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Article

Monetary policy dynamics in the United States

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Research Article

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Monetary Policy Dynamics in the United States

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Abstract: The recognised approach to designing an optimal monetary policy model is based on the central bank's ability to mitigate losses using a quadratic criterion subject to the linear structure of the economy. This study examines the United States Federal Reserve's (Fed) monetary policy in different economic environments. It provides an empirical solution to the central bank's optimisation problem when preferences are asymmetric in both inflation and output gaps. The study tested for structural breaks and uncovered potential evidence of nonlinearities in the Fed's reaction function, which provides more information on policy objective. The empirical evidence suggests that the Fed's policy rate differs in these periods. This strongly indicates the presence of asymmetry. Further evidence suggests that the predictive power of the estimated model increases when a smoothing process is allowed.

Keywords: Monetary policy; Asymmetric preference; Taylor rule; Structural breaks; United States

JEL: E32, E45, E52, E58

1 Introduction

The traditional approach to monetary policy is to use fund rates as a tool to manage irregular fluctuations in the economy. During a recession, the reserve bank rate is the most efficient policy instrument to spur a recovery (Shobande & Shodipe, 2019a, 2021). However, caution must be exercised to ensure that the rates do not drop below the thresholds (Shobande, 2019a; Shobande & Shodipe, 2019b). For the United States Federal Reserve (Fed), unconventional monetary policy is often used in response to macroeconomic uncertainty. However, it is unclear whether this approach is effective, especially during economic turmoil. In this study, we examine the complex events that characterise the actions of the Fed in terms of changing periodic asymmetry in policy responses. By addressing the optimal control problem, we examine how central banks mitigate losses using a quadratic criterion to determine target rules in response to macroeconomic fluctuations and provide new information that has important policy implications for effective and efficient monetary policy formation in the United States.

There are three reasons to investigate the dynamic nature of the Fed's monetary policy. First, major empirical efforts have been based on the quantitative measures of monetary policy, whereas little attention has been paid to the issue of structural breaks and policy rules for asymmetry, which are important for forming expectations about the future (Moosavi & Cao, 2020; Luo & Tsang, 2020; Hang Xue, 2020). For example, Jansen (2011) has suggested that information asymmetry often misinforms the public regarding expectations, while Cihak and Jansen (2013) have shown that financial market volatility is a product of unclear communication by monetary authorities. Second, a proper understanding of the linear and nonlinear nature of monetary policy can provide effective communication between the monetary authorities and the public that can help to mitigate volatility in the financial market and improve the forecasting accuracy of inflationary expectations

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(Jarocinski & Karadi, 2020; Heider et al., 2019; Mankiw & Reis, 2018; Clarida, 2019; Daetz, 2018; Shobande & Enemona, 2021). Third, many studies have argued that understanding how policymakers adjust their preferences within the macroeconomic environment can serve as yardsticks for designing policy rules to capture the time-varying properties of threshold values (Shobande, 2019b; Taylor & Davradakis, 2006; Bunzel & Enders, 2010; Koustas & Lamache, 2012; Qin & Enders, 2008; Tan & Habibullah, 2007; Kin, 2004; Martin & Milas, 2004).

Empirical evidence on the dynamics of the Fed's policy is inconsistent and widely controversial. The Fed's use of optimal policy rules has been examined in both conventional and unconventional studies. For example, studies by Taylor (1993), Clarida et al. (1999), and Woodford (2007) have extensively used the conventional linear functional approach to analyse the Fed's behaviour on monetary policy responses, but a lack of agreement among these scholars has continued to stimulate a growing body of literature on the subject. In another example, Bernanke (2010) has rejected the claim by Taylor (2009) that low Fed rates have caused the financial meltdown. Mankiw et al. (2003) investigated 50 years of inflation expectations and discovered that time factors account for variations in the inflation rate. In another study, Filardo and Guinigundo (2008) reported that disagreements about inflation outlook were due to a lack of transparency. Dovern et al. (2012) analysed monetary policy behaviour in a panel of G7 countries and observed that disagreement on future expectations arise from an increase in uncertainty. The second group has focused on the dynamic macroeconomic environment that drives the Fed's behaviour to encourage economic recovery using unconventional monetary policy. For example, a study by Ben-habib et al. (2001) has highlighted that the policy rule is subject to multiple equilibria under the zero-lower bound (ZLB). Some studies have recognised that optimum monetary policy relies on the exogenous, endogenous inelastic, or endogenous elastic attention of agents (Luo & Tsang, 2020). For example, Luo & Tsang (2020) have shown that under elastic consideration, optimal monetary policy produces balances that are not feasible under the other two conditions: no exposure to any shocks that cause unstable economic fluctuations. A similar study by Ouerk et al. (2020) used the shadow rate to measure monetary policy stance and reported that the effect of unconventional monetary shocks was weaker and less persistent than that of conventional monetary policy. Duffy and Engle-Warnick (2006) have applied a non-parametric method to examine the multiple policy regimes of the Fed's behaviour and reported that a structural test approach requires the identification of a number of policy regimes prior to the test and might pose a serious threat to the test outcomes. Siklos (2013) has shown that central bank forecasts increase disagreements, while Zhu and Chen (2017) examined a forward-looking threshold Taylor rule for the United States and have reported that response to inflation and output gaps are asymmetric. In addition, Bunzel and Enders (2010) have suggested that the Fed is likely to be more aggressive when inflation is high than when it is low. Marin and Milas (2004) have noted that if monetary policy is asymmetric, policymakers are more likely to respond to upward deviations of inflation away from inflation targets; while Shobande and Shodipe (2019) have argued that inflation targeting often leads to a change in monetary policy formation.

This study extends the existing literature in the following way. (1) It examined the asymmetric nature of monetary policy in the United States. (2) By allowing for the presence of asymmetric preferences, the study tested for the structural break and uncovered potential evidence of nonlinearities in the Fed's reaction function and thereby provides more information on asymmetry in the policy objective. Our study used quarterly data and implemented both traditional and modernised models. Empirical evidence showed that monetary policy behaviour in the United States can be effectively and efficiently characterised as a partial nonlinearity policy rule. Further findings showed that the predictive power of the policy model increases when smoothing is allowed, both in the linear and asymmetric models. This new information can help policymakers conduct their monetary policy at a zero lower rate.

The remainder of this paper is organised as follows. Section 2 presents the empirical model, while Section 3 presents the data, sources, and descriptions. Section 4 presents the empirical results, and Section 5 provides concluding observations.

2 The Model

This section discusses the buildup for the policy rule. The traditional monetary policy framework links changes in nominal interest to macroeconomic fundamentals. Since policy credibility relies on consistency, an unwarranted reversal in the policy stance is usually avoided. Thus, the Fed depends on rules for policy guidance.

Taylor (1993) defines short-term nominal interest rates as a function of long-run equilibrium real interest rate, actual inflation, inflation and the output gaps. Historically, Taylor's policy setting was first to compensate for the liquidity effect and the fisher effect as it allows the central bank to pursue short-term expansion through a low nominal interest rate or a high nominal interest rate for long-term growth. Apparently, this policy rule offers a guide for simultaneous inflation control and dampening the cyclical business fluctuation.

$$i_t = \bar{r} + \pi + \beta(\pi_t - \pi^*) + \gamma y_t + \xi_t \quad (1)$$

i_t is the reactive short-term nominal interest rate desired by the Fed, \bar{r} and π^* are the long-run equilibrium nominal interest rate and inflation target. π_t and y_t represent the inflation rate and output gap which constantly steers the policy strategy of the central bank. This strategy is determined by the parameters β and γ . The Fed pursues an active and stabilizing strategy if $\beta, \gamma > 0$. Otherwise, if policy responses lag, $\gamma < 0$ and $\beta < 0$, the Fed is merely accommodating the changes in the inflation; this policy stance leads to self-fulfilling burst of inflation (Bernanke & Woodford, 1997; Clarida et al., 1999). The model follows some random walk, ξ_t , arising from the unanticipated exogenous shock to the interest rates. That is, ξ_t is independently and identically distributed (iid), $\mathbb{E}[\xi_t] \sim (0, \sigma^2)$. In the other specification we impose the assumption of the zero conditional mean of error terms $\mathbb{E}[\xi_t | \pi_t, y_t] = 0$ as it is plausible to make a case for endogeneity in the model.

