Measuring Monetary Policy: Discretion versus Rules *

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Abstract

In this paper we propose a novel method to measure the strength of commitment versus discretion in monetary policy. We estimate a Taylor-type monetary policy rule with time-varying heteroskedasticity, decomposing the policy into rule-based and discretionary components. Deviations from the committed rule, in form of volatility of a policy shock, are linked to macroeconomic variables, disclosing the nature and strength of discretion of a central banker. We estimate our model for the period 1967-2005 focusing on the determinants of volatility of policy shocks in the United States. The proposed heteroskedastic model provides a better fit to the data than the standard Taylor rule without heteroskedastic shocks. Inflation has positive significant effects on volatility of shocks in the full sample, pre-Volcker and Volcker periods, while during the Greenspan era, the degree of discretion is decreasing in headline inflation, but increasing in core inflation. We also find significant positive association between stock market volatility and policy discretion, but no relationship between the shock volatility and output gap.

Keywords: Monetary policy, Taylor rule, discretion, time-varying volatility.

JEL Classification Codes: C58, E43, E52, E58.

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1 Introduction

Monetary policy has been analyzed extensively in the context of rule-based versus discretionary policies. While the theoretical advancements provide sound explanations to these phenomena, in empirical work it is often difficult to describe the implemented policies as rule-based or discretionary. Although the term "discretion" presumes a certain rule in the recent literature[1], it has initially been perceived as deviation from the rule - the systematic and hence time consistent component of the conducted policy. According to the original contributions of Kydland and Prescott (1977) and Barro and Gordon (1983), a policy rule is considered as "optimal" or "precommitted", whereas deviations from it represent discretionary policy, referred to as "inconsistent" or "shortsighted" solution.

In this paper we propose a methodology to answer the following question: do central banks follow a policy course described by a committed rule, or they rather deviate from that rule systematically, possibly in co-variation with key macroeconomic indicators? In our context, it is of particular interest to study how the deviations from the rule are linked to the dynamics of economy. For instance, whenever there is a temporary inflationary pressure in economy, will it entail a discretionary policy move and a larger deviation from the rule or will the central bank stick to the rule with the objective that the committed rule will bring the economy to its long term path with lower costs?

Evidence about rule-based and discretionary policies has emerged in many recent papers. Taylor (2012) divides the monetary history of the United States into periods of "rule-based" policies, when the policy followed Taylor-type policy rule, and periods of "ad-hoc" or "discretionary" policies, when the policy deviated from the course implied by that rule. Nikolsko-Rzhevskyy et al. (2014) examine the eras of "rule-based" and "discretionary" policies focusing on deviations from the Taylor rule. They investigate periods of "small" and "large" deviations from the Taylor rule, thereby identifying rule-based and discretionary periods in the US monetary policy.

However, rules and discretion to some extent are present in monetary policy in all times. Therefore, the division of the monetary policy history into distinct eras of "rule-based" and "discretionary" policies is rather conventional. As Taylor (2012) points out, distinction between rules and discretion is "more a matter of degree", than a matter of different policies. He argues that rule-based policy is "systematic and more predictable". In contrast, discretionary policy exhibits decisions that are "less predictable and more ad hoc".

Consistent with Taylor (2012) definition of rule-based and discretionary policies, we refer to the volatility of policy shocks as a measure of the discretionary component of the monetary policy. With this formulation, monetary policy commits to the rule and follows it closely in

[1] For analytical derivation of policy rules under discretion and commitment, see Clarida et al. (1999) and Clarida et al. (2000)

times of low volatility of policy shocks. On the other hand, when the volatility is high, monetary policy is more likely to deviate from the rule and exhibit discretion.

We propose a new model-framework for learning the nature of monetary policy in the context of rules versus discretion. The new approach enables to effectively decompose policy response into commitment and discretion components. Monetary policy decisions constitute both commitment and discretionary components, and our model allows to separately explain the two components using a set of macroeconomic fundamentals. In our model, commitment from the central bank to follow a certain policy rule transforms into a deterministic monetary policy rule. Deviation from the policy rule, possibly explained by the fundamentals, will then capture discretion.

