variables was less in the 1980s when compared to that in the 1990s. This rules out smaller variations in fundamentals as a potential answer, the aggressiveness of the Fed clearly dominated the lower variations of the fundamentals in the 1990s. Comparing the share[13] of the forward-looking variables, we observe that it has increased by 26 percent and has remained important over this time. The share of the backward-looking variables has decreased by 5 percent to 40.9 percent. These numbers confirm the rising aggressiveness of the Fed has dominated the lower variation in the explanatory variables, especially with respect to the forward-looking variables.

In Model 3, we substitute a computed Taylor's rule target for the current period variables. Figure 3 shows the target rate computed by Taylor's rule. In Table 8, we present the parameter estimates of Model 3. Since the change in the desired rate is affected one to one for a change in the computed target rate, the current changes in gap and inflation are incorporated in the desired rate though with the stipulated weights on them. Comparing Table 8 and Table 9, the LR statistic value of 13.89 implies the forward-looking variables are important even in the presence of current period indicators. From the Wald statistic we see a significant increase in the coefficients on expected inflation and the spread in the 1990s suggesting a more forward-looking behavior. Coefficients estimates are not greatly different from those in Table 6, suggesting that the issue of proxying for current period

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Jorda, 2002).

[12] See McConnell and Quiros (McConnell and Quiros, 2000) and Kim, Nelson and Piger (Kim *et al*., 2002) for a discussion on this issue.

indicators is not of great importance. Overall, the forward-looking variables were important to Fed in the 1980s and became more important in the 1990s.

5. Summary and conclusion

To summarize, we have several strong results robust across all our models. We begin with the datum that there was a sharp decline in the variance of the change in the federal funds rate in the last decade. One, we find that this is due principally to a decrease in the variance of the desired rate. While the noise component of the actual funds rate declined, it was small to begin with. Two, the non-linear feature of no movement in the desired rate is much more important in the 1990s than before. There is a large increase in the steady-state probability of the Fed holding the desired rate constant, which accounts for a significant fraction of the decline in variation of the desired rate. Three, the lower variance was not due to a less aggressive monetary authority. In fact, empirical evidence suggests a more aggressive Fed in the 1990s. Four, the results also suggest a more forward-looking Fed than before. Five, majority of the smaller variance comes from Fed sticking closer to an interest rate rule-like behavior.

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[13] The share of each type of variables was computed as a percentage of total explained variation by all four variables.

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Table 1: Standard deviations of Changes in Federal Funds Rate

Volatilities	*1982:11- 2000:12*	*1982:11- 1991:03*	*1991:04 - 2000:12*
$\sigma(\Delta i_t)$	0.255	0.331	0.165

Table 2: Unit Root Test of Federal Funds Rate

Sample	1982:11-2000:12	1982:11-1991:03	1991:04-2000:12	*10%- value*
ADF-Stat	-0.917 (1)	-0.795 (1)	-0.068 (3)	-1.616

Note: The numbers in the parentheses are the number of lags used in computing the test statistic. The lag selections were based on minimum AIC criterion using EVIEWS package. We did not allow for a constant and time trend in the regression.

Table 3: Level Stationarity Test of Federal Funds Rate

Sample	1982:11-2000:12	1982:11-1991:03	1991:04-2000:12	*5%- value*
KPSS-Stat	0.793 (15)	0.269 (10)	0.493 (11)	0.463

Note: The numbers in the parentheses are the number of lags used in computing the test statistic. They were selected by taking the square root of number of observations in that sample.

Table 4-A: Estimation Results for the Unobserved Desired Rate Model

Parameters	*"1980s"*	*"1990s"*	*Wald Test*
p	0.743	0.796	$H_0[\Pr ob(S_t = 0 \mid t \leq 1991:03)$
	(0.20)	(0.08)	$= \Pr ob(S_t = 0 \mid t \geq 1991:04)]$
q	0.971	0.801	**W = 7.453**
	(0.04)	(0.11)	
ϕ	0.485	0.802	
	(0.11)	(0.11)	*Wald Test*
σ_ε	0.064	0.045	$H_0[Var(u_t) \mid t \leq 1991:03$
	(0.02)	(0.01)	$= Var(u_t) \mid t \geq 1991:04]$
σ_v	0.295	0.131	**W = 4.421**
	(0.03)	(0.03)	
Log L	**253.444**		

Note: Standard errors are in parentheses and are computed using the delta method.