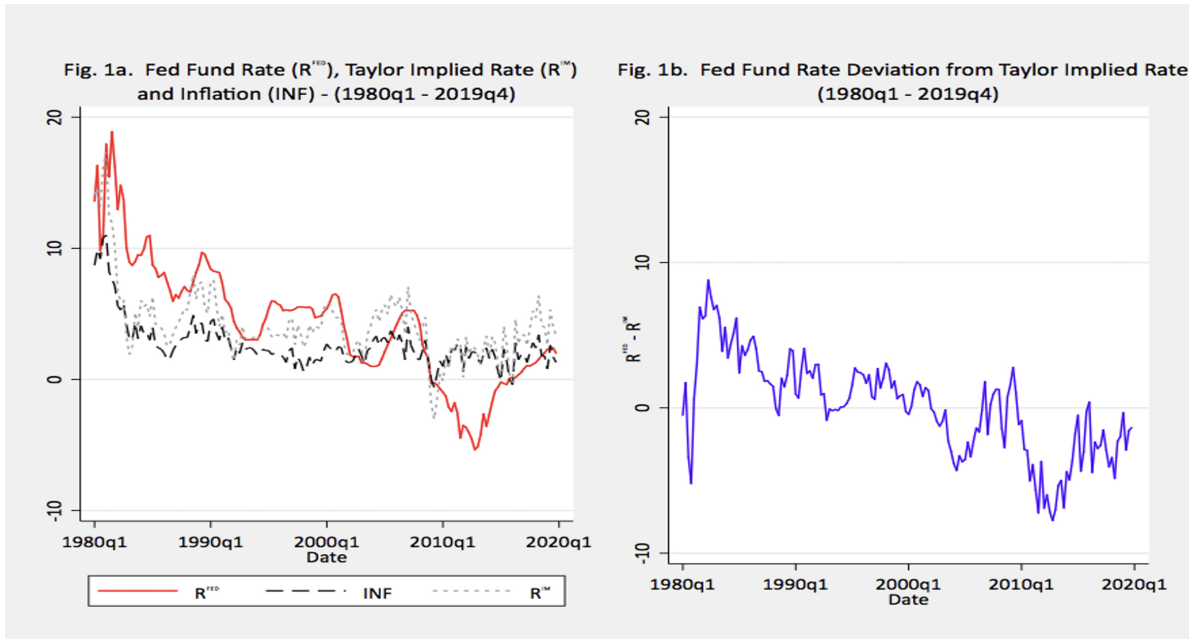
3 The Data

This study used the annualized fed funds rate (R^{FED}), inflation rate (INF) and output gap (CBO-Est) data from 1980:Q1 to 2019:Q4 for the model estimations. The fed funds rate is the quarterly short-term nominal interest rate. That is, the average rate the banks charge each other on the short-term basis - overnight lending rate. The output gap is constructed by GDP filtering. The filter shows the real GDP percentage deviation from potential. A negative deviation indicates a recession while positive represents an expansion. Inflation is measured with the GDP implicit deflator data measured by year-over-year changes in the GDP deflator index. The GDP deflator is the nominal to real GDP ratio.

The dataset we used account for the recent dynamic changes to the macroeconomic environment. For instance, the period 2009:Q1 and 2017:Q2 correspond to the ZLB time therefore the fed funds rate is replaced with the Krippner's (2019) shadow interest rate for the period and we used the updated Holston et al. (2017) estimated time-varying natural rate in the modified model. Besides, we consider the sensitivity of the structural parameters to methods used in measuring output gap. Preliminary analyses reveal that the gap measure provided by the Congressional Budget Office (CBO) predicts the business cycle better than other measures. As depicted in Fig.2, the CBO's gap prediction is clear, discovers recession dates earlier and these dates significantly correlate with major recession dates reported by National Bureau of Economic Research (NBER). The studied data are sourced as follows.

The fed funds rate, inflation and real GDP data are from US Federal Reserve Bank of St-Louis, the real GDP potential is from the US Congressional Budget Office (CBO), the Krippner's (2019) shadow rate from Reserve Bank of New Zealand and the Holston et al. (2017) natural rate of interest estimate is from US Federal Reserve Bank of Atlanta. Event-based historical relationships between the data are provided below.

The 1980 Paul Volker's aggressive policy stance came as a result of too much inflation in the late 1970s. The interest rate rose up to 17% in the 1982 and relaxed at 10% by 1985, Fig.1. The Fed defended this policy while understanding the need to control the excess of inflation. The commitment to this strategy continued till



1984. Although Volker’s policy tightening has its minor adverse economic impact, inflation fell approximately 300% within 5 years, see Fig.1.

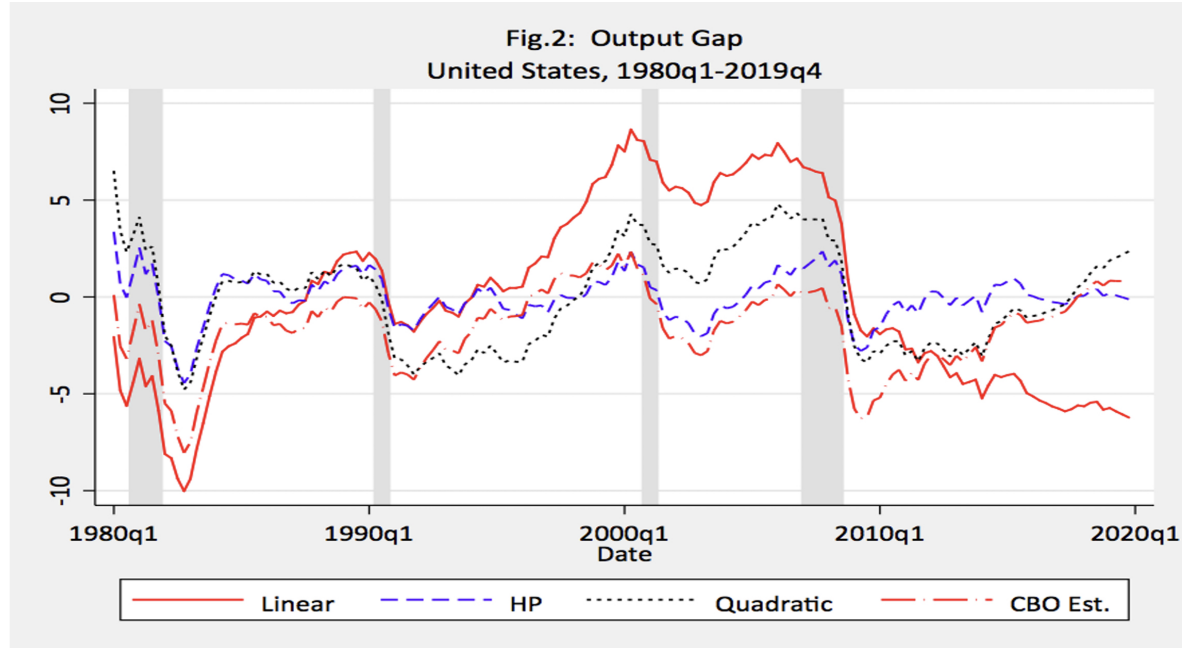
John B.Taylor is the most prominent in the Fed’s policy critique of the 2008 financial stress. Taylor (2009) characterized the Fed policy as loose and weak before the crisis. Many critics essentially linked the housing bubble to an overly low interest rate. The functional policy rule proposed is of the form:

$$i_t^{im} = 1 + 1.5\pi_t + 0.5y_t \tag{2}$$

Equation 2, according to Taylor (1993), is an implied policy guide the Fed would coherently pursue in a stable environment. Simply, an active Fed policy responds by 1.5% to 1% changes in inflation and 0.5% to 1% output gap dynamics. Observers felt this simple policy requirement was lacking before the 2008 recession. Fig.1, from 2002 to the start of the crisis, the implied Taylor rate (R^M) rose significantly above the Fed rate. For instance, policy-based rule peaked around 6% relative to the fed rate which hovered around 2% in the first quarter of 2005. As a consequence, the wave of housing burst cut across all financial departments, mortgage default surged and stock market crashed, by December 2007, the economy plunged into a deep recession and in the fourth quarter of 2009, unemployment surged to a 25 year high at about 10%. As the crisis deepened far into depression, the Fed resorted to unconventional policy measures.