We estimate our empirical model for the U.S. economy, covering the period 1967-2005. Our key findings are the following. Overall, suggested heteroskedastic model provides a better fit to the data. Inflation has positive significant effects on volatility of shocks, except for Alan Greenspan's period of chairmanship. During Greenspan's chairmanship, the degree of discretion is decreasing in the temporary component of inflation, but increasing in permanent inflation. This suggests that monetary policy has been more tied to the rule in times of positive temporary shocks and more flexible in times of negative shocks. The output gap is statistically significant only in Alan Greenspan's period. We do not find evidence of discretion persistence in the United States.

The rest of the paper is organized as follows. The relevant literature is briefly discussed in Section 2. We describe the empirical model in Section 3. Data description is in Section 4. Model estimations and the robustness checks are in Sections 5 and 6, respectively. Concluding remarks follow in Section 7.

2 Literature Review

Relatively early literature estimates only backward looking type of policy rules (e.g. Ozlale (2003) and Favero and Rovelli (2003)), in which the issue of time inconsistency is not relevant, since the policy is not a function of variables that have ex post realization. The recent literature examines monetary policy rule in the forward looking framework. Discretionary policies in different time intervals for the U.S. economy have been studied by e.g. Dennis (2004) and Soderstrom et al. (2005), and Salemi (2006) examines the case of commitment.

There are however few papers that test which type of policy (commitment or discretion) is empirically relevant. Givens (2012) estimates a New-Keynesian model of the US economy, in which the forward-looking behavior allows to distinguish two modes of optimization, namely, commitment and discretion. Coroneo et al. (2013) provide an alternative procedure for testing the degree of commitment to time inconsistent optimal plans, relying on set-identification on the basis of the first order conditions.

There are numerous papers testing how well the Taylor rule implied policy can explain actual data[2]. There are some papers estimating monetary policy rules for sets of emerging economies and these are implicit tests of Taylor rules. Fendel et al. (2011) tested perceived Central Bank consistency for emerging markets, looking at the magnitude of estimated coefficient of inflation rate. They considered policy to be consistent if the coefficient of inflation is higher than 1.

The vast majority of papers that test the relevance of Taylor rule in practice focus on the policy response parameters, whereas the regression errors often are out of their scope of analysis. The monetary policy rule is potentially very complex, and it seems reasonable to consider the policy reaction function as the "rule" component of the policy, while deviations from the rule represent the discretionary component. The variance equation captures the dynamics of and possible determinants of volatility of policy shocks or discretion. A few attempts by Sims and Zha (2006), Boivin (2006) and others explicitly allow for time variation in variances of policy shocks and show that the volatility of policy shocks changed significantly during recent decades in United States. However, these papers do not explore the sources of these changes, which we do in this paper.

While monetary policy before Greenspan was more tied to mechanistic restrictions on the conduct of monetary policy, the Greenspan era was characterized by a successful mix of discretionary and rule based monetary policy and has generated voluminous policy debates and scholarly work on the topic (Friedman, 2006).[3] The policy, nevertheless, did not depart from the rule entirely, and it definitely attributed to the success of the Greenspan era (Taylor (2005)). Nevertheless, there is no consensus that monetary policy of the Greenspan era was rather discretionary and instrumental for favorable economic outcomes (e.g., Blanchard and Simon (2001); Orphanides (2003)).[4]

Different from the voluminous literature, we propose a model with conditional heteroskedasticity for estimation of monetary policy rules. The model allows to decompose monetary policy decisions into the rule and discretion components. The use of heteroscedastic model to disentangle the two components has been initiated by Cerqueiro et al. (2011), who identify the determinants of loan granting policy and interpret explained deviation from the loan granting policy rule as evidence of the banks' discretionary use of market power. Agnello and Sousa

[2] For the early literature, see Clarida et al. (2000), Orphanides (2004) and the references therein

[3] Friedman (2006) concludes that the era may stand as the modern day pinnacle of "discretion" rather than "rule".

