Monetary Policy Rules and Macroeconomic Stability

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Abstract

This paper attempts to characterize the monetary policy regimes in the United States and analyze their effects on macroeconomic stability. It does so by estimating Taylor-type forward-looking monetary policy reaction functions for the pre- and post-1979 periods, and simulating the resultant coefficients in a basic New Keynesian business cycle model. The feedback coefficient on inflation in the estimated policy reaction function is found to be less than unity for the 1960-1979 period, suggesting an accommodative monetary policy stance of the Federal Reserve. However, for the 1979-2017 period, the feedback coefficient on inflation is estimated to be substantially greater than unity, implying that the Federal Reserve adopted a proactive policy stance towards controlling inflation. It is also found that in recent times, the Federal reserve has shifted its focus from short one period ahead inflation targets to longer target horizons such as one year ahead inflation targets. Meanwhile, the model simulations show that the economy exhibits greater stability under a model with post-1979 calibration than a model with a combination of pre-1979 parameters and 'sunspot' shocks.

1 Introduction

Monetary policy plays an important role in stabilizing inflation and business cycle fluctuations, and its effectiveness of doing so has been extensively studied both theoretically and empirically under numerous approaches. However, with the emergence of new challenges in the global economic landscape, discussions centered around the role of monetary policy and its effectiveness continue to resurface.

The seminal work by Clarida, Galí, and Gertler (2000) analyzed the role played by the US monetary policy in achieving macroeconomic stability after the 'great inflation' of the 1970s and ignited many discussions around this topic. Clarida et al. (2000) demonstrate the Federal Reserve's policy change from a 'passive' to an 'active' response by estimating a monetary policy rule of the sort proposed by Taylor (1993) during two subperiods, before and after Paul Volcker's appointment as the Chairman of the Federal Reserve, and combining the estimated rule with a basic New Keynesian model to analyze determinacy. Moreover, they show that the estimated policy rule for the pre-Volcker period results in greater macroeconomic instability leading to self-fulfilling changes in expectations. Lubik and Schorfheide (2004) also show the validity of this argument by estimating a New Keynesian model jointly with a Taylor-type rule during two subperiods, before 1979 and after 1982, using a Bayesian approach that allows for indeterminacy and sunspot fluctuations. While studies of the sort Clarida et al. (2000) emphasize the role played by improved monetary policy in great moderation, certain other studies (e.g. Sims and Zha (2006) and Justiniano and Primiceri (2008)) emphasize a decline in the volatility of shocks to the US economy during the great moderation period.

The objective of this paper is to reproduce the main results of Clarida et al. (2000), and extend the analysis up to the post great recession era. Clarida et al. (2000)'s study is performed employing quarterly time series data spanning the time period 1960-1996. Considering the challenging macroeconomic environment existed in the last two decades, it would be an interesting exercise to assess the responsiveness of monetary policy to inflation expectations and other macroeconomic variables in the post-1996 period. Moreover, since 1996, the US economy was faced with two major recessions. Following the burst of the 'dot-com' bubble, the economy experienced a recession in the early 2000s. Subsequent to this, interest rates in the US were held stable at low levels during the 2003-2005 period, where Taylor (2007) argues that the Federal Funds rates was "too low for too long" during this period, departing from the more systematic policies followed in the 1980s and 1990s. Then comes the great recession era where the Federal Reserve even had to resort to unconventional monetary policy tools as the Federal Funds rate approached the zero lower bound. The exit from the zero interest rate environment also became not only a big issue within macroeconomic theory but also an actual problem that the policy makers at the Federal Reserve faced.

The first part of the paper analyzes the change in monetary policy conduct of the Federal Reserve by estimating Taylor-type forward-looking monetary policy reaction functions for the pre- and post-1979 eras. According to the estimates for the 1960-1979 period (pre-Volcker era), the feedback coefficient on inflation in the policy reaction function is found to be less than unity, confirming the results of Clarida et al. (2000) for the pre-Volcker era. This suggests that the Federal Reserve, during the pre-Volcker era, has taken an accommodative monetary policy stance leaving real interest rates to decline in response to rising inflation expectations. However, estimates for the 1979-2017 period (post-Miller era) results in a feedback coefficient on inflation which is substantially greater than unity. This suggests that during the 1979-2017 period as a whole, the Federal Reserve adopted a proactive policy stance towards controlling inflation by systematically raising both nominal and real interest rates in response to increased inflation expectations. Hence, Clarida et al. (2000)'s claim that the feedback coefficient on inflation in the policy function shifted from a value less than unity in the 1960-1979 period to a value sufficiently greater than unity in the 1979-1996 period holds true even if the latter subperiod is extended to 2017 (i.e. 1979-2017).

When the time horizon from 1979 to 2017 is divided into two subsamples, pre-2000 and 2000 onward, it is found that the coefficient on inflation in the policy function is statistically not different from zero during the 2000-2017 period, if a one quarter ahead target horizon for inflation is considered (the baseline target horizon). However, when the target horizon for inflation is increased from one quarter to four quarters, the coefficient becomes statistically significant with a value greater than unity. This implies that if a one year target horizon for inflation is considered, the Federal Reserve has pursued an 'active' monetary policy during the 2000-2017 period. This tend to imply that in the era from 2000 onward, the Federal Reserve has shifted its focus from immediate inflation targets to longer horizon inflation targets.

The second part of the paper presents a theoretical model in the lines of Clarida et al. (2000) to analyze the effects of observed changes in the policy rule on macroeconomic performance. The estimated policy functions are embedded into a basic New Keynesian business cycle model to analyze the resulting equilibrium outcome and the dynamics of main macroeconomic variables. The model simulations show that the economy exhibits greater stability under a model with post-1979 calibration than a model with a combination of pre-1979 parameters and 'sunspot' shocks.

The rest of the paper is structured as follows. Section II presents the forward looking monetary policy rule considered for the analysis, and Section III discusses the estimation methodology and the type of data used. Section IV provides the estimation results for the the pre- and post-1979 eras with a special emphasis on the 2000s. Further, a number of robustness checks are also reported. Under section V, the main features of the policy reaction function derived for pre- and post-1979 eras are tested with the context of a basic New Keynesian macroeconomic model. Concluding remarks are presented in section VI.

2 A Forward-Looking model of the Federal Reserve's Policy Reaction Function

A simple forward-looking rule is used as the baseline specification of the monetary policy reaction function, following Clarida et al. (2000). Accordingly, the following linear relation is considered:

$$r_t^* = r^* + \beta(\mathbb{E}[\pi_{t,k} \mid \Omega_t] - \pi^*) + \gamma \mathbb{E}[x_{t,q} \mid \Omega_t] \tag{1}$$

where r_t^* denotes the target rate for the Federal Funds rate in nominal terms in period t. $\pi_{t,k}$ denotes the annualized percentage change in the price level from period t to $t+k$, while $x_{t,q}$ denotes the average output gap between period t and $t+q$ with the output gap defined as the deviation of actual output from its potential level, expressed as a percentage of the potential output. π^* is the targeted level of inflation, and r^* is the desired level of nominal interest rate when both inflation and output are at the targeted levels. The expectation operator is denoted by $\mathbb{E}$. The information set at the time the Federal Reserve sets the interest rate is given by Ω_t.

The monetary policy reaction function given by equation (1) is in line with both theoretical literature and empirical work in this area. The proposed policy function is optimum for a central bank that tries to minimize a quadratic loss function in deviation of inflation and output from their targeted levels, under certain assumptions (Svensson, 1999; Clarida, Galí, & Gertler, 1999). With regards to empirical work, a number of authors (e.g., Taylor, 1993, 1999) emphasized that approximate forms of equation (1) characterize the decision making process of major central banks around the world. Taylor (1993) is a notable paper in this regard which ignited many discussions on simple interest rate rules. However, according to the original rule proposed by Taylor (1993), the Federal Funds rate responds to lagged inflation and output, whereas the policy function specified in (1) provides a forward-looking rule. Clarida et al. (2000) argue that a policy function of the form given by equation (1) nets Taylor rule as a special case. If either lagged inflation or a linear combination of lagged inflation and output gap is a sufficient statistic for forecasting future inflation, then equation (1) collapses to rule specified in Taylor (1993).