Table 4-B: Estimation Results for the Unobserved Desired Rate Model Using Earlier Breakpoint

Parameters	*"1980s"*	*"1990s"*	*Wald Test*
p	0.000	0.803	$H_0[\Pr ob(S_t = 0 \mid t \leq 1989:11)$
	(0.00)	(0.07)	$= \Pr ob(S_t = 0 \mid t \geq 1989:12)]$
q	0.942	0.815	**W = 12.80**
	(0.06)	(0.09)	
ϕ	0.413	0.804	
	(0.11)	(0.09)	*Wald Test*
σ_ε	0.028	0.045	$H_0[Var(u_t) \mid t \leq 1989:11$
	(0.02)	(0.01)	$= Var(u_t) \mid t \geq 1989:12]$
σ_v	0.319	0.137	**W = 5.91**
	(0.03)	(0.02)	
Log L	**256.930**		

Note: Standard errors are in parentheses and are computed using the delta method.

Table 5: Decomposition of the Reduction in Variance

Categories	*Numbers*
$\frac{V_{80s}(i_t - i_{t-1}) - V_{90s}(i_t - i_{t-1})}{V_{80s}(i_t - i_{t-1})}$	0.7515
$\frac{(1-\Pr_{80s})\sigma^2_{u,80s} - (1-\Pr_{90s})\sigma^2_{u,90s}}{V_{80s}(i_t - i_{t-1})}$	0.7118
$\frac{2(\sigma^2_{\varepsilon,80s} - \sigma^2_{\varepsilon,90s})}{V_{80s}(i_t - i_{t-1})}$	0.0365
$\Omega \equiv (1-\Pr_{80s})\sigma^2_{u,80s} - (1-\Pr_{90s})\sigma^2_{u,90s}$	
$\frac{(1-\Pr_{80s})(\sigma^2_{u,80s} - \sigma^2_{u,90s})}{\Omega}$	0.7595
$\frac{-\sigma^2_{u,80s}(\Pr_{80s} - \Pr_{90s})}{\Omega}$	0.5720
$\frac{-(\sigma^2_{u,90s} - \sigma^2_{u,80s})(\Pr_{80s} - \Pr_{90s})}{\Omega}$	-0.3314

Note: The terms '$\Pr_i$', i = 80s, 90s denote steady state probability of being in the static state in the first period (1980s) or in the second period (1990s) respectively. The terms '$V_i(.)$', i = 80s or 90s denote variances in the first or second period respectively. The terms '$\sigma^2_{(\cdot),i}$'denote estimated variances of the variables concerned in period i, i = 80s, 90s. There are some minor rounding-off errors.

Table 6: Estimation Results for the Model with 4 Fundamental Pressures

Parameters	***"1980s"***	***"1990s"***
p	0.727	0.799
	(0.20)	(0.08)
q	0.966	0.823
	(0.04)	(0.08)
β_{π}	0.464	1.604
	(0.45)	(0.39)
β_{π^e}	0.586	2.025
	(0.35)	(0.51)
β_x	0.375	0.032
	(0.20)	(0.15)
β_R	-0.082	0.257
	(0.12)	(0.09)
ϕ	0.320	0.657
	(0.15)	(0.20)
σ_{ε}	0.063	0.043
	(0.01)	(0.01)
σ_v	0.285	0.106
	(0.03)	(0.02)
Log L	**269.900**	

Wald Test

$$H_0[\Pr ob(S_t = 0 \mid t \leq 1991:03) = \Pr ob(S_t = 0 \mid t \geq 1991:04)]$$

W = 6.334

Wald Test

$$H_0[\beta_{\pi,1980s} = \beta_{\pi,1990s}; \beta_{\pi^e,1980s} = \beta_{\pi^e,1990s}; \beta_{x,1980s} = \beta_{x,1990s}; \beta_{R,1980s} = \beta_{R,1990s}]$$

W = 19.375

Wald Test

$$H_0[\beta_{\pi^e,1980s} = \beta_{\pi^e,1990s}; \beta_{R,1980s} = \beta_{R,1990s}]$$

W = 11.600

Wald Test

$$H_0[\beta_{\pi,1980s} = \beta_{\pi,1990s}; \beta_{x,1980s} = \beta_{x,1990s}]$$

W = 5.242

Wald Test

$$H_0[\beta_{x,1980s} = \beta_{x,1990s}]$$

W = 1.876

Note: Standard errors are in parentheses and are computed using the delta method.