[4] Orphanides (2003) shows that the systematic component of the monetary policy in the Greenspan era was not much different from earlier times. Kahn (2012) analyzed the transcripts of Federal Open Market Committee (FOMC) during this period and found a large number of references by committee members to monetary policy rules. On the contrary, Blinder and Reis (2005) conclude that *"Federal Reserve policy under his chairmanship has been characterized by the exercise of pure, period-by-period discretion, with minimal strategic constraints of any kind, maximal tactical flexibility at all times, and not much in the way of explanation."* (p.14).

(2014) studied the determinants of fiscal policy discretion by examining the factors affecting the volatility of fiscal policy shocks.

We describe the econometric model in the next section.

3 The Empirical Model

We propose to refer to monetary policy as a mix of rule-based and discretionary components, rather than being described either pure rule-based or discretionary. In mathematical terms the rule-based component is the policy rate implied by a deterministic policy rule. Consequently, deviations from the rule represent the discretionary component of the monetary policy.

The monetary policy rule considered has a classic Taylor rule representation, where the central bank responds to deviations of inflation and output gap from their target levels. The monetary policy shock captures innovations in the policy and represents the deviations of the policy rate from the level implied by the rule.

In most of empirical Taylor rule estimates, heteroskedasticity of policy shocks is addressed by using Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors. We propose modeling policy shocks as time-varying heteroskedasticity process augmented with exogenous variables (see Engle (1982) and Bollerslev (1986) for detailed discussion of models with time-varying heteroskedasticity). With this methodology, the variance of policy shocks is linked to the state of the economy, which allows to study the factors driving the magnitude of discretionary component.

The specification of the policy rule is close to the one estimated in Clarida et al. (2000). For the variance equation, inflation and output gap are natural candidates for explaining volatility of policy shocks. These two variables are the key indicators of the state of the economy that may drive discretion.

We estimate a family of Taylor rule equations with the following basic from

$$\begin{aligned} r_t &= \rho(L) r_{t-1} + (1-\rho)\left[rr^* + \pi^* + \psi_\pi(\pi_{t+i} - \pi^*) + \psi_x x_{t+j}\right] + \varepsilon_t \\ \sigma^2_{\varepsilon,t} &= exp\left(\delta_0 + \delta_\pi \pi_{t+m} + \delta_x x_{t+n}\right) + \alpha_1 \varepsilon^2_{t-1} + \alpha_2 \sigma^2_{\varepsilon,t-1} \end{aligned} \tag{1}$$

where r_t is the federal funds rate, rr^* is the neutral real interest rate, π^* is the target inflation rate, π_{t+i} and π_{t+m} are the i and m periods ahead projection of inflation, x_{t+j} and x_{t+n} are the j and n periods ahead projections of output gap.

In its simplest form, the policy rule is defined over the inflation and output gap. It embeds an interest rate smoothing mechanism characterized by the lag polynomial $\rho(L) = \rho_1 + \rho_2 L + \ldots + \rho_p L^{p-1}$, with $\rho \equiv \rho(1)$. The second term in the mean equation with square brackets represents the target rate of the Fed, which would be appropriate in the absence of interest rate smoothing. The target rate responds to deviations of core inflation π_t from the Fed's objective π^* with parameter ψ_π and to output gap x_t with parameter ψ_x.

The variance equation has a GARCH structure with exogenous covariates. The parameter δ_π captures the effect of inflation on the variance of monetary policy shocks. A positive coefficient will indicate an increasing degree of discretion in relation with high inflation and commitment to the policy rule in times of low inflation. Conversely, a negative coefficient will provide evidence of discretionary behavior in times of low inflation and adherence to the rule when inflationary pressures were present.

Output gap is another important variable that may drive discretion. The parameter δ_x shows the contribution of output gap to the variance of monetary policy shocks. A positive coefficient will be a sign of an increasing degree of discretion in relation with high (positive) output gap and commitment to the policy rule in times of low (negative) output gap. Conversely, a negative coefficient will provide evidence of discretionary behavior in times of negative output gap and adherence to the rule when positive output gap was present.