The sign and magnitude of the slope coefficients β and γ characterize the response of the Federal Reserve to cyclical behavior of the economy. Rewriting equation (1) in terms of real interest rates helps determine the possible range of values that the slope coefficients should take for the policy rule under consideration to be stabilizing. As such, the forward-looking rule policy rule can be re-specified as:

$$rr_t^* = rr^* + (\beta - 1)(\mathbb{E}[\pi_{t,k} \mid \Omega_t] - \pi^*) + \gamma \mathbb{E}[x_{t,q} \mid \Omega_t] \tag{2}$$

where $rr_t^* = r_t^* - \mathbb{E}[\pi_{t,k} \mid \Omega_t]$ is the real interest rate, and $rr^* = r^* - \pi^*$ is the long run equilibrium real rate. According to standard macroeconomic theory, lower real interest rates stimulate economic activity and causes price levels to increase. Therefore, a policy rule like (2) will tend to be stabilizing if $\beta > 1$ and destabilizing otherwise. On a similar note, $\gamma > 0$ will be stabilizing.

In practice, the Federal Reserve tend to change interest rates gradually due to various reasons. Moreover, according to Rudebusch (1995), targets for the Federal Funds rate are adjusted in limited amounts at a restrained, deliberate pace. Therefore, the policy rule given by equation (1) is too restrictive to describe the observed changes in the Federal Funds rate since it assumes an immediate adjustment to achieve the target level of Federal Funds rate. In order to overcome this issue, an interest rate smoothing behavior is introduced where the actual Federal Funds rate, r_t is given by:

$$r_t = (1 - \rho) r_t^* + \rho(L) r_{t-1} \tag{3}$$

Equation (3) specifies a general form for interest rate smoothing considering n lags of the Federal Funds rate, where $\rho(L) = \rho_1 + \rho_2 L + ... + \rho_n L^{n-1}$ and $\rho \equiv \rho(1)$. ρ can be interpreted as an indicator of the degree of smoothing in interest rate changes.

Combining equation (1) with (3), and judiciously adding and subtracting $\pi_{t,k}$ and $x_{t,q}$ terms yield the following form of the policy reaction function.

$$\begin{aligned} r_t = {} & (1 - \rho)[rr^* - (\beta - 1)\pi^* + \beta \pi_{t,k} + \gamma x_{t,q}] + \rho(L) r_{t-1} \\ & + (1 - \rho)\{\beta(\mathbb{E}[\pi_{t,k} \mid \Omega_t] - \pi_{t,k}) + \gamma(\mathbb{E}[x_{t,q} \mid \Omega_t] - x_{t,q})\} \end{aligned} \tag{4}$$

However, it is noteworthy that a linear combination of forecast errors is orthogonal to the variables in the information set Ω_t. Therefore, equation (4) can be simplified as follows:

$$r_t = (1-\rho)[rr^* - (\beta-1)\pi^* + \beta\pi_{t,k} + \gamma x_{t,q}] + \rho(L)r_{t-1} + \epsilon_t \tag{5}$$

where the error term, ϵ_t, denotes the term $(1-\rho)\{\beta(\mathbb{E}[\pi_{t,k} \mid \Omega_t] - \pi_{t,k}) + \gamma(\mathbb{E}[x_{t,q} \mid \Omega_t] - x_{t,q})\}$ which encompasses the forecast errors.

3 Estimation Methodology and Data

Equation (5) coupled with the associated orthogonality conditions provide the basis for the estimation of parameters of interest using the Generalized Methods of Moments (GMM) technique. The GMM approach identifies the key parameters of interest, β, γ and ρ. Further, it identifies the term $rr^* - (\beta-1)\pi^*$ as a whole, but does not identify rr^* and π^* separately unless additional restrictions are imposed[1]. Quarterly data covering the time span 1960:Q1 to 2017Q4 are used for the analysis. Clarida et al. (2000) depend on data obtained from a database named CITIBASE for their study. However, given the fact that CITIBASE is discontinued, economic data available through the FRED database of the Federal Reserve Bank of St. Louis are used.

This study treats the Federal Funds rate as the instrument of monetary policy. As such, the average Federal Funds rate in the first month of each quarter is used as the measure of interest rate, r_t. Except for the brief period of reserves targeting at the beginning of the Volcker's era, the Federal Funds rate is a reasonable choice to reflect the US monetary policy operations (Bernanke & Mihov, 1998). However, the zero lower bound episode with the onset of the great recession could be of concern since the operations of the Federal Reserve were supposed to be constrained with limited policy options. In order to overcome this issue, the shadow Federal Funds rate derived by Wu and Xia (2016) is used as an alternative measure of the Federal Funds rate for the zero lower bound period. Figure 1 depicts the movements in the Federal Funds rate over time along with the shadow rate for the zero lower bound period.

Annualized quarter-on-quarter change of GDP deflator is used as the measure of inflation, $\pi_{t,k}$. In order to check for robustness, the estimates are also reported using inflation as measured by the Consumer Price Index for All Urban Consumers. Estimates by the Congressional Budget Office (CBO) are used as the measure of output gap, $x_{t,q}$. Robustness is checked using two alternative measures of the output gap. The alternative measures of the output gap are constructed using a HodrickPrescott (HP) filter based detrended series of the real GDP and the unemployment rate[2]. Meanwhile, lags of the Federal Funds rate, inflation

[1] Clarida et al. (2000) take the observed sample average as a measure of the equilibrium real rate, rr^*, and identify π^* along with other parameters. However, under this approach, one would be indirectly considering the observed sample averages of the Federal Funds rate and inflation (since $rr^* = r^* - \pi^*$), thereby already assuming a value for π^* which is yet to be estimated.

[2] Sign of the unemployment gap measure is inverted to make the interpretation of coefficients in line with the other output gap measures.

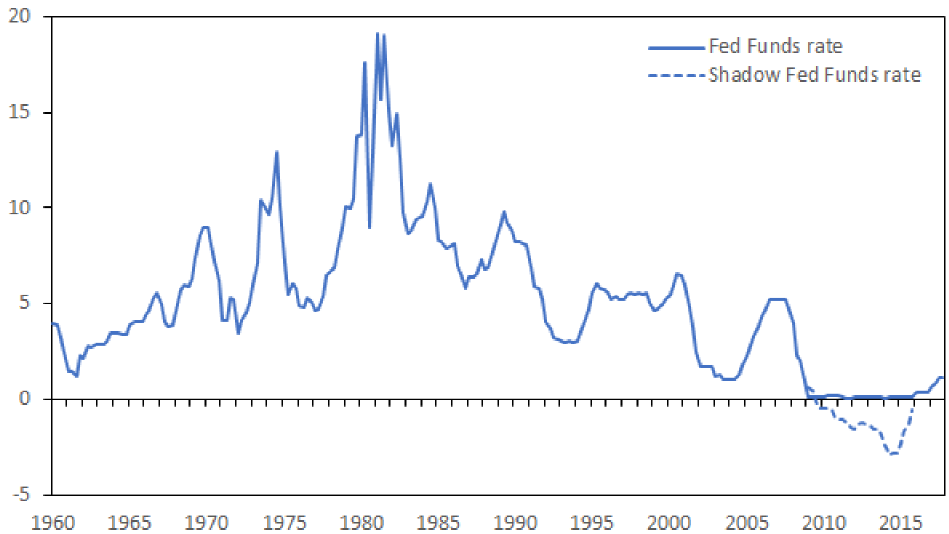

Figure 1: Movements in the Fed Funds rate over time and the shadow rate

and output gap are used as instruments. In addition, the set of instruments includes lags of inflation based on the Producer Price Index for All Commodities, and the spread between the 10-year government bond yield and the three month Treasury bill rate.