Apparently, the relationship between the fed funds rate, inflation and output gap exist. However, what was not clear is how the Fed’s behavior interacts with these macroeconomic fundamentals, Shodipe (2019). We explored this analysis under linearity and non-linearity in the Fed’s responses.

Fig.2 reports output gap measured by Hodrick Prescott (HP) , linear, quadratic data filtering method and the estimate from CBO. All the methods are virtually similar as they exhibit co-movement, but they exhibit slight dissimilar characteristics. The linear filtering over-exaggerates the size and length of the fluctuation over the entire sample. Both HP and quadratic closely moved together from 1980 to 1990 but departed thereafter. More so, the HP measure underestimates output gap and shows a rapid recovery during the period of severe recession. During the heat of the great recession, HP’s predicted gap barely went down to -2.78% in 2009:Q2 and in 2012, it gravitated around 0%. The quadratic filtering completely missed the 2001 recession. The CBO - based estimates show close to perfect predictions and align with the common knowledge about US recessions and its gradual recoveries, see Fig. 2. Therefore, we proceed with the CBO estimates in the analysis.



4 Empirical Strategy

4.1 Structural Break Test

At the foremost, the study tests for structural breaks in the fed funds rate. The rationale leading to the break test arises from the presupposition that policy changes can inadvertently cause a shift in the fed funds rate. For example, the Volker's policy, Alan Greenspan's - Great Moderation and policy challenge from the Year 2000s glitch are credible to cause multiple breaks in the fed funds data.

We follow two steps in determining the structural breaks (see Nikolsko-Rzhevskyy et al., 2019). First, the rate deviation (\bar{i}_t) from the implied policy rules¹ is derived and second, the break dates are serially determined using the deviation data. Because the result becomes skeptical using an intuition for obtaining a number of breaks in a given time-series data, we adopt Bai and Perron (1998) Sequential test with an Unknown Number of Breaks for multiple structural breaks. Equation 3 considers $m + 1$ policy regimes with m possible structural break points, where m is unknown.

$$\begin{aligned}\bar{i}_t &= \eta + z_t \tau_j + v_t & (3) \\ t &= T_{j-1} + 1, \dots, T \\ j &= 1, \dots, m + 1\end{aligned}$$

$\bar{i}_t = i_t - i_t^{im}$ represents the deviation of fed funds rate from the implied Taylor rule. η is a constant term. z_t is a vector of covariates. τ_j is the corresponding vector coefficient. v_t is the random term. Also, $z_t \sim i.i.d N(1, 1)$ and $v_t \sim i.i.d N(0, 1)$ and both are uncorrelated. The $t = T_1, \dots, T_m$ captures the break points. The focus is to estimate the regression and identify the number of the breaks and the breakpoints.

The procedure sequentially tests the null of l versus $l+1$ breaks. The test starts with l number of break point, $l \in (0, 1, \dots)$. Then, the F-statistics, $F_T(l+1|l)$ is tested against the null. If null fails to reject, the test is done, no structural breaks exist. By rejecting the null, the procedure is repeated by sequentially increasing l until the null cannot be rejected. Andrew (1993) procedure also yields parallel results. That is, allowing the

¹ Two deviations are constructed: deviation from the implied Taylor rule (4) and the deviation from the implied modified Taylor rule (19) - where $\beta, \gamma, \pi^*, \bar{r} = 0.5, 0.5, 2, 2$ respectively and \bar{r}_t is the natural rate of interest.

Table 1: Multiple Structural Break Tests

SupF sequential test	Constant Natural Rate		Time-Varying Natural Rate		
	C.V (5%)	Break Dates	F. Stat	Break Dates	F. Stat
SupF(1 0)	8.5	1986:Q4	160.4*	-	-
SupF(2 1)	10.13	2002:Q1	26.0*	2002:Q1	69.2*
SupF(3 2)	11.14	2010:Q2	29.84*	2010:Q2	16.5*

- C.V ~ Bai-Perron Critical Value, * $P < 0.05$, trimming of 0.15, 5 max breaks allowed
- Bai-Perron test of $L+1$ Vs L , sequentially determined breaks

first l obtained from the regression to be the global minimizer of the residual sum of the square, tested by Sup $F_T(l+1|l)$. The Bai and Perron (2003) trimming parameter, $\epsilon = 0.15$ and the maximum number of breaks, $m = 5$ are used for obtaining the break dates.

Table 1 reports the test results for the multiple breaks in the fed funds rate using both the constant and time-varying natural interest rate models. The tests depict evident structural changes in the Fed's policy behavior. For constant natural rate data, three breaks are identified summing up to four monetary policy regimes between 1980 to 2019. The break dates identified are; 1986:Q4, 2002:Q1 and 2010:Q2. However, using the implied time-varying natural rate model (19), the test significantly identified two major breaks, 2002:Q1 and 2010:Q2. The second test overlooked the break in 1987. The test results are remarkably similar using the Andrew (1993) multiple break test.

4.2 The Baseline

Equation (5) is the reduced version of (1) and summarizes the simple optimal linear rule that minimizes the symmetric quadratic loss function of the central bank (Castrol, 2011). According to Taylor principle, both $1 + \beta$ and γ are the key response parameters. By simplification, equation (1) can be rearranged as:

$$i_t = \bar{r} - \beta\pi^* + (1 + \beta)\pi_t + \gamma y_t + \xi_t \quad (4)$$

$$i_t = \theta + \psi\pi_t + \gamma y_t + \xi_t \quad (5)$$

$\psi \equiv 1 + \beta$ is the interest rate response to inflation. $\theta \equiv \bar{r} - \beta\pi^*$ is the time-invariant intercept and composed of a natural rate of interest and fraction of inflation target. This type of rule implies both long-run parameters are constant. From (5), it is possible to derive the implicit inflation target, π^* , practically pursued by the Fed and the implicit policy response to inflation, ψ^* . The implicit value depicts the model-based long-run response to inflation at the chosen inflation target and nominal natural rate of interest. These parameters are constructed using the long-run averages of nominal interest rates and the inflation target.

$$\pi^* = \frac{\bar{r} - \theta}{\psi - 1} \quad (6)$$

$$\psi^* = \frac{\bar{r} + \pi^* - \theta}{\pi^*} \quad (7)$$

The traditional Taylor rule has received a mixed review from critics. Svensson (1999) underscores the importance of traditional policy rule of inflation targeting in a backward looking model. On the other hand, Woodford (2003) draws attention to time-varying equilibrium interest rate in policy function. Laubach & Williams (2016) and the update in Holston et al. (2017) provides the US varying natural rate estimates.