The effects of macroeconomic variables on the variance of the policy shocks are of particular interest. Both inflation rate and output gap are expected to have positive coefficients in the Taylor rule, however, the impact direction as well as the magnitude of these variables on the variance of policy shocks are unknown. We note that the above variables *may* or *may not* have a positive impact on the variance, that is, the sign of the coefficient of a variable in the mean equation *per se* does not determine the sign of the coefficient of that variable in the variance equation. On the other hand, if policy contains a source of increasing discretion, then it will perpetuate over time, if there is persistence in the process in form of positive coefficients on ε_{t-1}^2 and σ_{t-1}^2.

Monetary policy decisions constitute both commitment and discretionary components, and our model allows to identify rule-based and discretionary policies, consistent with the definitions of Taylor (2012). This approach allows to effectively decompose policy actions in form of changes in the Fed funds rate into rule-based and discretion components. In particular, we refer to estimated policy rule as the rule-based and to the volatility of policy shocks as a measure of the discretionary components of monetary policy. The decomposition of changes in the fed funds rate can be easily done using the estimated model according to Equation 2 below:

$$\Delta r_t = \rho(L)\Delta r_{t-1} + (1-\rho)\left[\phi_\pi \Delta\pi_{t+i} + \phi_x \Delta x_{t+j}\right] + \Delta\varepsilon_t \tag{2}$$

where the sum of the first two terms $\rho(L)\Delta r_{t-1} + (1-\rho)\left[\phi_\pi \Delta\pi_{t+i} + \phi_x \Delta x_{t+j}\right]$ represents the rule-based component and the last term $\Delta\varepsilon_t$ represents the discretionary component of monetary policy.

Our first research question is of positive nature - identify the monetary policy rule and deviations from it. Taylor and Williams (2010) suggest using deviations from the policy rule as a measure of accountability of the central bank. With our framework, it's possible to obtain such a measure and observe how accountability, and therefore credibility evolve over time. In our setting, rising volatility is consistent with increasing discretion in policy, and decreasing credibility of the central bank. This will lead to a rather time inconsistent nature of the policy and the central bank will lose its credibility towards the public. In contrast, a commitment to the policy rule with low volatility of policy shocks will enable the central bank to earn credibility. The level of time (in)consistency is subject to continuous variation and we provide only qualitative judgment (increasing or decreasing pattern over time) for it.

4 Data

Next, we proceed to the estimation of our proposed model. In the empirical model, we use quarterly data of the United States for the period 1967Q1-2005Q4. The time span covers the full periods of two chairmen, Alan Greenspan (1987Q3-2005Q4) and Paul Volcker (1979Q3-1987Q2), as well as the pre-Volcker period (1967Q1-1979Q2).[5]

Following Orphanides (2004), we use data on real-time projections of inflation and output gap obtained from the Board of Governors of the Federal Reserve System Greenbook datasets. As forecasts conditional on the information available at the time, these projections reflect the real-time data on macroeconomic variables available for the policymakers. Therefore, projections of inflation and output gap do not include the effect of interest rate changes.

Greenbook projections on the output gap are not available until 1987Q3, and for the full sample we obtain estimates of the output gap by detrending the real-time series of real GDP available to the policymakers.[6] Following Orphanides (2001) and Nikolsko-Rzhevskyy et al. (2014) we use quadratic detrending to get measures of the output gap. We obtain real-time data on real GDP from the website of the Federal Reserve Bank of Philadelphia. Then we use Greenbook forecasts on real GDP growth to construct projections of real GDP for the current and upcoming quarters. We obtain output gap series by detrending the resulting series with a quadratic time trend from a running windows of past ten years.

Greenbook projections include real-time data for different measures of inflation including GDP deflator, headline and core inflation.[7] However, the series of headline and core CPI inflation are available only from 1979Q4 and 1986Q1, respectively, while projections on GDP

[5] In the pre-Volcker period 1967Q1-1979Q2, the Fed-Reserve had been chaired by William Martin, 1951-1970; Arthur Burns, 1970-1978; and William Miller, 1978-1979.

[6] Although Greenbook projections are available until 2012, we use data up to 2005Q4 in order to exclude effects of possible structural changes in the rule resulting from Ben Bernanke's appointment as the chairman of the Federal Reserve, as well as the effects of the Great Recession and unconventional monetary policy measures implemented after 2008.