4 Estimates of the Federal Reserve's Policy Reaction Function

4.1 Baseline Estimates

The entire sample is divided into two main subperiods, the pre-Volcker era and the remainder. The pre-Volcker era under analysis spans from 1960:Q1 to 1979:Q2, covering the tenures of William Martin, Arthur Burns and William Miller as Federal Reserve chairmen. The post-Miller era runs from 1979:Q3 to 2017Q4 covering the tenures of Paul Volcker, Alan Greenspan, Ben Bernanke and Janet Yellen. This separation is done following Clarida et al. (2000), considering the relatively unstable and stable eras in macroeconomic history.

The target horizon for both inflation and the output gap is assumed to be one quarter (i.e., $k = q = 1$) for the baseline specification. Further, estimates are based on two lags of the interest rate. This means $\rho(L)$ in equation (3) can be specified as $\rho(L) = \rho_1 + \rho_2 L$. Clarida et al. (2000) argue that two lags are sufficient to eliminate any serial correlation associated in the error term. Accordingly, the following form of equation (5) is used for the baseline estimation:

$$r_t = (1 - \rho_1 - \rho_2)[const. + \beta\pi_{t,1} + \gamma x_{t,1}] + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \epsilon_t \quad (6)$$

Parameters for the two subsamples are estimated using GMM, where the set of instrument variables includes four lags of the Federal Funds rate, inflation, output gap, short-long interest spread and producer price inflation.

Table 1: Baseline Estimates

	const	β	γ	ρ_1	ρ_2	p
Pre-Volcker	1.39***	0.85***	0.31***	0.94***	-0.27***	0.865
	(0.37)	(0.05)	(0.09)	(0.08)	(0.06)	
Post-Miller	0.74	2.27***	1.28***	0.57***	0.26***	0.649
	(0.93)	(0.23)	(0.23)	(0.06)	(0.05)	
Post-1982	-0.26	2.73*	0.92***	1.33***	-0.37***	0.639
	(3.24)	(1.35)	(0.27)	(0.07)	(0.06)	

Notes: ***, * - significant at 1 and 5 percent levels, respectively. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

Table 1 summarizes GMM estimates for the parameters in the policy reaction function for the subperiods under consideration. The p-value associated with Hansen's J-test is above the conventional significance levels for all estimates. This means that the overidentifying restrictions are valid and the models under review are not rejected. The estimates for β and γ are significant and having the expected sign. However, the magnitudes are notably different across the periods. The coefficient associated with inflation, β, is smaller than one for the pre-Volcker era, whereas in the post-Miller period, β is considerably greater than one. Furthermore, γ takes a higher value for the post-Miller period indicating that the Federal Reserve's sensitivity to the deviation of output to its potential increased in the post 1979 era. Meanwhile, parameter values for ρ are large and significant, indicating a high degree of interest rate smoothing. Only around 15 to 30 percent of the change in the interest rate target is reflected in the actual Federal Funds rate.

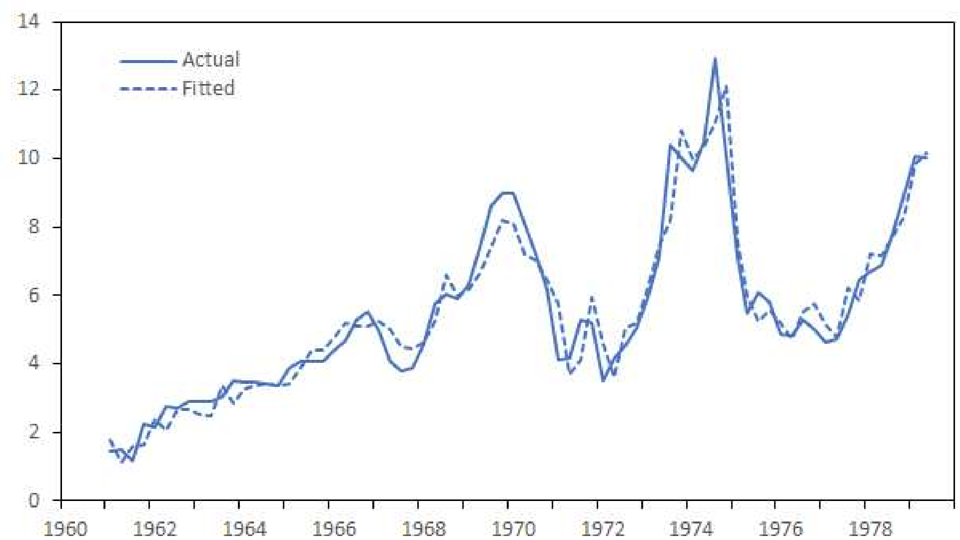

Figure 2: Actual versus fitted Fed Funds rate - Pre-Volcker era

Figures 2 and 3 denote the actual and fitted values of the Federal Funds rate in each subperiod under analysis. The fitted values estimated by the baseline specification of the model appears to track the actual Federal Funds rate reasonably well[3]. Moreover, the estimated interest rate captures the ups and downs in actual interest rate with a minimum variation, even in periods where a high degree of interest rate volatility is observed.

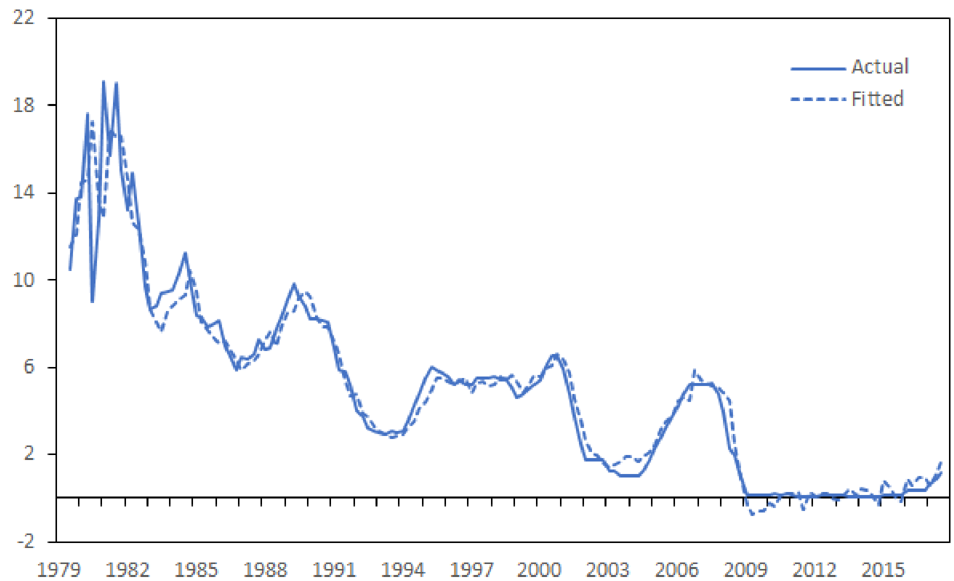

Figure 3: Actual versus fitted Fed Funds rate - Post-Miller era

4.2 Robustness Analysis

The robustness of the results obtained in the baseline model is checked through several approaches. The first approach considers alternative measures of inflation and the output gap, as well as a shadow Federal Funds rate for the zero lower bound period. Under the second approach, the model is estimated using alternative target horizons for inflation and the output gap. A third approach involves estimating backward-looking specifications for the two subperiods.