Clarida et al.(1999) specifies policy rules differently based on two facts. The first is the argument that the central banks react to the expected rather than the lagged inflation. The second is that the central banks do not have complete information available at the time of making policy. Fundamentally, it is instructive to think that the central banks respond to the macroeconomic aggregates using broad imperfect information.

$$i^* = \bar{r} + \psi(\mathbb{E}[\pi_{t+n}|I] - \pi^*) + \gamma(\mathbb{E}[Y_t|I] - Y_t^*) \quad (8)$$

i_t^* is the short-term (*nominal*) policy rate target. I is the information set available to the central bank. \mathbb{E} is the expectation operator. \bar{r} is the underlying equilibrium nominal interest rate/natural nominal rate which comprises the natural real rate and inflation expected in future date, $\mathbb{E}[\pi_{t+n}|I]$. Y_t is the real GDP and Y_t^* is the trend of real GDP. By expansion, it is easy to arrive at equation (9) and to ease the model estimation, let $y_t \equiv 100(Y_t - Y_t^*)/Y_t^*$ and $\theta \equiv \bar{r} - \psi\pi^*$ in equation (10).

$$i_t^* = \bar{r} - \psi\pi^* + \psi\mathbb{E}[\pi_{t+n}|I] + \gamma(\mathbb{E}[Y_t|I] - Y_t^*) \quad (9)$$

$$i_t^* = \theta + \psi\mathbb{E}[\pi_{t+n}|I] + \gamma(\mathbb{E}[y_t|I]) \quad (10)$$

To provide an adaptable monetary policy the central banks review past interest rate before deciding on new policy². Therefore, equation (10) requires a smoothing treatment to prevent sharp policy reversal between two periods.

$$i_t = \rho i_{t-1} + (1 - \rho)i_t^* + \mu_t \quad (11)$$

Where i_t is the actual policy rate, i_t^* is the target nominal interest rate, $\rho \in [0,1]$ is the degree of interest rate smoothing (*weight*) and μ_t is the i.i.d exogenous random shock. Substituting equation (10) into (11) results in the following constructs.

$$i_t = \rho i_{t-1} + (1 - \rho)[\theta + \psi\mathbb{E}[\pi_{t+n}|I] + \gamma(\mathbb{E}[y_t|I])] + \mu_t \quad (12)$$

$$i_t = \rho i_{t-1} + (1 - \rho)\theta + (1 - \rho)[\psi\mathbb{E}[\pi_{t+n}|I] + \gamma(\mathbb{E}[y_t|I])] + \mu_t \quad (13)$$

For ease of estimation, equation (13) is simplified as:

$$i_t = \rho i_{t-1} + (1 - \rho)\theta + (1 - \rho)\psi\pi_{t+n} + (1 - \rho)\gamma y_t + \xi_t \quad (14)$$

Equation (14) is popularly regarded as the modernized Taylor Rule. $\xi_t \equiv -(1 - \rho)[\psi(\pi_{t+n} - \mathbb{E}[\pi_{t+n}|I]) + \gamma(y_t - \mathbb{E}[y_t|I])] + \mu_t$ is the error term and comprises a stochastic exogenous term and the forecast error of inflation and output. The derivation of the implicit inflation target and response to inflation is similar to (6) and (7). Nonetheless, OLS econometric technique (14) would be impossible as it violates the Gauss-Markov assumption of zero conditional mean because both the output gap and inflation are components of ξ_t , such that $\mathbb{E}[\xi_t|\pi_{t+n}, y_t] \neq 0$ provides incorrect moment conditions for the population. Hence, to consolidate the complication in the estimation, equation (14) requires vector of instrument variables z_t that are correlated with π_{t+n}, y_t but uncorrelated with ξ_t, μ_t , that is, $\mathbb{E}[\pi_{t+n}, y_t|z_t] \neq 0$ and $\mathbb{E}[\xi_t|z_t] = \mathbb{E}[\mu_t|z_t] = 0$ that demonstrate the correct moment conditions for the population. This vector represents the information set available to the central bank at the time of deciding policy rate. As a norm, this study resolves to the Generalized Method of Moment (GMM) estimation technique. Although equation (14) is adaptable to any instrument-based estimation mechanisms, GMM estimation provides the advantages of arriving at the most efficient parameters. As the case warranted in each sample, this study used up to four lags of inflation, output gap and growth in price index as the instrument variables.

Single equation linear GMM rationalizes the unbiasedness and consistency of the results in equation (14) given the following conditions:

Consider the vector form of linear equation analogous to equation (14)

$$i_t = v_t \lambda + \xi_t, \quad t = 1, \dots, n \quad (15)$$

v_t is a $K \times 1$ vector of explanatory variables, λ is the vector of unknown parameters and ξ_t is the stochastic error term. Since λ is inconsistent and biased, it thus requires $H \times 1$ vector of instrumental variables z_t . Given

² Central banks smooth the policy rate curve to avoid loss of credibility that can result from sharp policy reversal. Other theoretical reasons are: presence of ZLB, unquantifiable economic shocks with some exogenous probabilities, presence of transaction frictions or fear of financial market disruption

that w_t is vector of all variables including the instrumental variables in equation (15) (i_t, v_t, z_t) and follows a stationary stochastic process, then z_t satisfy H orthogonality condition if:

$$\mathbb{E} [g_t(w_t, \lambda)] = \mathbb{E} [z_t \xi_t] = \mathbb{E} [z_t(i_t - v_t \lambda)] = 0 \quad (16)$$

Where $g_t(w_t, \lambda) = z_t \xi_t = z_t(i_t - v_t \lambda)$. Simplifying equation (16) results in

$$\sum_{z \otimes i} = \sum_{z \otimes v} \lambda \quad (17)$$

$\sum_{z \otimes i} = \mathbb{E} [z_t i_t]$ and $\sum_{z \otimes v} = \mathbb{E} [z_t v_t^*]$. For λ to be identified $H \times K$ matrix $\mathbb{E} [z_t v_t^*] = \sum_{z \otimes v}$ be of full rank K which is necessary for λ to be unique solution of equation (17). Similarly, identification of λ requires the order conditions $H \geq K$. That is, for λ to be identified in the equation (15) the number of instruments z_t must be greater than or equal to the number of the set of endogenous regressors v_t . Otherwise, the model is under-identified, hence the vector of parameters λ in the structural equation (15) is impossible.

Since it is most likely equation (15) will be over-identified considering the number of instruments available the Hansen (1982)'s J -statistics test of overidentifying restriction is examined for model misspecification. Where $J \sim \chi^2 (H - K)$. If some moment conditions are not satisfied, $\mathbb{E} [z_{kt} \xi_t] = \mathbb{E} [z_{kt}(i_t - v_t \lambda)] \neq 0$ for some k 's in (16) then the reported J -statistics will be larger relative to χ^2 ($df = H - K$). Therefore, there exists some redundant exogenous instrumental variables. Otherwise, the over-identifying restrictions cannot be rejected. The GMM procedure shows that by satisfying the above conditions the vector λ is consistent and asymptotic normal. Hence, equation (14) can be estimated.

Non-Linear Model

This study further examines whether the Fed policy preferences exhibit asymmetry, determined by the magnitude of the threshold variable such as current or lag value of interest rate, inflation, output, unemployment. Castro (2011) emphasizes that policy responses are best characterized as non-linear if the central banks attach different weights to negative and positive output gap and inflation in its loss function. We explored this analysis with threshold regression.

The widely used threshold autoregressive models in the literature are those proposed by Tong (1990) and Hansen (1999) where lag dependent is the threshold variable used for demarcating the regression into the regions. Whereas, this study used the output gap as a threshold variable because it provides coherent results compared to other choices of threshold variables.

By extension, equation (18) combines threshold variables with the equation (5)³ to form two regions endogenously chosen by the threshold χ . Region 1 defines the subset of the total sample where the threshold variable y_t is less than or equals the threshold χ and region 2 where the χ is greater than y_t . This approach is effective for identifying possible changes as it offers a smooth endogenous regime shifts.

$$\begin{aligned} i_t &= \theta_1 + \psi_1 \pi_t + \gamma_1 y_t + \xi_t & \text{if} & \quad -\infty < y_t \leq \chi \\ i_t &= \theta_2 + \psi_2 \pi_t + \gamma_2 y_t + \xi_t & \text{if} & \quad \chi < y_t \leq \infty \end{aligned} \quad (18)$$

$\theta_1, \psi_1, \gamma_1$ and $\theta_2, \psi_2, \gamma_2$ are the policy parameters in the region 1 and 2 respectively. i_t, π_t and y_t are the subset of data series for each region. Our focus is to investigate whether the Fed's behavior exhibits asymmetry given a low or a high output gap y_t .