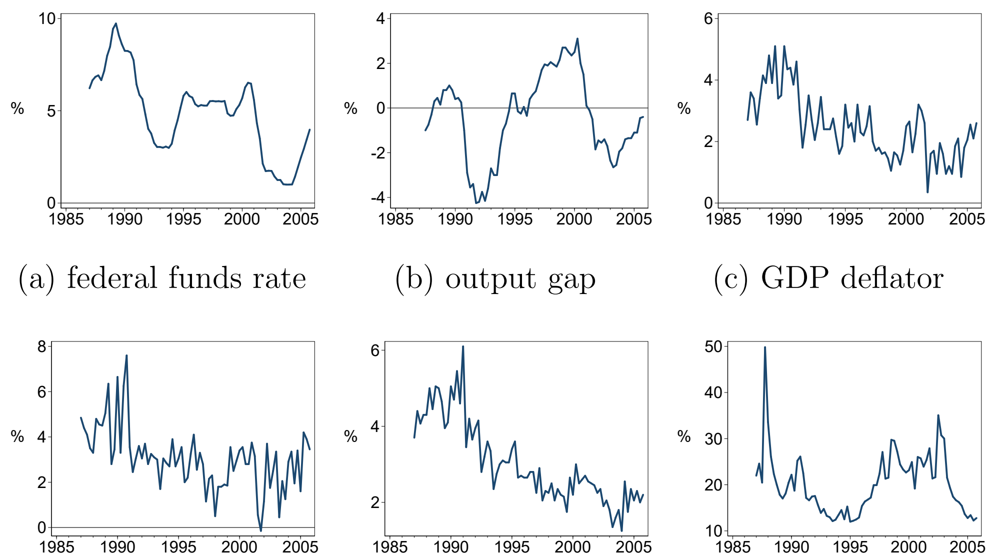
[7] The core measure of inflation excludes food and energy prices from the price index.

deflator begin from 1967Q1. Therefore, we use GDP deflator as a measure of inflation, similar to Clarida et al. (2000) and Orphanides (2004).

Table 1: Descriptive statistics

	Mean	Std.Dev.	Obs
Fed funds rate	6.61	3.36	156
Deflator	4.09	2.45	156
Headline Inflation	3.98	2.99	105
Core inflation	3.09	1.07	80
Output gap	1.46	4.46	156
VIX volatility index	20.24	6.46	80

We report descriptive statistics in Table 1 and plot the time series in Figure 1. Volatility of headline inflation is significantly larger than that of core inflation.[8] The mean difference of the two inflation measures is not significant. The F-test rejects the null hypothesis for equal standard deviations only at the 10 percent significance level.



(a) federal funds rate (b) output gap (c) GDP deflator

(d) headline inflation (e) core inflation (f) VIX

Figure 1: Time series of the main variables

In the model extension for Greenspan era, we use stock market volatility index (VIX) as a determinant of policy discretion[9] as a measure of uncertainty in financial markets and the

[8] The null hypothesis that the variance ratio F-statistic is less or equal 1 is rejected at the 5 percent significance level (P-value = 0.0216. The standard deviation of the series as a difference between headline and core inflation is 1.049, almost as high as that of the core inflation.

[9] We obtain data on VIX index from the FRED database of the Federal Reserve Bank of St. Louis.

economy. It represents the market's expectation of volatility implied by S&P 500 index options. VIX series does a good job to capture major events in the Greenspan era, as sources of uncertainty in the U.S. economy and worldwide. Our quarterly data for VIX captures one-day crash of the stock market in October 1987. The two wars in Iraq, 1990 and 2003, have caused significant jumps in VIX. The overall increase in uncertainty with local spikes is also observed in the emerging market crises of 1997-1998. The two low uncertainty periods, 1995-1997 and 2003-2005, are associated with productivity growth and deflationary expectations (Blinder and Reis, 2005). As we will see later in the paper, VIX is an important factor to explain the part of volatility of Fed funds rate, not explained by fundamentals. Deviations from the rule occur during irregular periods, and VIX as an uncertainty measure is highly volatile in these periods too.