Table 2 reports GMM estimates for the policy reaction function for the two main subperiods under alternative measures. The policy function is re-estimated using an alternative measure of inflation, where the GDP deflator based inflation is replaced by the Consumer Price Index based inflation, and the results are presented is the first section of Table 2. The estimated coefficients, β and γ are significant and have the expected sign. More importantly, the coefficient β continues to be less than one for the pre-Volcker period, and greater than one for the post-Miller period though the value is less compared to the GDP deflator based specification. Furthermore, the policy function is re-estimated using alternative measures

[3]The estimated Federal Funds rate in this paper tracks the actual rate more closely than in Figures I and II of Clarida et al. (2000, p. 158-159)

Table 2: Estimates for Alternative Measures

	const	β	γ	ρ_1	ρ_2	p
CPI						
Pre-Volcker	1.74***	0.76***	0.41***	0.84***	-0.15**	0.744
	(0.38)	(0.06)	(0.12)	(0.08)	(0.06)	
Post-Miller	1.90	1.57***	1.34***	0.63***	0.25***	0.615
	(1.17)	(0.24)	(0.32)	(0.05)	(0.05)	
Detrended output						
Pre-Volcker	1.96***	0.75***	0.68***	0.90***	-0.21***	0.745
	(0.40)	(0.06)	(0.21)	(0.07)	(0.06)	
Post-Miller	-2.03*	2.44***	2.23***	0.61***	0.27***	0.399
	(0.95)	(0.28)	(0.54)	(0.06)	(0.05)	
Unemployment rate						
Pre-Volcker	2.03***	0.75***	1.60***	0.78***	-0.14	0.751
	(0.28)	(0.04)	(0.41)	(0.09)	(0.08)	
Post-Miller	-1.07	2.10***	3.22***	0.63***	0.24***	0.445
	(0.96)	(0.25)	(0.73)	(0.05)	(0.04)	
Shadow Fed Funds rate						
Post-Miller	1.04	2.37***	1.66***	0.62***	0.25***	0.792
	(1.05)	(0.26)	(0.35)	(0.05)	(0.04)	

Notes: ***, **, * - significant at 1, 2 and 5 percent levels, respectively. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

of the output gap, where the first measure is an output gap constructed using an HP filter based detrended series of the real GDP and the second measure is an unemployment gap constructed using a similarly detrended series of the unemployment rate, with the sign of the resultant series switched. The second section of Table 2 presents results for the HP filter based output gap, while the third section presents results for the unemployment rate based output gap. Again, the estimated coefficients for β and γ have the expected sign and the magnitude of β change from less than unity to greater than unity from the first subperiod to the second. Meanwhile, alternative measures of output gap show that the Federal Reserve's sensitivity to the deviation of unemployment rate from its detrended series is greater than its sensitivity to the deviation of GDP from its trend. The policy function is also re-estimated using the shadow Federal Funds rate derived by Wu and Xia (2016) for the zero lower bound period[4] and the results are given in the last section of Table 2. This is done to assess whether the policy reaction function for the post-Miller era change materially if one account for the constraints faced by the Federal Reserve with regard to monetary policy implementation

[4]According to Wu and Xia (2016), the shadow interest rate becomes applicable when the actual Fed Funds rate falls below 0.25 percent. As such, the actual Fed Funds rate during 2009:Q1 to 2015:Q4 is replaced with the shadow rate computed by Wu and Xia (2016)

Table 3: Estimates for Alternative Time Horizons

	const	β	γ	ρ_1	ρ_2	p
$k=4$, $q=1$						
Pre-Volcker	1.42**	0.84***	0.43***	1.01***	-0.25***	0.744
	(0.58)	(0.09)	(0.14)	(0.08)	(0.05)	
Post-Miller	-0.25	2.62***	1.26 ***	0.56***	0.28***	0.770
	(1.01)	(0.25)	(0.21)	(0.05)	(0.05)	
$k=4$, $q=2$						
Pre-Volcker	1.24*	0.86***	0.45***	1.01***	-0.25***	0.757
	(0.62)	(0.10)	(0.16)	(0.08)	(0.05)	
Post-Miller	-0.26	2.67***	1.31***	0.57***	0.27***	0.819
	(1.00)	(0.25)	(0.22)	(0.05)	(0.04)	

Notes: ***, **, * - significant at 1, 2 and 5 percent levels, respectively. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

during the post-great recession period. The main results continue to hold the same with the coefficient β remaining considerably greater than one during the post-Miller period.

The second approach for robustness testing is to consider alternative target horizons. The baseline specification assumes that the Federal Reserve considers one period ahead inflation and the output gap (i.e., $k = q = 1$) when setting its policy interest rate. Under robustness testing, two alternative target horizons are assumed. The first assumes that the Federal Reserve considers a target horizon of one year for inflation and one quarter for the output (i.e., k=4, q=1), while the second specification considers the same one year target horizon for inflation, but two quarters for the output (i.e., k=4, q=2). Clarida et al. (2000) argue that the alternative target horizons are approximately in line with the conventional wisdom regarding monetary policy transmission lags and consistent with informal discussions of Federal Reserve's policy tactics. The estimation results for the two alternative time horizons are presented in Table 3, and in both cases the results are roughly similar to those of the baseline specification.

The final approach for robustness analysis is to estimate a backward-looking specification of the policy reaction function for the two subperiods along the lines of Taylor (1993). Accordingly, the general form of the policy reaction function as given by equation (5) is considered with a one period lag of inflation and the output gap (i.e., k=-1, q=-1). The estimates of the backward looking specification are reported in Table 4. The results are similar to the baseline forward-looking specification in terms of the main qualitative features. Hence, although a forward-looking policy reaction function is the preferred specification, the change in the conduct of monetary policy from 1979:Q3 onward is apparent in a backward-looking policy function as well.

Table 4: Backward-Looking Estimates

	const	β	γ	ρ_1	ρ_2	p
Pre-Volcker	2.58***	0.63***	0.52***	1.04***	-0.33***	0.792
	(0.33)	(0.07)	(0.13)	(0.07)	(0.05)	
Post-Miller	1.95	1.67***	1.16***	0.66***	0.22***	0.759
	(1.10)	(0.29)	(0.25)	(0.06)	(0.06)	

Notes: *** - significant at 1 percent level. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

4.3 Estimates for 2000 onward

The estimates so far confirm the results of Clarida et al. (2000) for the pre-Volcker era. Further, they show that the policy function estimated by Clarida et al. (2000) for the 1979:Q3-1996:Q4 period, when re-estimated incorporating post 1996 data till 2017 results in similar characteristics or qualitative features. This means that Clarida et al. (2000)'s claim that the feedback coefficient on inflation in the policy function, β, shifted from a value less than unity in the pre-Volcker era to a value sufficiently greater than unity in the 1979:Q3-1996:Q4 period holds true even if the latter subperiod is extended as 1979:Q3-2017:Q4.

The period from 1979 to 2017, however, encompasses several economic events, specially in the post-Clarida et al. (2000) time period. The US economy experienced a recession in the early 2000s following the 'dot-com crash'. Subsequent to this, interest rates in the US were held low and stable particularly during the 2003-2005 period. Some argue that the Federal Reserve held interest rates "too low for too long" during this period, departing from the more systematic policies it followed in the 1980s and 1990s (e.g. Taylor (2007)). Then comes the great recession where the Federal Reserve even had to resort to unconventional monetary policy tools as the Federal Funds rate approached the zero lower bound. Given this context, it would be an interesting exercise to see whether the results obtained for the broader period 1979:Q3-2017:Q4 hold true if one considers the time span from 2000 onward.