Table 7: Variance Decompositions in 1980s and 1990s

Categories	***1980s***	***1990s***
Change in $V(u)$	0.0235	0.0249
$V(\phi_{\pi}\Delta\pi_{t-1}+\phi_{\pi^e}\Delta\pi^e_{t-1}+\phi_x\Delta x_{t-1}+\phi_R\Delta R_{t-1})$	0.0192	0.0301
$V(\Delta\pi_{t-1})$	0.0111	0.0048
$V(\Delta\pi^e_{t-1})$	0.0169	0.0032
$V(\Delta x_{t-1})$	0.0557	0.0272
$V(\Delta R_{t-1})$	0.0969	0.0406
Share of $\Delta\pi_{t-1}$ and Δx_{t-1}	45.48%	40.86%
Share of $\Delta\pi^e_{t-1}$ and ΔR_{t-1}	29.39%	55.67%

Note: The terms $V(.)$ denote variances of the variable concerned. The first row is the change in $V(u)$ from model 1 to model 2. There are some minor rounding-off errors.

Table 8: Estimation Results for the Model with Taylor's Rule and Forward-Looking Variables.

Parameters	*"1980s"*	*"1990s"*
p	0.717	0.842
	(0.18)	(0.08)
q	0.954	0.869
	(0.04)	(0.09)
β_{π^e}	0.381	1.583
	(0.34)	(0.60)
β_R	-0.079	0.247
	(0.12)	(0.11)
ϕ	0.378	0.591
	(0.12)	(0.17)
σ_ε	0.067	0.044
	(0.01)	(0.01)
σ_v	0.294	0.138
	(0.03)	(0.02)
Log L	**259.751**	

Wald Test

$$H_0[\Pr ob(S_t = 0 \mid t \le 1991:03) = \Pr ob(S_t = 0 \mid t \ge 1991:04)]$$

W = 3.968

Wald Test

$$H_0[\beta_{\pi^e,1980s} = \beta_{\pi^e,1990s}; \beta_{R,1980s} = \beta_{R,1990s}]$$

W = 7.635

Note: Standard errors are in parentheses and are computed using the delta method.

Table 9: Estimation Results for the Model with Taylor's Rule Only

Parameters	*"1980s"*	*"1990s"*
p	0.727	0.828
	(0.18)	(0.08)
q	0.959	0.843
	(0.04)	(0.10)
ϕ	0.402	0.638
	(0.23)	(0.17)
σ_ε	0.066	0.045
	(0.01)	(0.01)
σ_v	0.297	0.153
	(0.03)	(0.03)
Log L	**252.805**	

Wald Test

$$H_0[\Pr ob(S_t = 0 \mid t \le 1991:03) = \Pr ob(S_t = 0 \mid t \ge 1991:04)]$$

W = 4.970

LR Test

$$H_0[\beta_{\pi^e,1980s} = \beta_{\pi^e,1990s} = \beta_{R,1980s} = \beta_{R,1990s} = 0]$$

LR = 13.892

Note: Standard errors are in parentheses and are computed using the delta method.