5 Estimation

In this section, first we estimate the model for the whole sample, from 1967 to 2005. As headline and core CPI inflation series are jointly available from 1986Q1, we estimate extended models with additional determinants of policy discretion for Greenspan era. We also add market volatility index (VIX), available from 1987, to the extended models.

Following Clarida et al. (2000), we use one period ahead projections of core inflation and output gap (i.e. $i = j = 1$) and two lags of fed funds rate (i.e. $p = 2$) to eliminate serial correlation in residuals. We use GARCH(1,1) specification with exogenous variables for the variance equation. For exogenous covariates, we use one period ahead projections of core inflation and output par in the variance equation (i.e. $m = n = 1$).

We estimate models with Gaussian Maximum Likelihood methods, assuming conditionally Normal distribution for policy shocks. For standard errors, we calculate a sandwich form of Variance-Covariance matrix of coefficients, that is robust to model misspecification (see. White (1982)).

We begin with estimating the policy rule without the variance equation. Then we add ARCH and GARCH terms, as well as exogenous covariates to the variance equation. The estimation results are presented in the Table 2.

Table 2: The estimation results of the model for the whole sample

Variable	Parameter	Baseline	Garch	Het	Garch-Het
Mean equation					
Fed funds rate	ρ	0.877***	0.915***	0.927***	0.923***
Inflation	ϕ_π	1.727**	2.234***	1.579***	1.616***
Output gap	ϕ_x	0.388***	0.538***	0.594***	0.553***
Variance equation					
Inflation	δ_π			0.625***	0.640***
Output gap	δ_x			-0.010	-0.006
Arch	α_1		0.327***		0.163
Garch	α_2		0.735***		0.367**
N		156	156	156	156
AIC		430.59	293.50	277.43	273.24
BIC		448.89	317.90	301.82	303.73

Significance levels : * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

Note: The table presents estimation results for the whole sample from 1967Q1 to 2005Q4.

The literature on monetary policy rules documents several structural changes in the way monetary policy was conducted. In particular, several empirical studies find that policy response coefficient on inflation was lower than one, and did not satisfy the Taylor principle before Paul Volcker was appointed as the Chairman of the Federal Reserve Board (see Clarida et al. (2000) and Orphanides (2004)). However, during the period of Volcker's chairmanship the response on monetary policy to inflation was significantly higher than one, and it helped to stabilize the economy in 1970s. On the other hand, several studies report changes in the monetary policy rule after Alan Greenspan's appointment as the chairman of the Federal Reserve(Friedman (2006); Blinder and Reis (2005); Taylor (2005), among others).

To study the role of heteroskedasticity in the monetary policy rule during the periods of different chairmans, we split our sample into three subsamples. The first subsample covers the period from 1967Q1 to 1979Q2, after which Paul Volcker was appointed as the Chairman of the Federal Reserve. Second and third subsamples cover the periods of Paul Volcker's and Alan Greenspan's chairmanship from 1979Q3 to 1987Q2 and 1987Q3 to 2005Q4, respectively.

We estimate two specifications for each subsample. The first specification (Baseline) is the commonly used version of the Taylor rule without a variance equation. In the second specification (Extended), we estimate the model with time-varying heteroskedasticity in the residuals. In this specification we do not include ARCH and GARCH terms, since inclusion of these terms results in a flat likelihood function in our small subsamples. We include inflation and the output gap as exogenous regressors in the variance equation. The estimation results are presented in the Table 3.