In order to assess whether the results obtained for the broader time span 1979:Q3-2017:Q4 hold true for 2000s, a subsample analysis is carried out. Accordingly, the dataset is divided into two subperiods, 1979:Q3-1999:Q4 and 2000:Q1-2017:Q4, and the same GMM estimates are carried out. The results are reported in Table 5. The first part of the table presents estimates for the entire post-Miller era as well as for the individual subperiods. The qualitative features of the policy function estimated for 1979-1999 is largely inline with the estimates of Clarida et al. (2000) for the 1979-1996 period. However, in the policy function estimated for 2000-2017, the feedback coefficient β is not statistically different from zero. This is somewhat surprising as the estimate for β in the post-Miller era as a whole (1979-2017) is greater than unity with a relatively high precision. In order to verify this, the policy

Table 5: Subsample Analysis for the post-Miller era

	const	β	γ	ρ_1	ρ_2	p
Post-Miller	0.74	2.27***	1.28***	0.57***	0.26***	0.649
	(0.93)	(0.23)	(0.23)	(0.06)	(0.05)	
1979-1999	2.72***	1.65***	0.61*	0.48***	0.22***	0.854
	(0.58)	(0.17)	(0.27)	(0.05)	(0.06)	
2000-2017	5.65***	-0.82	1.01***	1.64***	-0.72***	0.912
	(1.82)	(0.72)	(0.26)	(0.09)	(0.09)	
Alternative Measures for 2000-2017						
CPI						
2000-2017	3.08***	0.05	0.73***	1.64***	-0.71***	0.803
	(0.93)	(0.23)	(0.23)	(0.08)	(0.07)	
Shadow Fed Funds rate						
2000-2017	7.67***	-1.25	1.65***	1.55***	-0.61***	0.930
	(2.42)	(0.86)	(0.36)	(0.09)	(0.08)	

Notes: ***, * - significant at 1 and 5 percent levels, respectively. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

function is re-estimated for 2000-2017 using two alternative measures and the results are reported in the second part of Table 5. In one estimate, the GDP deflator based inflation is replaced by the Consumer Price Index based inflation, while in the other estimate the shadow Federal Funds rate is used instead of the actual rate during the zero lower bound period. Despite using alternative measures, the outcome for β remains the same for the 2000-2017 period (i.e. not statistically different from zero).

With the above finding that the feedback coefficient on inflation is less than unity in the policy function estimated for 2000-2017, can one simply say that the Federal Reserve has followed a 'passive' monetary policy during the period under review? Before reaching a conclusion of that nature, it is worthwhile to consider alternative policy horizons, as over time, the Federal Reserve might have shifted its attention to a different target horizon. As such, the policy reaction function is changed to accommodate alternative target horizons and the estimated results are reported in Table 6. The first alternative assumes that the Federal Reserve considers a target horizon of one year for inflation and one quarter for the output (i.e., k=4, q=1), and the coefficient estimates for this specification are presented in the first row of the table. The second alternative, which is reported under the second row of the table, considers the same one year target horizon for inflation, but two quarters for the output (i.e., k=4, q=2). According to these estimates, the coefficient β is statistically significant and more importantly it is having a value greater than unity. This implies that if a

Table 6: Estimates for 2000-2017 under Alternative Time Horizons

Time Horizon	*const*	β	γ	ρ_1	ρ_2	p
$k = 4$, $q = 1$	-2.26	2.73***	0.65***	1.43***	-0.53***	0.899
	(3.03)	(1.34)	(0.20)	(0.19)	(0.18)	
$k = 4$, $q = 2$	-2.29	2.81*	0.70***	1.40***	-0.49***	0.911
	(2.95)	(1.31)	(0.20)	(0.19)	(0.18)	
Estimates for Alternative Measures						
CPI						
$k = 4$, $q = 1$	-0.08	1.37***	0.60***	1.48***	-0.57***	0.815
	(1.27)	(0.52)	(0.18)	(0.10)	(0.08)	
$k = 4$, $q = 2$	0.05	1.36***	0.66***	1.46***	-0.55***	0.834
	(1.32)	(0.52)	(0.19)	(0.11)	(0.09)	
Shadow Fed Funds rate						
$k = 4$, $q = 1$	-0.71	2.17*	1.20***	1.39***	-0.47***	0.866
	(2.17)	(1.00)	(0.25)	(0.10)	(0.09)	
$k = 4$, $q = 2$	-0.42	2.11*	1.29***	1.38***	-0.46***	0.854
	(2.19)	(0.99)	(0.28)	(0.10)	(0.09)	

Notes: ***, **, * - significant at 1, 2 and 5 percent levels, respectively. Standard errors are reported in parentheses. Last column reports the p-value associated with Hansen's J-test.

one year target horizon for inflation is considered, the Federal Reserve has pursued an 'active' monetary policy during the 2000-2017 period. In order to assess the robustness of this claim, the policy function is re-estimated using alternative measures as before - Consumer Price Index based inflation and the shadow Federal Funds rate. The outcome is reported in the second part of Table 6, which shows that the estimation results are approximately similar. Hence, although the feedback coefficient on inflation is not statistically different from zero for a one quarter target horizon for inflation, once the target horizon is increased to four quarters the coefficient becomes statistically significant with a value greater than unity. This tend to imply that in 2000s the Federal reserve has shifted its focus from immediate inflation targets to longer horizon inflation targets.

5 Interest Rate Rules and Macroeconomic Stability: A Model based Analysis

In this section, the implications of the estimated policy reactions function on macroeconomic stability are assessed. A simple New Keynesian macroeconomic model with sticky prices, incorporating the estimated monetary policy reaction function is used for this purpose. Attention is particularly directed towards comparing stability of the model when the parameters of the monetary policy rule are those estimated for the pre-Volcker era to those estimated for the post-Miller era.

5.1 The Model

A simple macroeconomic model along the lines of Clarida et al. (2000) is used, as the focus is not to perform a comprehensive assessment of the properties of the model, but to narrow down the analysis to the implications of the changes in the systematic component of monetary policy. As such, the basic three equation New Keynesian model with interest rate smoothing is considered for the study. Log-linearization of the model around its steady state results in the following equations:

$$\pi_t = \delta\mathbb{E}[\pi_{t+1} \mid \Omega_t] + \lambda(y_t - z_t) \tag{7}$$
$$y_t = \mathbb{E}[y_{t+1} \mid \Omega_t] - (1/\sigma)(r_t - \mathbb{E}[\pi_{t+1} \mid \Omega_t]) + g_t \tag{8}$$
$$r_t^* = \beta\mathbb{E}[\pi_{t+1} \mid \Omega_t] + \gamma y_t \tag{9}$$
$$r_t = (1 - \rho_1 - \rho_2)r_t^* + \rho_1 r_{t-1} + \rho_2 r_{t-2} \tag{10}$$

A New Keynesian Philips curve is represented by Equation (7). It postulates that inflation today is a function of the expected inflation in the next period and the deviation of output, y_t from its natural level, z_t, where the natural level of output is the level of output that can be achieved under flexible prices. As before, Ω_t corresponds to the set of available information at time t. Equation (8) presents an IS curve relationship which assumes that the output today is a function of the expected output in the next period, the ex-ante real interest rate and an exogenous demand factor g_t. Both z_t and g_t are assumed to be AR(1) processes. Equations (9) and (10) in combination represent the monetary policy reaction function specified for GMM estimation under equations (6).

The model is solved using tools based on the techniques of Blanchard and Kahn (1980), and simulated for the two subperiods under consideration (i.e. the pre-Volker era and post-Miller era)[5]. The parameters for the policy rule (β, γ and ρ) are based on the estimated parameters for the policy reaction function under respective subperiods. The remaining nonpolicy parameters are based on Clarida et al. (2000). Accordingly, the quarterly discount factor, δ is assumed to be 0.99. The output elasticity of inflation, λ is set at 0.3 and the coefficient of relative risk aversion, σ is set at 1.

5.2 Simulating the Model for the pre-Volcker Era

The policy rule itself could be a source of instability if the coefficient on inflation gap, β, is below unity (Bernanke & Woodford, 1997). Values of β below unity lead to indeterminacy of equilibrium and could result in 'sunspot' equilibria, in which the endogenous variables

[5]Dynare is used for solving and simulating the model.

respond to random variables that are unrelated to the structure of the model simply because they are expected to do. Intuitively, when β is less than unity, an increase in expected inflation leads to a decline in real interest rate. This simulates aggregate demand in the economy, which in turn leads to an increase in inflation expectations.