Figure 1: The Change in the Federal Funds Rate

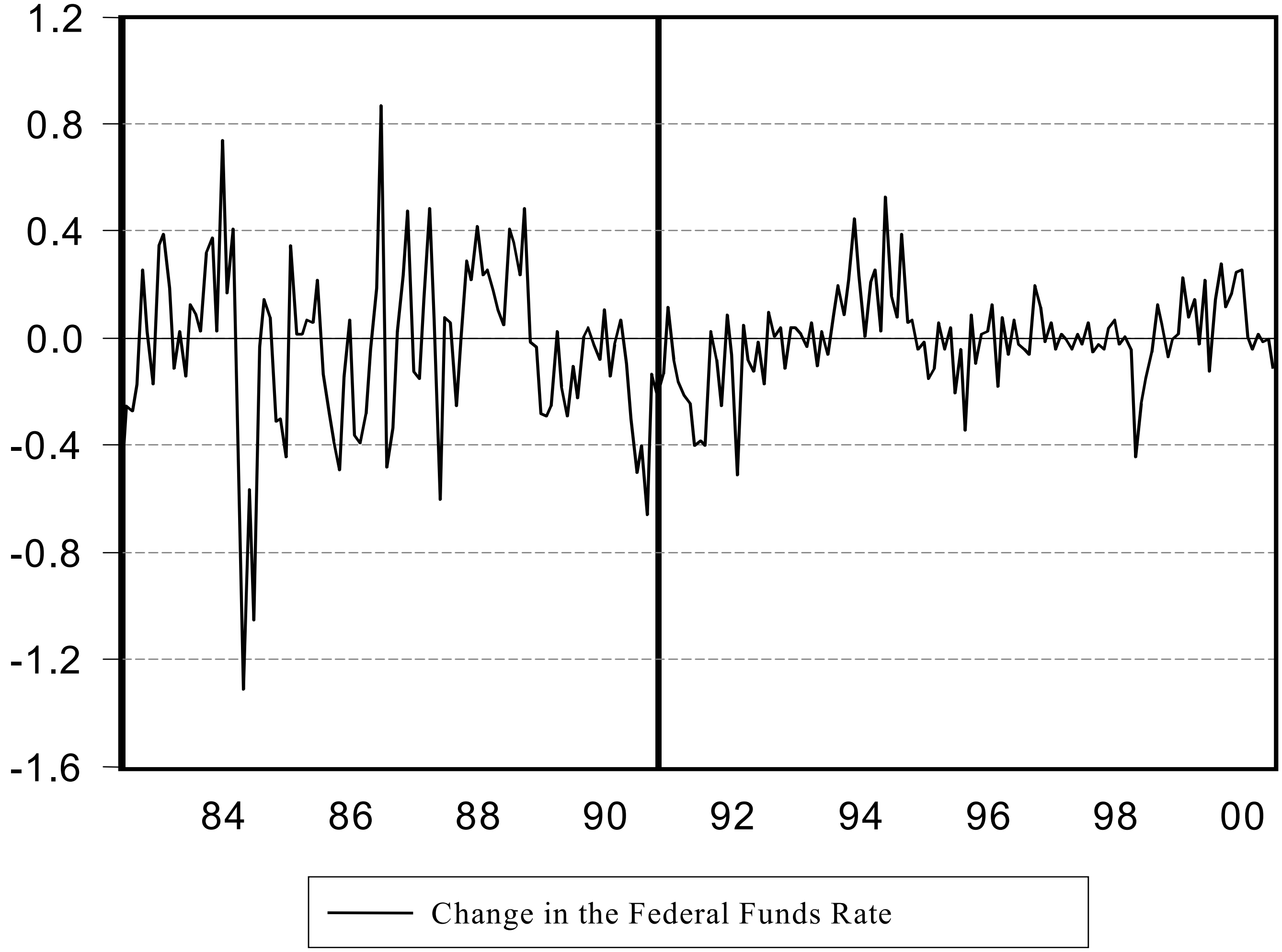


Figure 2: Smoothed