Table 3: The estimation results of the model for the subsamples

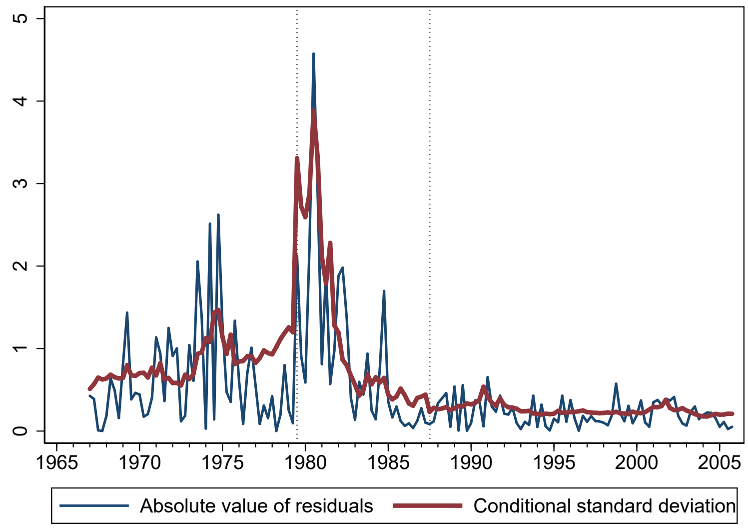
Variable		Pre-Volcker Baseline	Pre-Volcker Extended	Volcker Baseline	Volcker Extended	Greenspan Baseline	Greenspan Extended
Mean equation							
Fed funds rate	ρ	0.797***	0.767***	0.729***	0.625***	0.954***	0.956***
Inflation	ϕ_π	0.741	0.907**	2.772***	1.964***	3.340***	3.031**
Output gap	ϕ_x	0.100	0.011	0.673***	0.307***	1.332***	1.178***
Variance equation							
Inflation	δ_π		0.313*		0.558***		0.169
Output gap	δ_x		-0.009		-0.000		-0.078**
N		50	50	32	32	74	74
AIC		139.40	136.84	121.32	96.95	22.58	21.09
BIC		150.88	152.13	130.12	118.68	36.40	39.52

Significance levels : * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

Note: The table presents estimation results for Baseline and Extended models estimated for subsamples corresponding to Pre-Volcker's period from 1967Q1 to 1979Q2, Volcker's period 1979Q3 to 1987Q2 and Greenspan's period 1987Q3 to 2005Q4.

As it can be seen from Table 3, Extended models with heteroskedastic error terms provide better fit to the data in terms of the information criteria. For Pre-Volcker and Greenspan's periods Bayes's (BIC) criterion favors models without conditional heteroskedasticity, but favors the heteroskedastic model for Volcker's period. However, BIC criterion consistently selects the true model in large samples, whereas Akaike's (AIC) is known to have better performance in small samples. In our estimates the AIC criterion favors heteroskedastic models for all subsamples.

Figure 2 plots the deviations (in absolute value) from the rule and the implied volatility from the model estimated for three subsamples (vertical lines represent Volcker's and Greenspan's appointment as Fed Chairman).



Note: The blue line represents the absolute value of deviations from the estimated policy rule ε_t and the red (thicker) line represents the conditional standard deviation of the error terms $\sigma_{\varepsilon,t}$ from the models estimated for subsamples corresponding to Pre-Volcker's period from 1967Q1 to 1979Q2, Volcker's period 1979Q3 to 1987Q2 and Greenspan's period 1987Q3 to 2005Q4. Vertical lines represent Volcker's and Greenspan's appointment as the Fed Chairman

Figure 2: Actual and fitted volatility of policy shocks in the subsamples

The estimation results provide interesting insights about the role of heteroskedasticity in monetary policy rules. Inflation has positive contribution to the volatility of shocks at the conventional levels of significance except for Alan Greenspan's period of chairmanship. The output gap has negative but not statistically significant coefficients, except for Alan Greenspan's period. We explore the role of heteroskedastic policy shocks during Greenspan chairmanship in the next section.

5.1 Alan Greenspan and discretionary monetary policy

Although the series of GDP deflator have the longest span among the Greenbook projections, other measures of inflation, such as headline and core measures of inflation, are of particular interest for estimating monetary policy rules. The Federal Reserve has targeted different measures of inflation over time (Nikolsko-Rzhevskyy et al., 2014) and has put more emphasis in responding to the core inflation as opposed to the headline inflation. This tendency has been evident especially during the chairmanship of Alan Greenspan.