An attempt to solve the model using the Blanchard and Kahn (1980) technique failed as expected for the parameters of the pre-Volcker era, since the estimate of β for that subperiod is 0.85. Although there are two forward-looking (jump) variables in the model, only one eigenvalue is found be greater than unity in modulus, thereby resulting in model indeterminacy. Consequently, the model specified by equations (7)-(10) is modified to accommodate for 'sunspot' shocks. Farmer and Khramov (2013) specify two alternative ways to redefine non-fundamental shocks as new fundamentals in a simple three equation New Keynesian model. One approach is to define the forecast error on output gap $\eta_{1,t} = y_t - \mathbb{E}_{t-1}[y_t]$ as a fundamental shock, whereas the other approach is to define the forecast error on inflation $\eta_{2,t} = \pi_t - \mathbb{E}_{t-1}[\pi_t]$ as a fundamental shock. For this study, the model is solved and simulations are carried out specifying the forecast error on output gap as a fundamental shock. Accordingly, equation (8) is modified as follows to arrive at a 'sunspot' equilibria,

$$y_t = y_{t+1} - (1/\sigma)(r_t - \mathbb{E}[\pi_{t+1} \mid \Omega_t]) + g_t + \eta_{t+1} \tag{11}$$

where η_{t+1} is the expectational shock.

Figure 4 displays the impulse responses of inflation, the output gap and nominal interest rate to a sunspot shock. Parameters of the policy rule in the model are those derived for the pre-Volcker era under GMM estimation (Table 1 - first row). As shown by Figure 4, a 'sunspot' shock generated through the forecast error on output gap results in an increase in the output gap and inflation. However, the increase in nominal interest rate falls short of the increase in expected inflation, thereby resulting in a negative real interest rate during the first few quarters. The real rate approaches zero thereafter, but it does not move to the positive territory despite having a positive inflation gap. Moreover, the impulse responses exhibit that the main variables remain deviated from their respective steady state values for a prolonged period after the 'sunspot' shock.

The model is simulated using randomly generated 'sunspot' shocks to expectations from a standard normal distribution. Figure 5 depicts the simulated response of the economy to a sequence of 'sunspot' shocks which can be interpreted as a sequence of self-fulling revisions in expectations (Clarida et al., 2000). One clear observation from the simulation is that the output gap and inflation remain highly volatile although no fundamental shocks (i.e. demand and supply shocks) are present. More importantly, the movements in inflation show that there are certain periods where inflation continue to trend upwards (e.g. first 15 periods of the simulation). However, nominal interest rate continue to fall short of the expected inflation during the episodes of high inflation. This is in line with the impulse responses observed in Figure 4. Nonetheless, the full length of the simulation exhibits the cyclical behavior of inflation, output and the nominal interest rate.

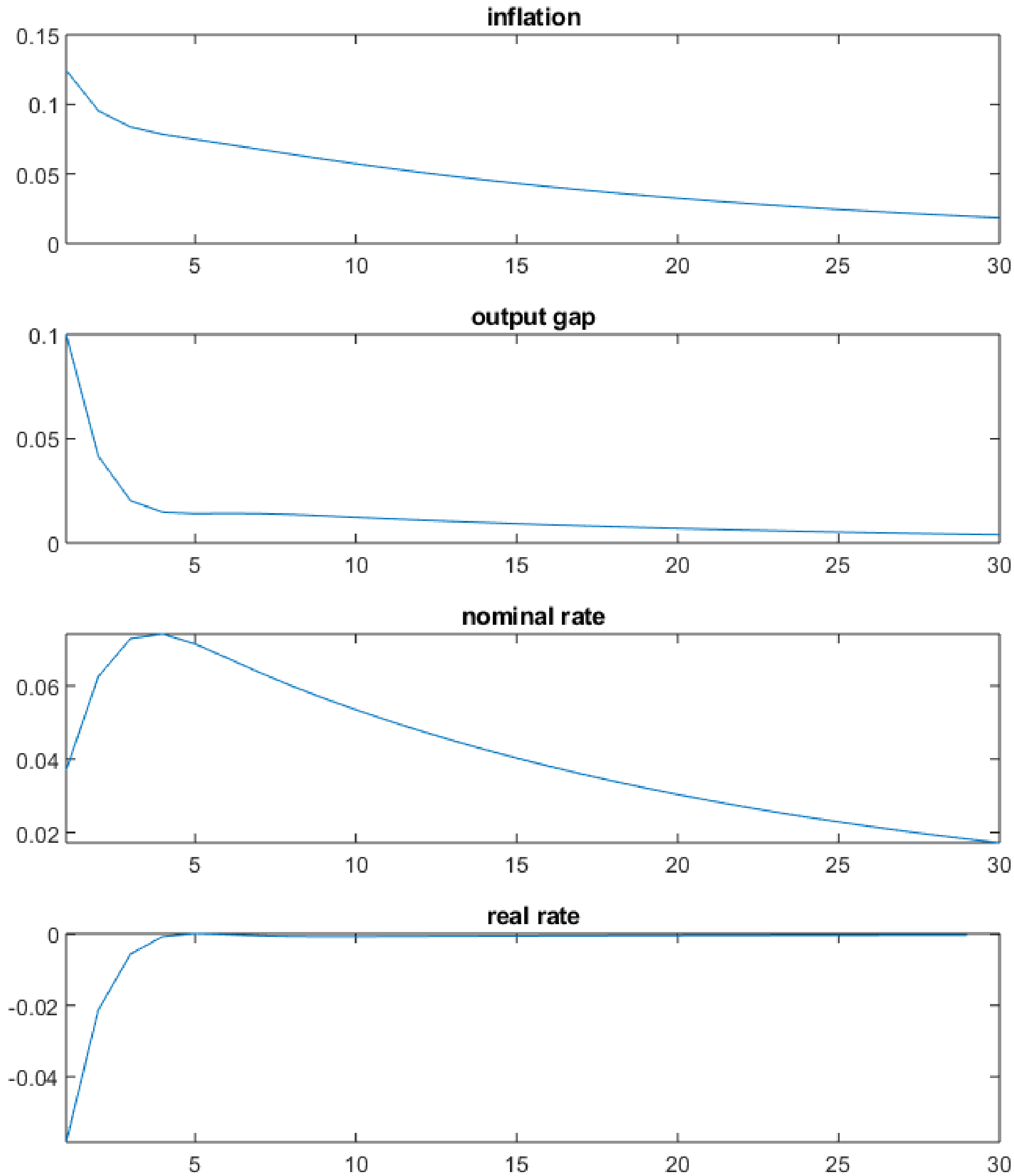

Figure 4: Impulse Responses to a Sunspot Shock

5.3 The Model in the post-Miller Era

Calibrating the policy reaction function with parameters estimated for the post-Miller era (Table 1 - second row), and solving the model using the Blanchard and Kahn (1980) technique resulted in a unique solution as expected since the estimate of β for that subperiod is 2.27. For the two forward-looking (jump) variables in the model, two eigenvalues are found be greater than unity in modulus. Figure 6 shows the impulse responses generated by the model to a demand shock. The demand shock results in an increase in the output gap and inflation. In contrast to the model calibrated for the pre-Volcker era, the increase in nominal