Probability of a Static Desired Rate

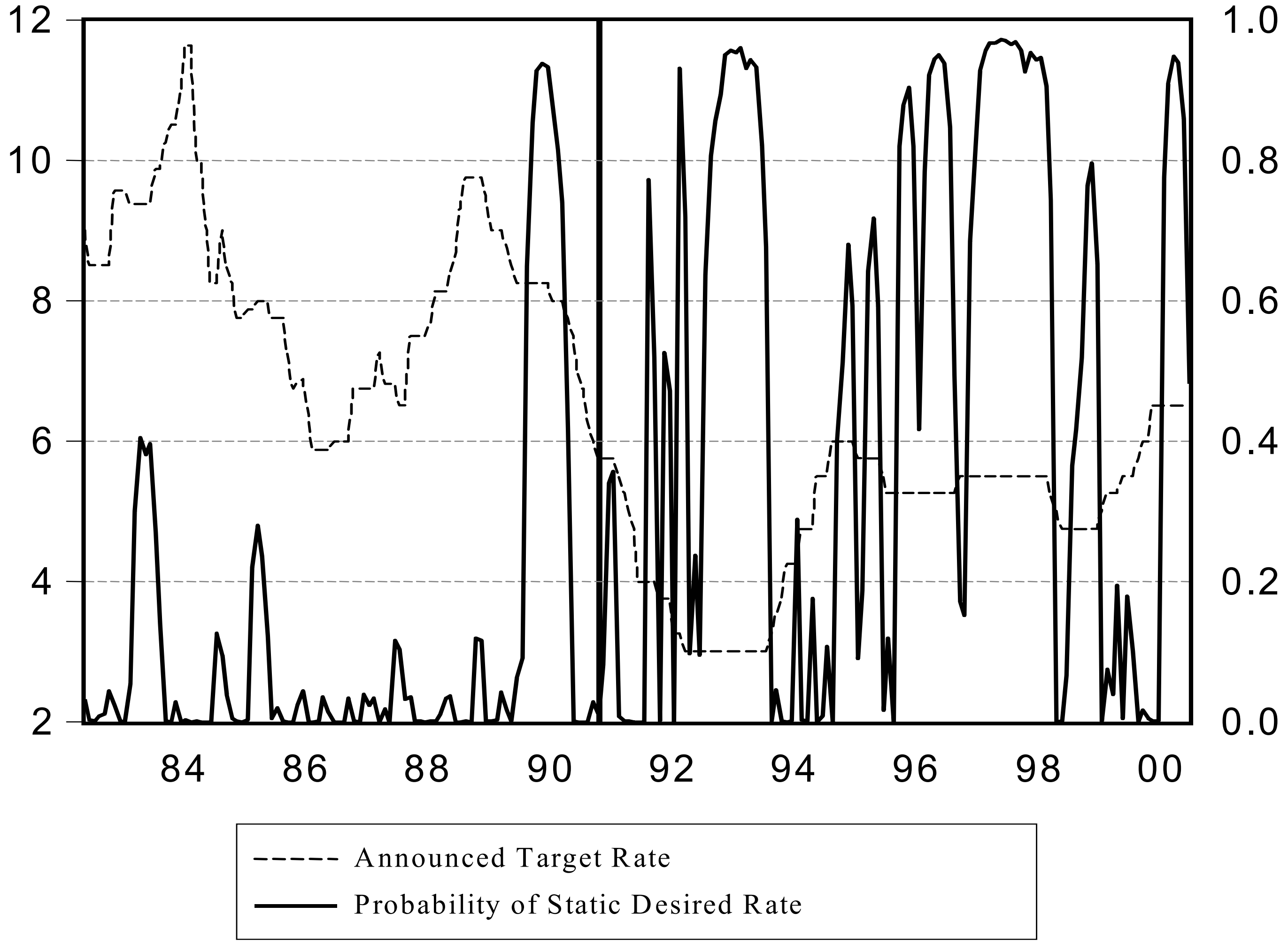
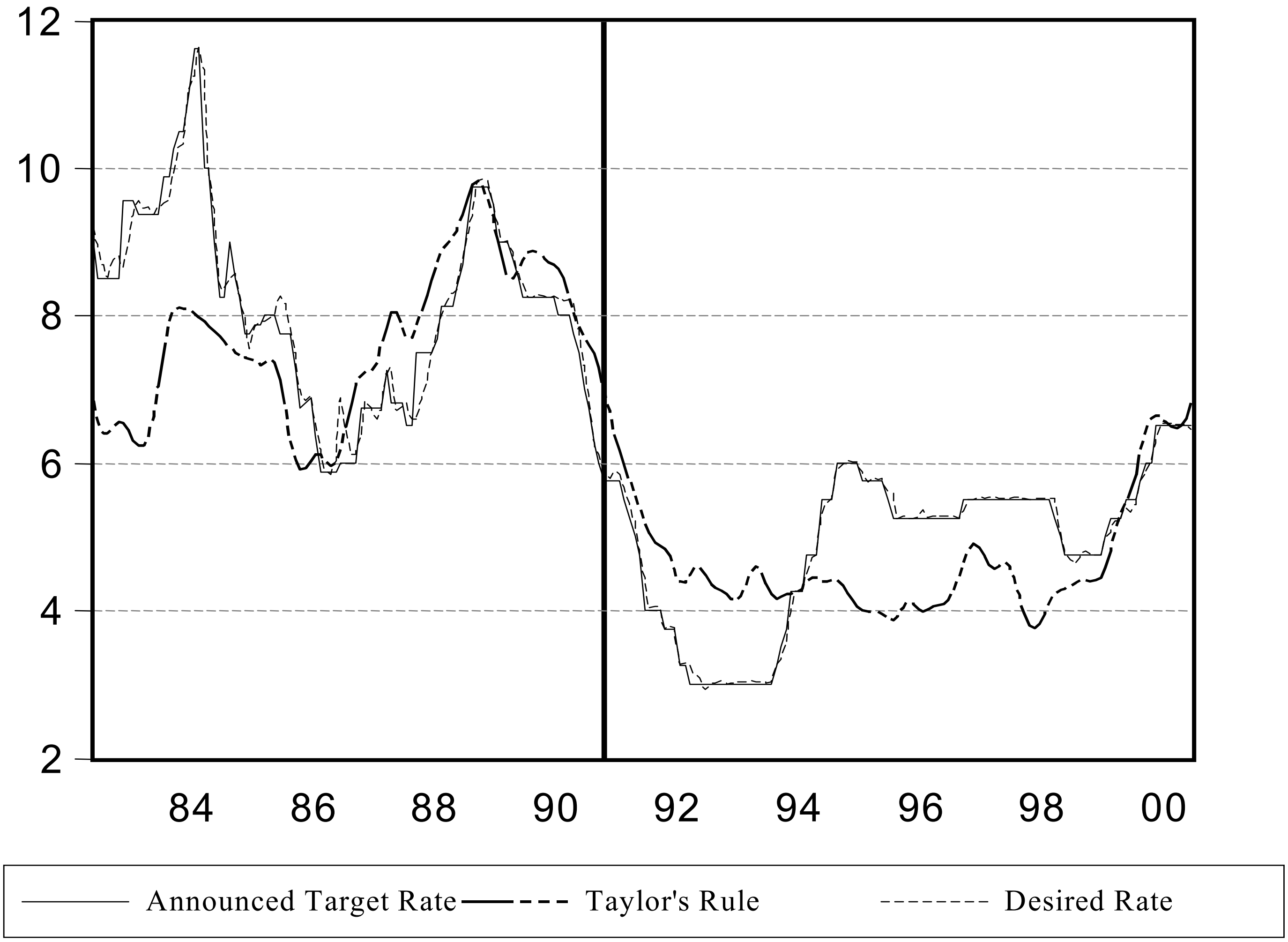