Baseline Results

The results offer a new perspective to the Fed's policy actions between 1980 and 2019. The presence of structural breaks in the Fed rate data motivates separate regression analyses in this study. Table 2 presents the

³ This study only examined non-linearity in traditional model due to estimation complexities arising from other model

estimation results of the baseline models (5) & (14) with the identified samples; 1980:Q1 - 1986:Q4, 1987:Q1 - 2002:Q1, 2002:Q2 - 2010:Q2, 2010:Q3 - 2019:Q4 and the full sample 1980:Q1 - 2019:Q4. The table also presents the estimates' standard errors, the threshold regression results, the implicit inflation target (π^*) and the implicit policy response to inflation (ψ^*).

Apparently, policy response to inflation diminished in the samples; 2002:Q2 - 2010:Q2, 2010:Q3 - 2019:Q4. One explanation we arrive at is that variation in inflation data is insufficient in the two periods. We also infer that these outcomes may have resulted from policy inconsistency. As a result, Fed's policy is insensitive to inflation during these periods. In spite of this, the response to output gaps improved generally. We observe that this result contradicts the trade-off between inflation and output. For the full sample, the Taylor's principles; $\psi > 1$, $\gamma > 0$ abide. In reaction to the inflation gap, the Fed raises the nominal interest rate significantly enough to stabilize the price level. Comparing the full sample results to the sample results show that econometric analysis is sensitive to the breaks in the data. The estimations reveal a slow down in the natural real interest rate, θ . The results also show that smoothing interest rate is relevant for policy consistency. More so, the result reveals that the Fed's policy exhibits a non-linear preference under different macroeconomic situations. Nevertheless, the preference can be regarded as being partial because the output gap is insignificant in the second regime. It is interesting that all the estimated parameters are statistically significant. More importantly, Hansen's J -tests of overidentifying restrictions fail to reject all the results. Thus, the structural parameters are identified, consistent and asymptotic normal. Our findings connect with the literature as follows.

The study supports the modernized policy rule of Clarida, et al. 1999 but rejects the traditional rule of Taylor, 1993. The study lends support to the declining natural rate of interest asserted in Bullard, 2018; Laubach & Williams, 2016 but refutes the findings of Taylor & Wieland (2016). The study partially supports the findings of Zhu and Chen, 2017; Beckmann et al., 2017; Gogas et al., 2018 on policy asymmetry but refutes the findings of Castro, 2011. The study supports the Nikolsko- Rzhnevskyy et al. (2019) on multiple structural breaks in the fed rate. Our analysis contradicts the second-order partial smoothing treatment demonstrated in Clarida et al. (1999).

To have a feel of the result predictions in each sample and to provide insights to the disparity in the estimates, Fig.3a depicts the fed funds rate (R^{FED}) and the baseline predictions (R^C , R^T), and Fig.3b shows the deviations from policy rule ($R^{FED} - R^C$, $R^{FED} - R^T$). R^T is the traditional rule prediction and R^C is the modernized rule prediction. From the results, it is obvious the outcomes of the traditional (5) and the modernized (14) rule offer parallel findings about the Fed's policy stance, but the predictions remarkably differ in size.

The estimates of the sample, 1980:Q1 - 1986:Q4, show that interest rate moved to stabilize the inflation and output gap. However, the traditional policy rule (5) demonstrates a downward bias, $\psi = 1.65\%$, $\gamma = 0.07\%$ relative to the modernized rule estimates; $\psi = 1.84\%$, $\gamma = 0.22\%$. In both cases, the estimates show that the Fed lived up to the expectation regarding the price stabilization objective. In Fig. 3b (*first column*), although the traditional rule depicts a gradual adjustment of the fed rate to one prescribed by rule before 1982, the result insignificantly reflects the fine-tuning policy strategy adopted during the period. The deviation from modernized rule shows an alternating spike shortly before 1982. An explanation for these spikes is possible policy glitches⁴ negligently motivated by the Fed. In the modernized rule, the smoothing parameter $\rho = 0.43$, *somewhat low for the sample*, keeps the natural real rate in a more stable distance. We infer that the lower ρ , relative to estimates in the later samples, could be the cause of the spikes in the policy rate. The takeaway from this result is that interest rate smoothing has improved the Fed's policy over the year. Given the high level of inflation started within the sample the estimated inflation target (π^*) is fairly large.

⁴ The volatility in the Fed's instrument settings caused much anxiety about the monetary policy behavior in early 1980s. Due to the 1970s inflation crisis the money and credit growth acutely slowed down in the years between 1979 - 1980. The Fed gradually reversed the policy tightening by a small growth in credit and money but the market perception of the stringent policy remained unchanged. In 1982, the Fed continued with the steady money and credit growth. Coupled with the other financial deregulation and innovations, the Fed's interest rate policy exhibited a little abnormality.

Table 2: Baseline Models

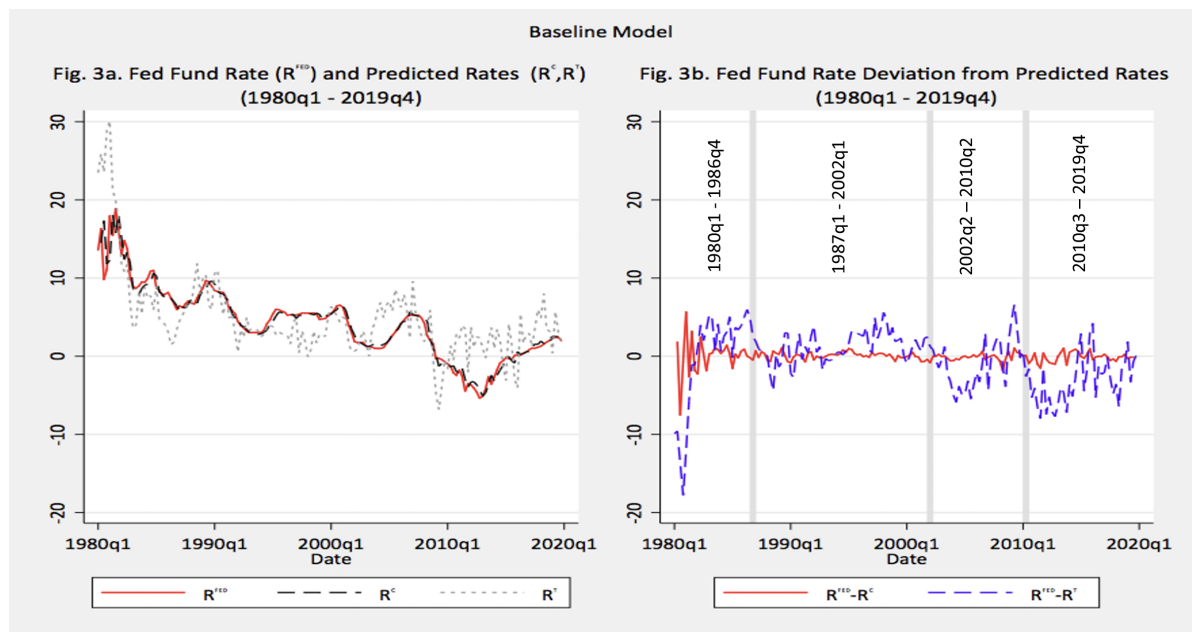
	Traditional Model					Modernized Model					
	θ	ψ	γ	$[\pi^*]$	$[\psi^*]$	ρ	θ	ψ	γ	$[\pi^*]$	$[\psi^*]$
1980:Q1 – 1986:Q4	4.16 (0.02)	1.65 (0.01)	0.07 (0.00)	10.5	2.88	0.43 (0.00)	4.11 (0.03)	1.84 (0.01)	0.22 (0.00)	8.25	2.39
1987:Q1 – 2002:Q1	1.81 (0.16)	1.74 (0.06)	0.51 (0.03)	5.15	2.62	0.83 (0.01)	0.69 (0.40)	2.30 (0.15)	1.12 (0.07)	3.81	3.06
2002:Q2 – 2010:Q2	6.17 (0.10)	-0.89 (0.05)	1.15 (0.02)	2.10	2.43	0.77 (0.02)	4.07 (0.24)	-0.04 (0.11)	1.18 (0.05)	1.80	0.13
2010:Q3 – 2019:Q4	1.89 (0.06)	-0.32 (0.02)	1.59 (0.02)	2.14	0.65	0.83 (0.02)	2.24 (0.18)	-0.19 (0.07)	1.40 (0.05)	3.13	-0.82
Total Sample	-2.33 (0.66)	2.96 (0.14)	0.43 (0.13)	3.38	1.51	0.89 (0.01)	-1.78 (0.74)	3.05 (0.31)	1.47 (0.14)	2.97	3.30
Threshold Model (Total Sample)											
Region 1	-5.51 (1.14)	2.69 (0.40)	2.63 (0.93)								
Region 2	0.78 (0.42)	1.63 (0.15)	-0.22 (0.41)								