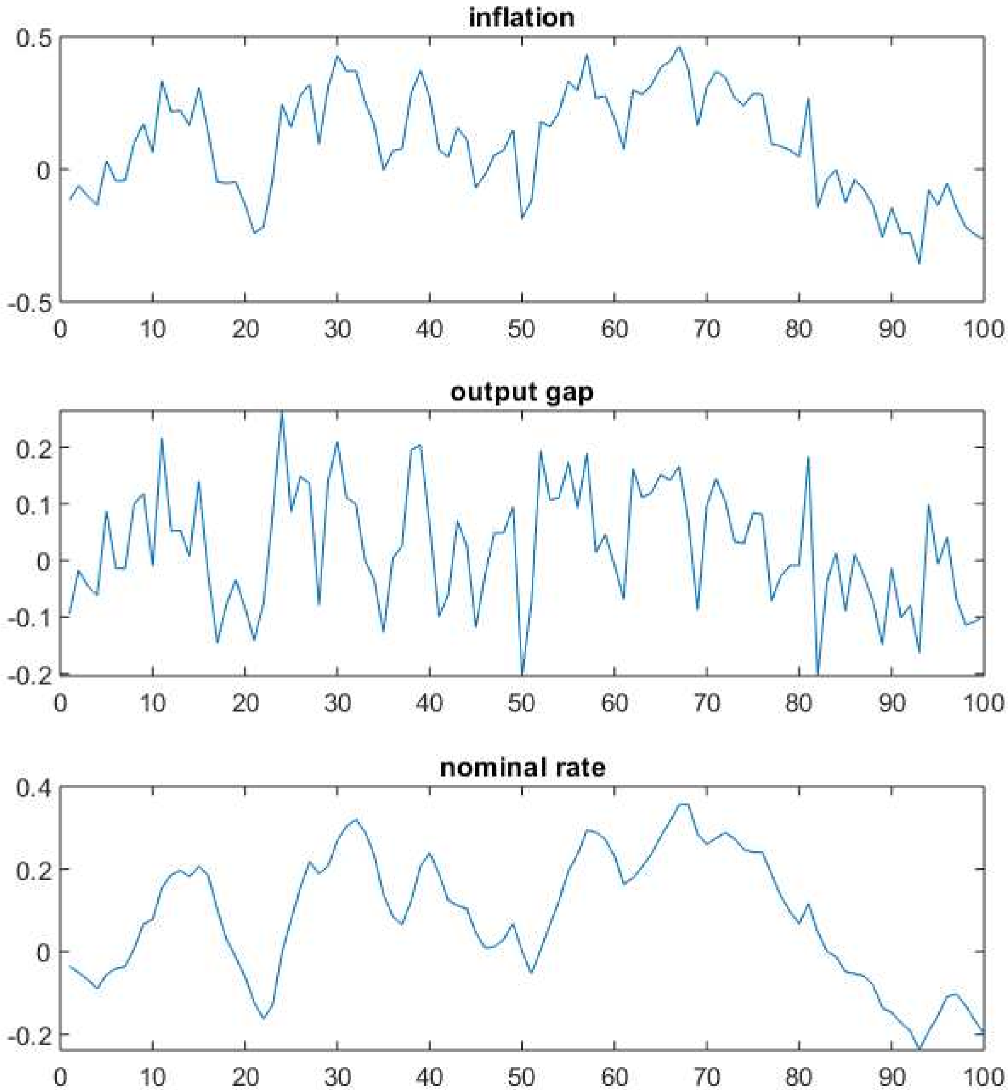

Figure 5: Simulated Sunspot Fluctuations

interest rate is greater than the increase in expected inflation, thus resulting in a positive real interest rate. Further, inflation and the output gap converge to their steady state values at a faster pace in comparison to the impulse responses observed for the pre-Volcker era.

In contrast to the pre-Volcker era, self-fulling fluctuations cannot arise in the post-Miller era since β in the estimated policy reaction function is well above unity. More importantly, the monetary policy rule under consideration in itself is not a source of macroeconomic instability (Clarida et al., 2000). As such, macroeconomic fluctuations can only arise in the presence of fundamental shocks such as demand and supply shocks. The way the economy reacts to these fundamental shocks, however, depend on the characteristics of the policy reaction function.

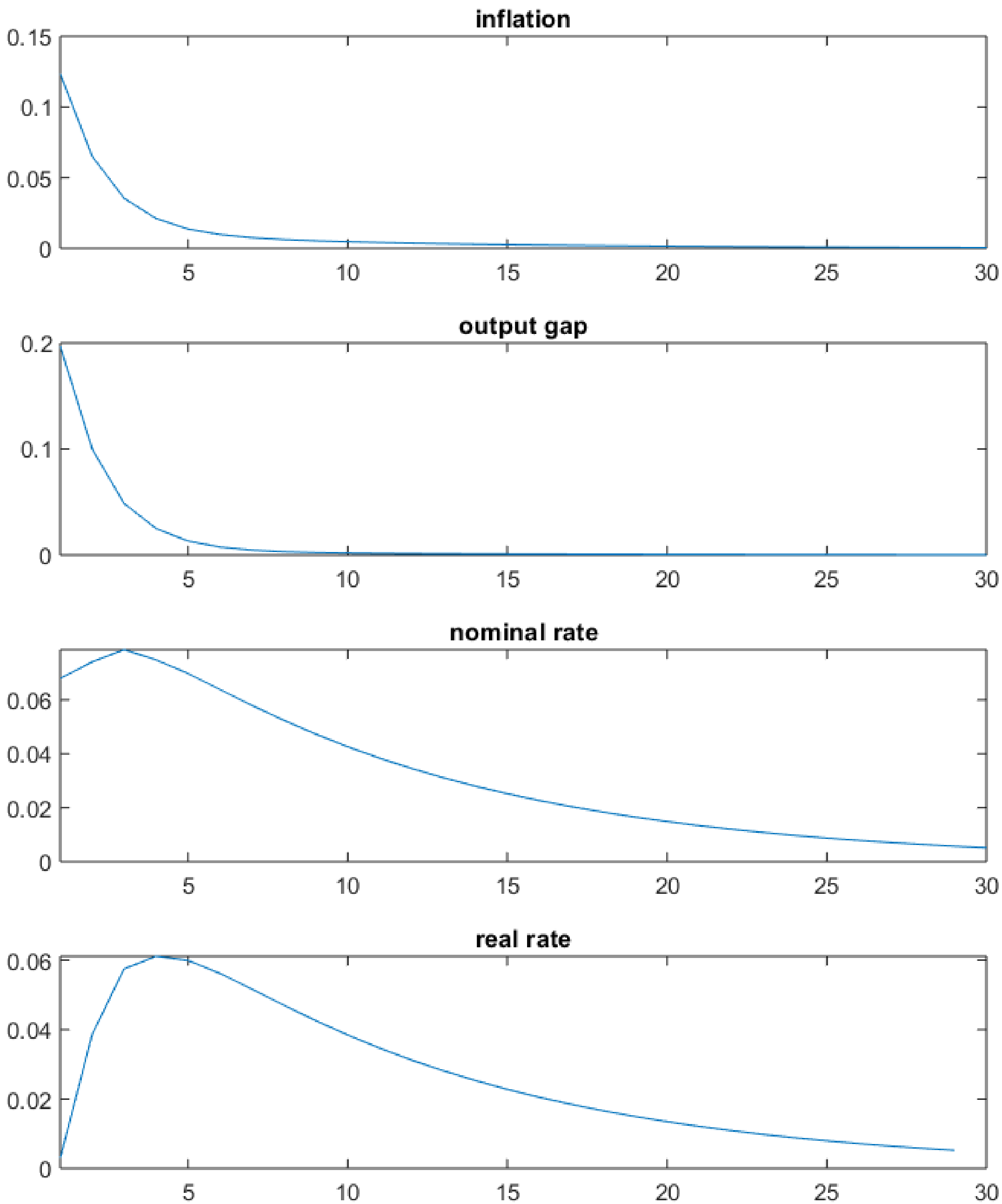

Figure 6: Impulse Responses to a Demand Shock

Even though 'sunspot' fluctuations are not possible in the model considered for the second subperiod, the degree of stability of the economy depends upon the size of the feedback coefficients of the policy reaction function. In order to assess the relative stability of the economy, the standard deviation of inflation, the output gap and interest rate are observed under different values of β for simulated fundamental shocks. The rest of the coefficients in the policy function are kept unchanged at the values estimated for the post-Miller period.

Table 7: Satbilty to Fundamental Shocks

	Demand shocks			Supply shocks		
β	$\sigma(\pi)$	$\sigma(y)$	$\sigma(r)$	$\sigma(\pi)$	$\sigma(y)$	$\sigma(r)$
2.5	1.00	1.00	1.00	1.00	1.00	1.00
2.0	1.11	1.08	1.02	1.24	0.94	1.18
1.5	1.26	1.20	1.04	1.61	0.99	1.46
1.0	1.49	1.37	1.09	2.29	1.42	1.96

Table 7 reports the standard deviation of key model variables for demand and supply shocks[6]. The reported standard deviations are normalized with respect to the model calibrated with $\beta = 2.5$ so that the changes can be easily tracked. The first three columns show that the standard deviation of inflation, the output gap and interest rate for fluctuations in demand (i.e. shocks to g_t) increase when the feedback back parameter on inflation, β, approaches unity. The last three columns show the change in standard deviation for fluctuations in supply (i.e. shocks to z_t). The standard deviation of inflation and interest rate gradually increases when β approaches unity. For the output gap, the standard deviation remains broadly unchanged initially and increases later when β is close unity.