Figure 3: Announced Target Rate, Taylor's Rule and the Desired Rate



Appendix:

Derivations for Table 5

$$i_t = i_t^* + \varepsilon_t \qquad \text{(A1)}$$

Or, $i_t - i_{t-1} = i_t^* - i_{t-1}^* + \varepsilon_t - \varepsilon_{t-1}$

Therefore, since ε_t is serially uncorrelated and independent of i_t^*, we have

$$V(i_t - i_{t-1}) = V(i_t^* - i_{t-1}^*) + 2V(\varepsilon_t) \qquad \text{(A2)}$$

Let $\Pr$ be the steady-state probability of being in static regime $(i_t^* = i_{t-1}^*)$. Then

$$V(i_t - i_{t-1}) = \Pr * 0 + (1-\Pr) * V(u) + 2V(\varepsilon_t) = (1-\Pr)\sigma_u^2 + 2\sigma_\varepsilon^2 \qquad \text{(A3)}$$

So, comparing 1980s and 1990s:

$$\frac{V_{80s}(i_t - i_{t-1}) - V_{90s}(i_t - i_{t-1})}{V_{80s}(i_t - i_{t-1})} = \frac{(1-\Pr_{80s})\sigma_{u,80s}^2 - (1-\Pr_{90s})\sigma_{u,90s}^2 + 2(\sigma_{\varepsilon,80s}^2 - \sigma_{\varepsilon,90s}^2)}{V_{80s}(i_t - i_{t-1})}$$

Decomposing the desired rate section further:

$$\begin{aligned}
&(1-\Pr_{80s})\sigma_{u,80s}^2 - (1-\Pr_{90s})\sigma_{u,90s}^2 \\
&= (1-\Pr_{80s})\sigma_{u,80s}^2 - [(1-\Pr_{80s}) + (\Pr_{80s} - \Pr_{90s})][\sigma_{u,80s}^2 + (\sigma_{u,90s}^2 - \sigma_{u,80s}^2)] \\
&= (1-\Pr_{80s})(\sigma_{u,80s}^2 - \sigma_{u,90s}^2) - \sigma_{u,80s}^2(\Pr_{80s} - \Pr_{90s}) - (\sigma_{u,90s}^2 - \sigma_{u,80s}^2)(\Pr_{80s} - \Pr_{90s})
\end{aligned}$$

Further Appendix (Not for Publication):

Section A1: Diagnostic checks and other variables

The standardized forecast errors from Model 1 are serially uncorrelated (refer to Table A1-A). The estimates of ε_t from Model 1 are also serially uncorrelated as specified (refer to Table A1-B and Figure A1-B). To determine the lag structure of the serially correlated shock in Model 1, we tried AR (2) specification and ARMA (1,1) specification. The gains in log likelihood values over AR (1) specification were insignificant in both cases. Figure A1-A shows the estimates of u_t.

Table A1-A: The Autocorrelation Structure of the Standardized Forecast Errors

Lags	*Autocorrelation*	*Partial AC*	*Q - Statistics*	*P-Value*
1	0.002	0.002	0.0005	0.981
2	-0.008	-0.008	0.0135	0.993
3	-0.011	-0.011	0.0385	0.998
4	-0.077	-0.077	1.3672	0.850
5	0.093	0.093	3.3031	0.653
6	0.016	0.014	3.3612	0.762
7	-0.064	-0.065	4.2957	0.745
8	-0.028	-0.032	4.4754	0.812
9	0.024	0.040	4.6088	0.867
10	0.005	-0.003	4.6143	0.915
11	0.027	0.013	4.7803	0.941
12	0.011	0.019	4.8065	0.964