- Std. Error in the parentheses
- The implicit inflation target (π^*) and the implicit response to inflation (ψ^*) are estimated using the sample averages of long-run trend of policy interest rate and inflation. The threshold $\chi = -2.37$ divides the total sample into regions 1 & 2.

The sample 1987:Q1 and 2002:Q1 marks the period of Alan Greenspan's policy as widely remarked as the "Great Moderation". The modernized rule estimation reveals that the Fed's policy exhibits minimum deviation. In fact, our result shows that the Fed strongly adhered to the rule. Fig.3a demonstrates that the Fed rate and the prediction closely moved together. We rationalize this policy improvement on the weight (ρ) increment. ρ remarkably increased to 0.83, depicting a strong smoothing process. The traditional model continued to over-exaggerate the prescribed target. The absence of smoothing treatment also plays out significantly in this sample. To anchor the claim that the smoothing treatment offers a central role in the policy setting, the traditional Taylor rule prescribes rates overly high above the policy requirement as against the modernized rule prediction. Therefore, the major disparity in this class of baseline model arises from smoothing treatment. Generally, the estimates demonstrate that Fed's policy was well responsive to inflation and output gap; $\psi = 1.74\%$, $\gamma = 0.51\%$ and $\psi = 2.30\%$, $\gamma = 1.12\%$ for the traditional and the modernized models respectively.

The sample results of 2002:Q2 -2010:Q2 and 2010:Q3 - 2019:Q4 demonstrate negative responses to inflation. These outcomes are the same for both baseline models; actually these do not characterize the principles expected in the standard policy rules. As indicated earlier, we make the case for two rationales for a negative relationship. First, to identify estimates in the policy function the inflation and output gap must possess sufficient variations, and the sample period must be long enough. Obviously, the sizes of these samples are relatively small and inflation has less variation. According to Stock and Watson (2012), there was a "Missing Inflation". More so, Fig.1b shows that inflation struggles to maintain the 2% target. Second, the US monetary policy behavior during these periods has earlier been characterized as being unconventional, erratic and unstable (see Taylor, 2009 & 2014; Kroeger et al., 2018). Farmer (2012) described the unconventional Fed's behavior - due to the effect of ZLB - as being effective in averting deflation. Nonetheless, we observe that, even though there is less variation in inflation, the output gap displays a significant level of variation. Although we were tempted to rely on the full sample, since it provides a sufficient long sample and the desired variation in the data, we realized that doing so provides an incoherent explanation to contradicting results in the earlier literature as compared to when we acknowledged the evidence of structural breaks in the data. For the purpose of analysis, this study explores the implication of the sample results with the notion that there was a dramatic change in the Fed's policies during those periods. Given that this is true, the estimates from these regressions can be rationalized as consistent and efficient as the Generalized Method of Moment (GMM) technique is well suited for a relatively small sample.

Pursuing the sample results from lack of sufficient variation and policy shift stand-point, we interpret the dynamics in fed rate for the periods 2002:Q2 -2010:Q2 and 2010:Q3 - 2019:Q4. Due to the insufficient variation in the inflation, the Fed redirected focus to the supply side in actualizing its (dovish) policy objective. Response to business cycles increased above one percentage point in the two samples. Obviously, this re-



response shift was motivated to incentivize the factor and goods markets during the recession and exercise policy tightening during a heated economy. Implication derived from this policy pursuit is that when inflation is below the target the Fed pursues policies that influence the supply side in a way that is synonymous to price stabilization. The smoothing parameter, $\rho = 0.77; 0.83$, significantly reveals that the Fed follows a pattern in deciding policy. The sample regressions generate interesting implicit inflation targets close to the desired 2%. The implicit target for the two sample regressions in the traditional model are: $\pi^* = 2.10\%$ and 2.14% ; and implicit targets for the modernized rules: $\pi^* = 1.80\%$ and 3.13% . As the traditional rule does not allow for the smoothing treatment and forward-looking behavior of the inflation, the outcome of the predictions (Fig.3) enormously differ from the fed rate and the prediction from the modernized model.

The non-linearity test in policy response reveals that over the entire sample the Fed's policy preference can be described to be partially non-linear. The results of this test are reported at the bottom-left of Table 2. The threshold is estimated at $\chi = -2.37\%$. This indicates the Fed switches regime when the output gap is greater than χ . Below this threshold level, the results show that the Fed is more aggressive on both inflation ($\psi = 2.95\%$) and output gap ($\gamma = 1.58\%$). Above it, the Fed still actively pursues inflation control ($\psi = 1.37\%$) but with a negative reaction to the business cycle. These results show partial asymmetry but the estimated parameters seem to possess some limitations. First, this test is conducted on the full sample without consideration to structural breaks in the data results⁵. Second, the test is conducted with traditional Taylor rule. We understand that these limitations can affect the consistency of the outcome of the results. Therefore, this study can be extended.

4.3 Time-Varying Natural rate Treatment

Woodford (2003) spurred research on time-variation in the US natural rates of interest. Over the years, significant bodies of studies have provided estimates for the underlying natural rates; for surveys, see Woodford, 2003; Barsky, et al., 2014; Kasyanenko & Papell, 2019. Recently, Laubach & Williams, 2016; Cúrdia et al., 2015; Holston et al., 2017; show evident decline in natural rate. To accommodate this piece of evidence in the policy

⁵ Because non-linear test performs very poorly with small samples, thus, conducting such analysis on individual samples identified by the break test may diminish the efficiency of the results

frameworks, the baseline model is adjusted for the time-varying natural rate of interest. We use the Holston et al. (2017) estimates of natural rate of interest because it is most acknowledged in the literature.

The traditional Taylor is modified by replacing the invariant nominal interest (r) in equation (5) with the Holston et al. (2017) estimates of natural rate of interest (\bar{r}_t). Where $i_t^\dagger \equiv i_t - \bar{r}_t$ and $\theta \equiv -\beta\pi^*$

$$i_t^\dagger = -\beta\pi^* + (1 + \beta)\pi_t + \gamma y_t + \xi_t \quad (19)$$

$$i_t^\dagger = \theta + \psi\pi_t + \gamma y_t + \xi_t \quad (20)$$

Also, the modernized Taylor rule (14) is modified for varying nominal natural rate of interest as follows. Let $i_t^\dagger \equiv i_t - (1 - \rho)\bar{r}_t$ and $\theta = -\psi\pi^*$

$$i_t = \rho i_{t-1} + (1 - \rho)(\bar{r}_t - \psi\pi^*) + (1 - \rho)\psi\pi_{t+n} + (1 - \rho)\gamma y_t + \xi_t \quad (21)$$

$$i_t - (1 - \rho)\bar{r}_t = \rho i_{t-1} + (1 - \rho)(-\psi\pi^*) + (1 - \rho)\psi\pi_{t+n} + (1 - \rho)\gamma y_t + \xi_t \quad (22)$$

$$i_t^\dagger = \rho i_{t-1} + (1 - \rho)\theta + (1 - \rho)\psi\pi_{t+n} + (1 - \rho)\gamma y_t + \xi_t \quad (23)$$

$$\pi^* = \frac{-\theta}{\psi - 1} \quad (24)$$

$$\psi^* = \frac{\pi^* - \theta}{\pi^*} \quad (25)$$

Results for the Time-Varying Treatment

Table 3 reports the (*modified*) rule results of the samples identified in the structural break tests (1980:Q1 – 2002:Q1, 2002:Q2 – 2010:Q2, 2010:Q3 – 2019:Q4) and the full sample (1980:Q1 0 2019:Q4). At the bottom-left of the table is the results for the asymmetric test. The table also reports the implicit policy responses, ψ^* . The predictions (R^{CV} , R^{TV}) for these alternative estimations are depicted in Fig.4. R^{TV} is the predicted rates from the modified traditional rule and R^{CV} is the predicted rate from the modified modernized rule. Overall, the result outcomes slightly parallel the baseline results but the major differences are underscored as follows.