Overall, the standard deviations summarized in Table 7 imply that the response of the economy to fundamental shocks is sensitive to β. Intuitively, a value of β equal to or just above unity suggests that the Federal Reserve raises nominal interest rates keeping the real rate broadly constant. Given the absence of a strong response to inflationary pressures, the fundamental shocks could generate considerable volatility in inflation and output. However, if the Federal Reserve is aggressively pursuing an anti-inflationary policy, a value of β which is considerably greater than unity can be expected. This, in turn, will result in less volatility in key macroeconomic variables.

Figure 7 exhibits how impulse responses change with the feedback coefficient on inflation, β. The figure plots the impulse response of inflation to a demand shock for multiple values of β. When the feedback coefficient equals unity, the response is large and relatively persistent. For a large value of the feedback coefficient (e.g. $\beta = 3.0$), only a transitory impact on inflation is observed. The analyses presented under Table 7 and Figure 7 in combination could explain, at least in part, the presence of high inflation and its excessive volatility in the pre-Volcker era, and the absence of such phenomena in the period afterwards.

[6] These are the values reported by Dynare for each variable when impulse responses are simulated

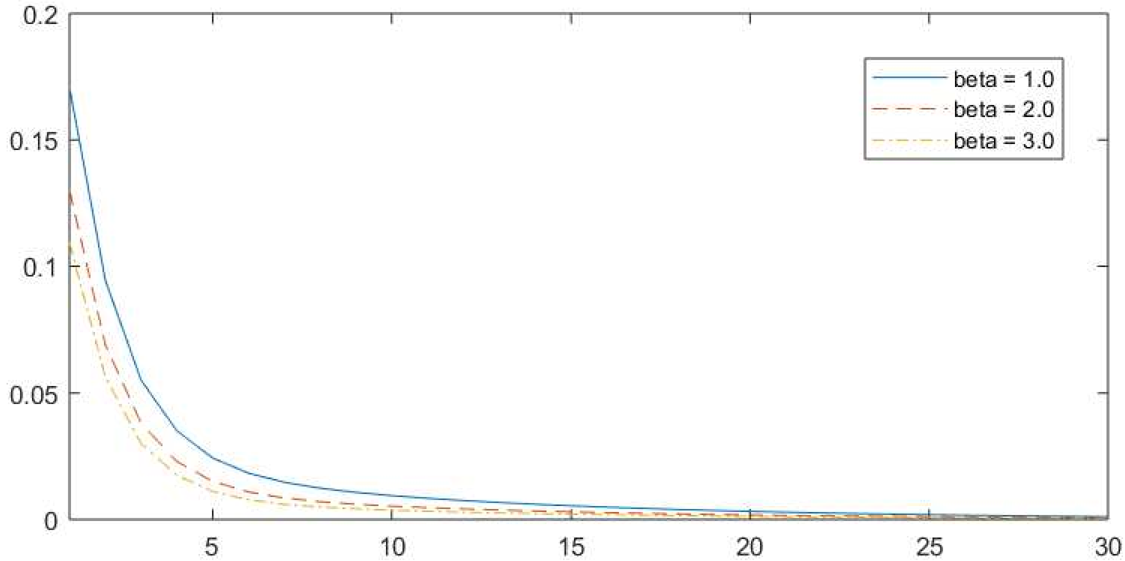

Figure 7: Impulse Response of Inflation to a Demand Shock

6 Conclusion

This paper analyzes the important role played by the US monetary policy in stabilizing inflation and business cycle fluctuations. It does so by estimating Taylor-type forward-looking monetary policy reaction functions for the pre- and post-1979 eras, and simulating the resultant feedback coefficients in a basic New Keynesian business cycle model.

The feedback coefficient on inflation in the estimated policy reaction function is found to be less than unity for the 1960-1979 period, suggesting that the Federal Reserve has taken an accommodative monetary policy stance during this era leaving real interest rates to decline in response to rising inflation expectations. However, the feedback coefficient on inflation is estimated to be substantially greater than unity for the 1979-2017 period. This implies that the Federal Reserve adopted a proactive policy stance towards controlling inflation in the post-1979 era by systematically raising both nominal and real interest rates in response to increased inflation expectations. In the meantime, a subsample analysis for the 1979-2017 period shows that during the 2000s and 2010s, the Federal reserve has shifted its focus from immediate one period ahead inflation targets to longer horizon targets such as one year ahead inflation targets. This finding could possibly be the main contribution of this paper for discussions centered around monetary policy rules.

The policy functions estimated for the pre- and post-1979 eras are embedded into a basic New Keynesian business cycle model to analyze the resulting equilibrium and the dynamics of macroeconomic variables. An attempt to solve the model using parameters of the policy function for 1960-1979 leads to indeterminacy of equilibrium and results in 'sunspot' equilibria. The model exhibits a high level of volatility for 'sunspot' shocks, with the main variables remaining deviated from their respective steady state values for a prolonged period.

Calibrating the policy reaction function with parameters estimated for the 1979-2017 period results in a unique equilibrium. Simulating impulse responses for this period reveals that the nominal interest rate increases more than one-to-one in response to an increase in expected inflation, thus resulting in a positive real interest rate. It is also shown that the degree of stability of the simulated economy depends upon the size of the feedback coefficients of the policy reaction function. Overall, the model simulations show that the economy exhibits greater stability under a model with post-1979 calibration than a model with a combination of pre-1979 parameters and 'sunspot' shocks.

References

Bernanke, B. S., & Mihov, I. (1998). Measuring Monetary Policy. *The Quarterly Journal of Economics*, *113*(3), 869–902.

Bernanke, B. S., & Woodford, M. (1997). Inflation Forecasts and Monetary Policy. *Journal of Money, Credit and Banking*, *29*(4), 653–684.

Blanchard, O. J., & Kahn, C. M. . (1980). The Solution of Linear Difference Models under Rational Expectations. *Econometrica*, *48*(5), 1305–1311.

Clarida, R., Galí, J., & Gertler, M. (1999). The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature*, *37*(4), 1661–1707.

Clarida, R., Galí, J., & Gertler, M. (2000). Monetary policy rules and macroeconomic stability: evidence and some theory. *The Quarterly Journal of Economics*, *115*, 147–180.

Farmer, R., & Khramov, V. (2013). *Solving and Estimating Indeterminate DSGE Models* (Vol. WP/13/200).

Justiniano, A., & Primiceri, G. E. (2008). The time-varying volatility of macroeconomic fluctuations. *American Economic Review*, *98*(3), 604–641.

Lubik, T. A., & Schorfheide, F. (2004). Testing for Indeterminacy: An Application to U.S. Monetary Policy. *American Economic Review*, *94*(1), 190–217.

Rudebusch, G. D. (1995). Federal Reserve interest rate targeting, rational expectations, and the term structure. *Journal of Monetary Economics*, *35*, 245 274.

Sims, C. A., & Zha, T. (2006). Were There Regime Switches in U.S. Monetary Policy? *American Economic Review*, *96*(1), 54–81.

Svensson, L. E. O. (1999). Inflation targeting as a monetary policy rule. *Journal of Monetary Economics*, *43*(3), 607–654.

Taylor, J. B. (1993). Discretion practice versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy*, *39*, 195–214.

Taylor, J. B. (1999). Introduction to "Monetary Policy Rules". In J. B. Taylor (Ed.), *Monetary policy rules.* University of Chicago Press.

Taylor, J. B. (2007). Housing and Monetary Policy. In *Proceedings - economic policy symposium - jackson hole* (pp. 463–476).

Wu, J. C., & Xia, F. D. (2016). Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound. *Journal of Money, Credit and Banking*, *48*(2-3).