Table A1-B: The Autocorrelation Structure of the Estimated Noise Term

Lags	*Autocorrelation*	*Partial AC*	*Q - Statistics*	*P-Value*
1	0.007	0.007	0.0106	0.918
2	0.025	0.025	0.1543	0.926
3	-0.019	-0.019	0.2348	0.972
4	0.003	0.003	0.2368	0.994
5	-0.012	-0.011	0.2698	0.998
6	0.146	0.145	5.0665	0.535
7	-0.024	-0.026	5.1960	0.636
8	0.019	0.013	5.2823	0.727
9	-0.021	-0.016	5.3865	0.799
10	-0.032	-0.034	5.6212	0.846
11	-0.106	-0.103	8.2324	0.692
12	0.091	0.075	10.169	0.601

Figure A1-A: The Estimate of the Serially Correlated Shock to the Desired Rate

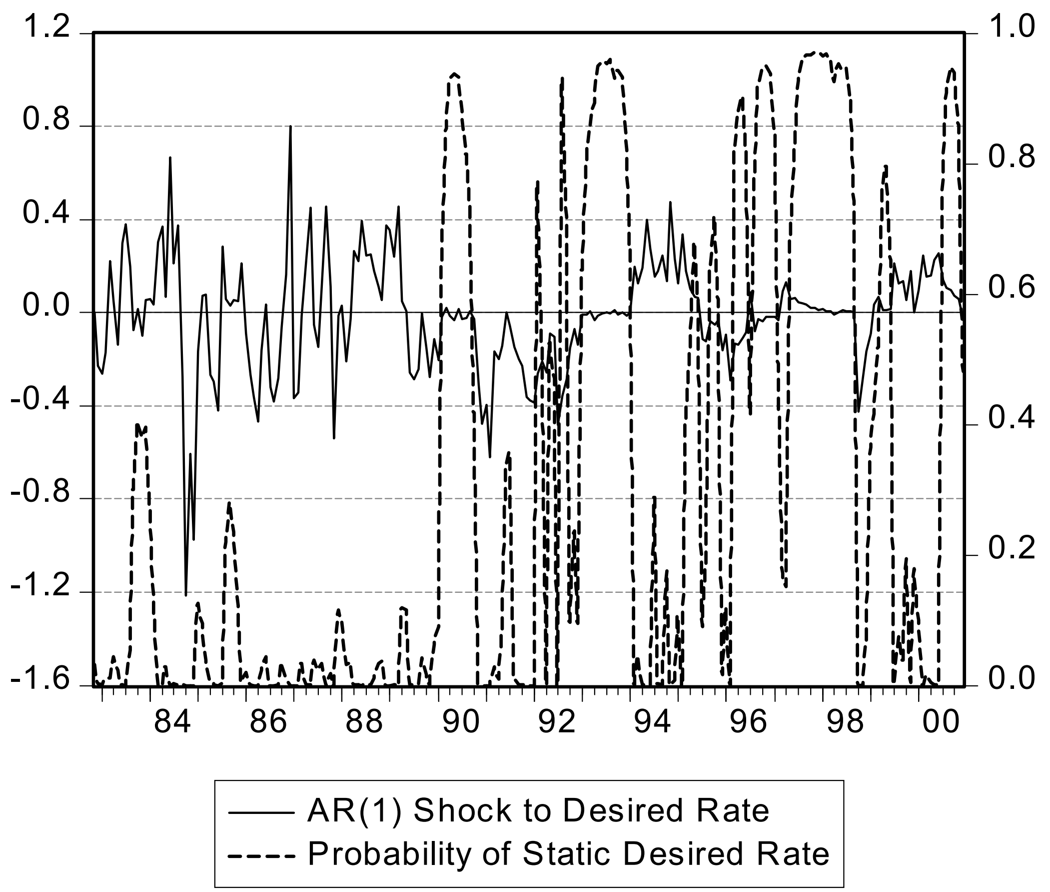
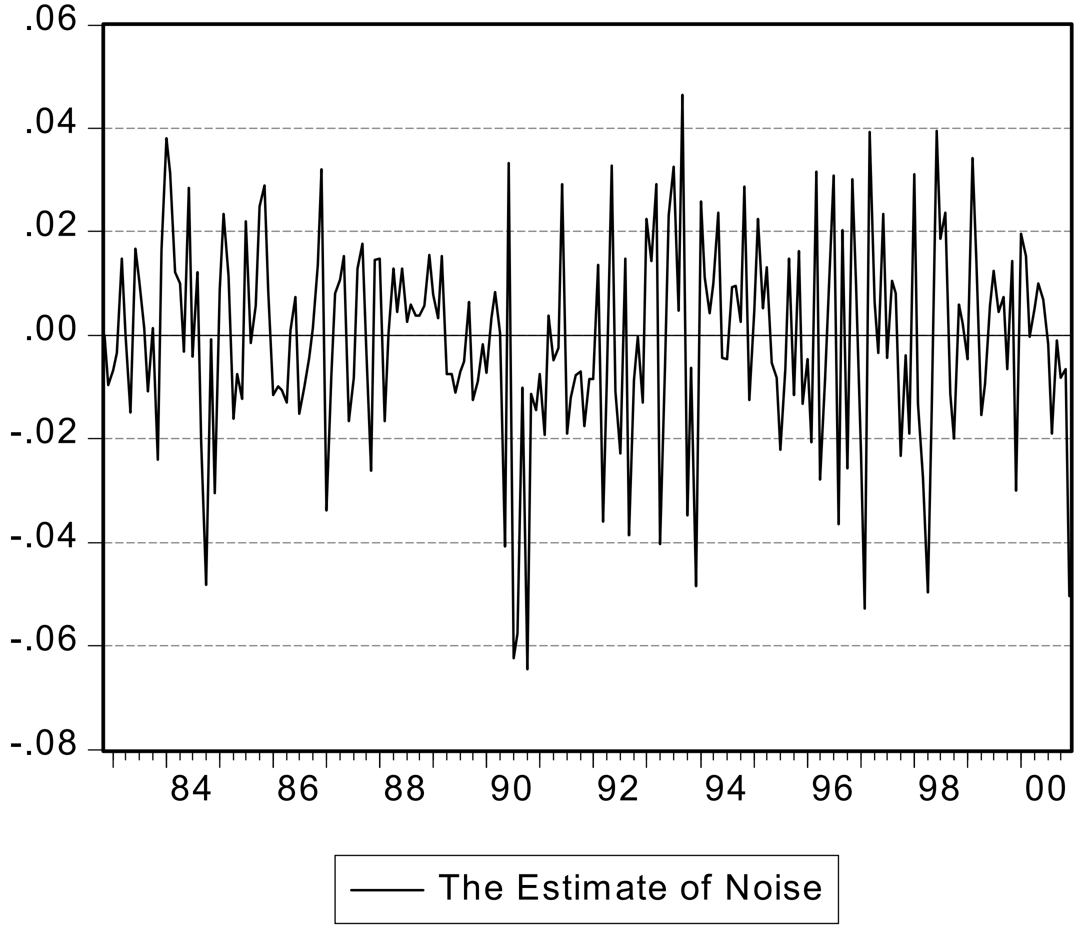