The result of the sample (1980:Q1 – 2002:Q1) replicates the combined outcomes of the baseline model. Fed's policy was active at stabilizing price and minimizing the effect of the business cycle. However, the response to the business cycle in the modified traditional Taylor rule is insignificant and is averagely little. The modified modernized rule shows that the Fed attached larger weight, $\rho = 0.75$, on the average, to past interest rate when deciding on policy; similar to the higher weight observed in the baseline estimations. The estimated implicit response to inflation, ψ^* , also closely aligns with the Fed's practices; 1.38%, 2.59% for the modified traditional and the modernized rules respectively.

The estimations of the samples (2010:Q3 – 2019:Q4, 1980:Q1 0 2019:Q4) provide concrete result comparison between the baseline and the modified policy rule (Table 2 and Table 3). Although the policy responses reported in the two tables have slightly different parameters, the generalized findings are analogous. Similar to the previous discussion, we show that response to inflation remains absurd but there was improvement to responses to the business cycle. The responses to inflation were negative in the modified traditional model, $\psi < 0$, and $\psi < 1$ in the modified-modernized models. In these two cases, inflation is frail in the Fed's policy equation. It appears apparently that such a policy stance can lead to a self-fulfilling burst in inflation but policy response to the business cycle is large enough to dampen an unanticipated surge in the inflation.

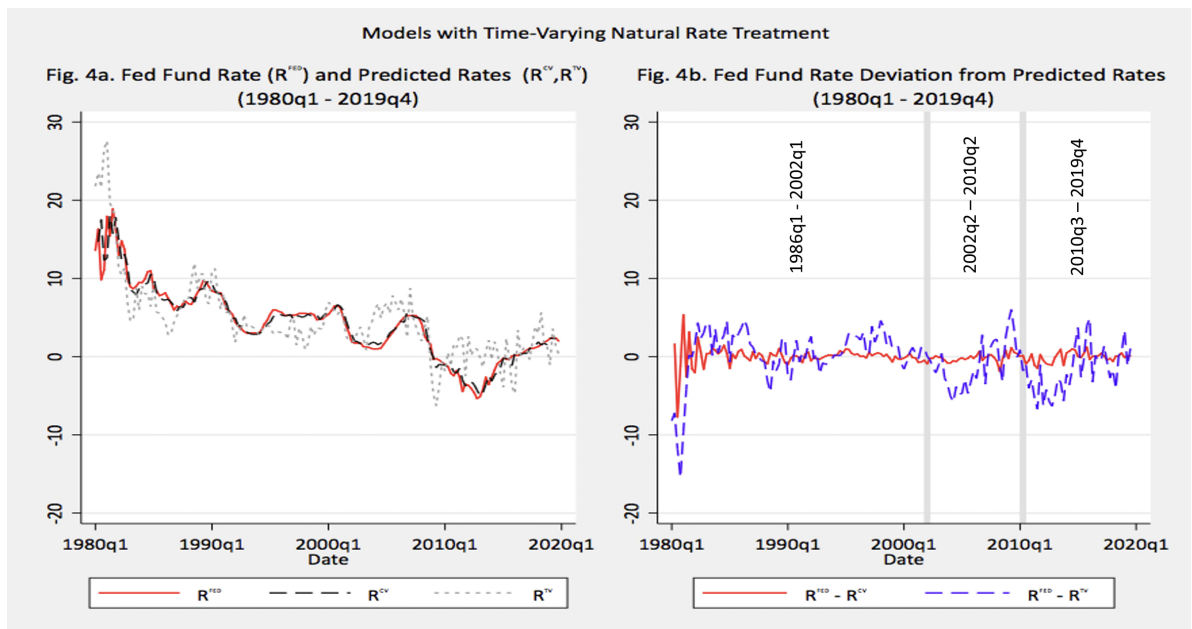
The full sample (1980:Q1 – 2019:Q4) averages demonstrate responses to inflation, $\psi = 2.51\%$ and business cycle, $\gamma = 0.29\%$ conform to the Taylor principle. The smoothing parameter is also sizable, $\rho = 0.85$. Over the entire sample, US monetary policy behavior can be said to be price stabilizing. The implicit response to inflation, $\psi^* = 1.68\%$, is close to the implied policy response, 1.5%, suggested by Taylor (1993).

The full sample results support the non-linearity in the US policy behavior with the threshold estimate, $\chi = -2.73\%$. Similar to the baseline, below the threshold, the Fed's reaction to inflation and output gap are aggressive while it is less aggressive to inflation above the threshold.

Table 3: Models with Time-Varying Natural Rate Treatment (Modified)

	Traditional Model				Modernized Model				
	θ	Ψ	Γ	$[\Psi^*]$	ρ	θ	ψ	γ	$[\Psi^*]$
1980:Q1 – 2002:Q1	1.60 (0.30)	1.98 (0.06)	0.002 (0.06)	1.38	0.75 (0.02)	2.01 (0.46)	2.22 (0.17)	0.45 (0.09)	2.59
2002:Q2 – 2010:Q2	-4.18 (0.09)	-1.04 (0.04)	0.93 (0.01)	2.48	0.82 (0.02)	-1.29 (0.36)	0.13 (0.16)	1.00 (0.08)	1.96
2010:Q3 – 2019:Q4	-1.55 (0.08)	-0.40 (0.02)	1.60 (0.03)	2.23	0.91 (0.01)	-2.72 (0.36)	0.06 (0.10)	1.21 (0.10)	0.50
Total Sample	3.71 (0.60)	2.51 (0.13)	0.29 (0.13)	1.68	0.85 (0.02)	3.38 (0.57)	2.62 (0.21)	1.02 (0.11)	1.64
Threshold Regression (Total Sample)									
Region 1	-7.44 (0.90)	2.95 (0.26)	1.58 (0.53)						
Region 2	-0.93 (0.31)	1.37 (0.11)	-0.25 (0.37)						

- Std. Error in the parentheses
- The implicit inflation target (π^*) and the implicit response to inflation (ψ^*) are estimated using the sample averages of long-run trend of policy interest rate and inflation. The threshold $\chi = -2.73$ divides the total sample into regions 1 & 2.



4.4 Second-Order Partial Treatment

Alternative policy mechanism studied in this paper is second-order partial adjustment mode. We allowed standard modernized Taylor to follow two lags weight, ρ_1, ρ_2 . Such policy setting is justified when the central banks use both the first and second lags for smoothing processes. Usually, the first lag treatment is sufficient to provide a smooth interest rate curve but a short-term disruption in the interest rate may occur if there is an unanticipated exogenous shock. Our survey of literature indicates no significant amount of recent studies have corroborated the piece of evidence reported in Clarida et al.(1999). We extended the author empirical piece using both baseline and modified. Equation (26) represents the model with constant natural rate of interest and (27) represents model with time-varying natural rate of interest.

$$i_t = \sum_{j=1}^2 \rho_j i_{t-j} + (1 - \sum_{j=1}^2 \rho_j) [\theta + \psi \pi_{t+n} + \gamma y_t] + \xi_t \quad (26)$$

$$\theta \equiv \bar{r} - \psi \pi^*$$

$$i_t - (1 - \sum_{j=1}^2 \rho_j) \bar{r}_t = \sum_{j=1}^2 \rho_j i_{t-j} + (1 - \sum_{j=1}^2 \rho_j) [\theta + \psi \pi_{t+n} + \gamma y_t] + \xi_t \quad (27)$$

$$\theta \equiv -\psi \pi^*$$

Where $\sum_{j=1}^2 \rho_j \in [0,1]$. Here, the sum of ρ_j is tested for significance. The derivation of the implicit inflation target, π^* and response to inflation, ψ^* , follow equations (6), (7) & (25).