Figure A1-B: The Estimate of the Serially Uncorrelated Noise Term



Section A2: Estimates of Model 2

In Table A2-A, we present the estimation results of Model 2 with a different measure of inflation. The inflation rate is calculated from the interpolated GDP deflator, as used in computing Taylor's rule. The estimates and the results are essentially same as that of Table 6.

Table A2-A: Estimation Results for the Model with 4 Fundamental Pressures

Parameters	***"1980s"***	***"1990s"***	*Wald Test*
p	0.734	0.792	$H_0[\Pr ob(S_t = 0 \mid t \le 1991:03)$
	(0.22)	(0.08)	$= \Pr ob(S_t = 0 \mid t \ge 1991:04)]$
q	0.972	0.835	**W = 6.12**
	(0.04)	(0.07)	
β_π	0.309	1.363	
	(0.45)	(0.37)	*Wald Test*
β_{π^e}	0.637	1.562	$H_0[\beta_{\pi,1980s} = \beta_{\pi,1990s}; \beta_{\pi^e,1980s} = \beta_{\pi^e,1990s};$
	(0.34)	(0.50)	$\beta_{x,1980s} = \beta_{x,1990s}; \beta_{R,1980s} = \beta_{R,1990s}]$
β_x	0.035	0.110	**W = 14.03**
	(0.07)	(0.05)	
β_R	-0.081	0.247	*Wald Test*
	(0.12)	(0.08)	$H_0[\beta_{\pi^e,1980s} = \beta_{\pi^e,1990s}; \beta_{R,1980s} = \beta_{R,1990s}]$
ϕ	0.348	0.730	**W = 8.07**
	(0.13)	(0.20)	
σ_ε	0.060	0.045	
	(0.03)	(0.01)	*Wald Test*
σ_v	0.290	0.089	$H_0[\beta_{\pi,1980s} = \beta_{\pi,1990s}; \beta_{x,1980s} = \beta_{x,1990s}]$
	(0.03)	(0.03)	**W = 4.52**
Log L	**270.873**		

Note: Standard errors are in parentheses and are computed using the delta method.