Results for the Second-Order Partial Treatment

Table 4: Modernized Models with Second - Order Partial Treatment

	Baseline Model						Time-Varying Treatment				
	$\rho_0 + \rho_1$	θ^1	Ψ	γ	$[\pi^*]$	$[\psi^*]$	$\rho_0 + \rho_1$	θ^2	ψ	γ	$[\psi^*]$
1980:Q1 –	0.55	3.54	2.15	0.51	6.47	2.50	0.77	2.91	2.64	0.74	2.37
1986:Q4	(0.04)	(0.13)	(0.05)	(0.04)			(0.08)	(0.51)	(0.16)	(0.08)	
/2002Q1											
1987:Q1 –	0.86	1.69	1.80	0.64	4.92	2.64	-	-	-	-	-
2002:Q1	(0.05)	(0.29)	(0.11)	(0.06)							
2002:Q2 –	0.77	4.83	-0.40	1.07	1.88	-0.22	0.82	-2.31	-0.35	0.87	3.09
2010:Q2	(0.07)	(0.19)	(0.07)	(0.03)			(0.06)	(0.36)	(0.14)	(0.04)	
2010:Q3 –	0.84	2.37	-0.05	1.40	3.15	-0.89	0.91	-3.01	-0.13	1.24	2.18
2019:Q4	(0.09)	(0.34)	(0.09)	(0.07)			(0.08)	(0.80)	(0.18)	(0.12)	
Total Sample	0.89	-2.65	3.54	1.66	2.74	3.63	0.85	3.95	2.95	1.17	1.14
	(0.01)	(0.66)	(0.22)	(0.15)			(0.09)	(0.56)	(1.72)	(0.14)	

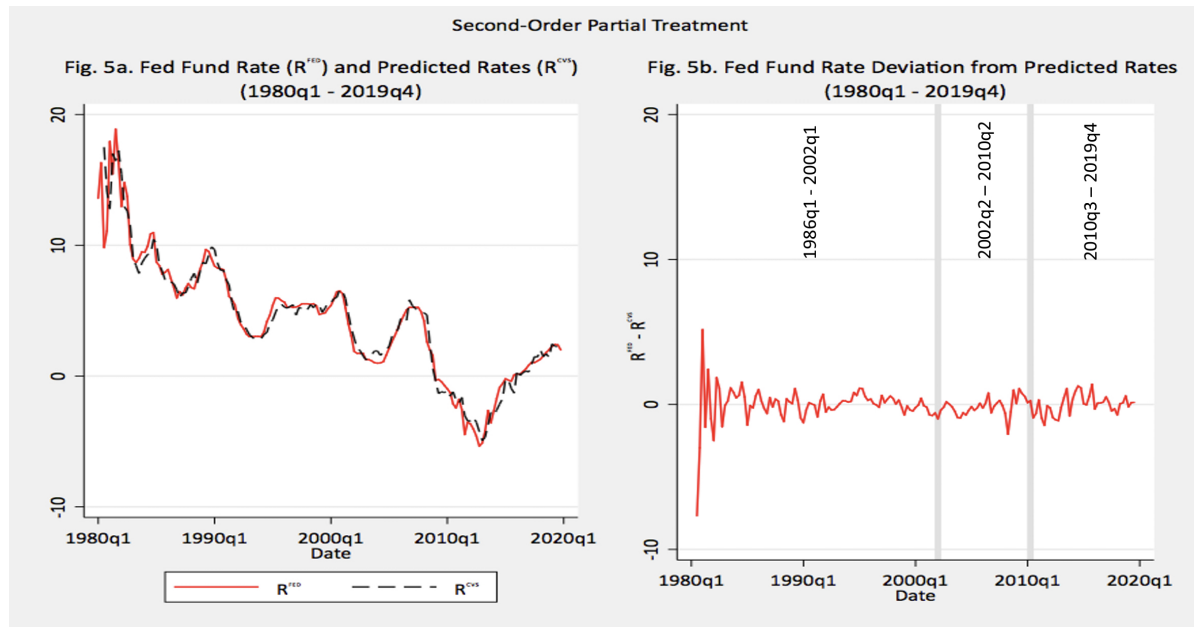
- Std. Error in the parentheses
- The implicit inflation target (π^*) and the implicit response to inflation (ψ^*) are estimated using the sample averages of long-run trend of policy interest rate and inflation. $\rho_0 + \rho_1$ is the sum of the weight on first and second lags of policy interest rate.

Table 4 reports the estimation from second-order partial adjustment models. We observe findings consistent with previous result comparisons. The model with constant natural rate of interest is upward bias of the time-variant models. The results demonstrate the same abnormal response between periods 2002:Q2 - 2019:Q4; $\psi < 0$ and $\gamma > 1$. On the average, over the years the Fed increasingly accords preference for smoothing processes, $\rho_1 + \rho_2$.

The inflation target gradually falls as inflation becomes more less variant. Over the entire sample (1980:Q1 - 2019:Q4), the Fed's policy can be described as stabilizing, $\psi > 1$ and $\gamma > 1$. The Fed sufficiently adjusts the nominal interest rate in response to the dynamics of the business cycle. Generally, the study finds little or no support for improvement in second-order partial adjustment models relative to first-partial adjustment. The predicted rates from these models are depicted in Fig. 5.

5 Conclusion and Policy Implications

This study is motivated by the periodic policy shifts and asymmetry observed in the Fed's behaviour. It discusses relevant issues surrounding policy setting and makes the following contributions First, it probes the presence of structural breaks in the Fed rate. Second, it provides estimations to test asymmetry over cyclical drift in the output. Third, it analyses the usefulness of interest rate smoothing and reports on disparities between alternative policy rules. These estimations were carried out using US data, 1980 Q1–2019 Q4.



The test results show that there were multiple breaks in the Fed's rate and the identified dates correlate with the Fed's reported dates of policy changes. Overall, the results of the full sample reveal that the Fed's policy is one of stabilising prices, also in the samples 1980 Q1–1986 Q4 and 1987 Q1–2002 Q1. We found that, even though the results of the samples 2002 Q2–2010 Q2 and 2010 Q3–2019 Q4 appear to fail Taylor principles, the Fed's policy stance was not weak, as criticised in the literature. Our results show that during the monetary crisis the Fed actively performed policy shifts towards the real sector.

The major findings are as follows. Fed's policy preference is partially asymmetric. The estimation shows better policy improvement with a higher interest rate smoothing treatment. The results show that forward-looking policy settings provide better predictions. Importantly, we found that the baseline policy rule has an upward bias compared to the modified policy rule. This study rejects second partial interest rate smoothing.

Our study makes two important contributions to the literature. At a theoretical level, it derived, tested, and provided solutions to the central bank optimisation problem when policy preference was asymmetric. We translated the quadratic form to a potential nonlinear monetary policy rule that engineers evidence in asymmetries in the objective. At an empirical level, our study indicates that the Fed's monetary policy behaviour follows a nonlinear policy rule. Our study shows that modelling inflation requires considering time variations within regimes. Similarly, evidence of a random path with a long cycle was observed.

Finally, the policy implication of our findings is that smoothing treatment is significantly beneficial during an economic crisis if the Fed adheres to its policy rule. Our results on structural breaks extends the literature. By integrating monetary and fiscal policy, future studies should consider testing structural breaks in time-series analyses, which may provide additional value to the findings of this study.

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