On the other hand, starting from 1987Q3 the Greenbook projections include real time estimates of the output gap. As discussed above, before that period the Federal Open Market Committee has used estimates of the output gap produced by the Council of Economic Advisers and the Department of Commerce (Orphanides, 2004). Given use of internal forecasts of the output gap, along with the policy response to CPI inflation instead of GDP deflator, monetary policy rules during Alan Greenspan's period of chairmanship would have been substantially different from the rules that have been prevailed during Paul Volcker's chairmanship.

To study the role of policy rules and discretion during Alan Greenspan's chairmanship period, we estimate our model using a subsample spanning the period from 1987Q3 to 2005Q4. We use the Greenbook projections of CPI inflation and the output gap in the policy rule, as well as in the variance equation as exogenous covariates for the volatility of policy shocks.

Table 4: The estimation results of the model for Alan Greenspan's era

Variable	**Parameter**	**Baseline**	**Extended**
Mean equation			
Fed funds rate	ρ	0.761***	0.771***
Core inflation	ϕ_π	1.763***	1.773***
Output gap	ϕ_x	0.789***	0.788***
Variance equation			
Core inflation	δ_π		0.349**
Output gap	δ_x		-0.060
AIC		9.85	8.99
BIC		23.67	27.42

Significance levels : * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

Note: The table presents estimation results for Baseline and Extended models estimated for Alan Greenspan's period 1987Q3 to 2005Q4.

The estimation results are presented in Table 4. The estimates of policy response parameters are similar to the previous estimates in the literature (see Orphanides (2004) and Clarida et al. (2000)). The estimates of the coefficients in the variance equation reveal a relationship between inflation and the degree of monetary policy discretion during the sample period. The volatility of policy shocks is increasing in the inflation, which means that monetary policy has been more tied to the rule in times of low inflation and relatively flexible in times of high inflation. The coefficient of output gap is statistically insignificant, and provides no evidence of any relationship between policy discretion and output gap.

This result provides an interesting evidence about the course of monetary policy in the US. With this result, a few questions emerge regarding the discretionary behavior of the Fed. Increasing degree of discretion in times of high inflation seems to be counterintuitive, since at that times high degree of commitment is necessary for anchoring inflation expectations and effectively tightening monetary policy. Similarly, in times of low inflation the Fed may "afford" relatively flexible policy, if there are no significant inflation risks in the economy.

The literature on policy discretion provides some insights about the relationship between the volatility of policy shocks and inflation. Clarida et al. (1999) provide theory for optimal monetary policy choices in response to different macroeconomics disturbances. They advocate for monetary policy tightening in response to demand shocks, when there is no trade-off between output gap and inflation. On the other hand, in case of a supply shock, optimal policy implies accommodation of transitory inflation pressures. This may be a reason for the Fed to deviate from the policy rule and exhibit some degree of discretion.

To explore the connection between policy discretion and inflation, we also include headline inflation in the variance equation of our model and study the effects of different measures of inflation on the volatility of policy shocks. Given the theoretical arguments on optimal policy response to different types of shocks, discretionary component of monetary policy can depend on core and headline measures of inflation differently. Therefore, in the next section we estimate our model with an extended set of variance regressors.

5.2 Extended Model

Inflation and output gap are the main variables that can drive both rule-based and discretionary components of monetary policy. However, the set of potential determinants is not limited to these two variables, since policy decisions take into account a wider set of macroeconomic indicators. Nevertheless, the policy response to inflation and output gap can be different, and not necessarily rule-based, depending on the nature of shocks hitting the economy. In this regard, Taylor (1993) suggests that monetary policy should deviate from the rule and exhibit discretion in times of temporary inflation pressures like the oil-price shocks in 1990s. On the other hand, Clarida et al. (1999) arguments about optimal monetary policy imply that the central bank should respond in different ways. In particular, they advocate for policy response to permanent shocks to inflation, but no reaction to transitory shocks. In other words, monetary authorities are advocated to respond to core inflation, rater than headline inflation. This approach has been also suggested by other studies (see, for example Mishkin (2007), Bodenstein et al. (2008)).

Given the two possible sources for shocks to inflation, the central bank may face a difficult choice for inflation measures in the policy rule. In times of permanent shocks, policy response to core or headline inflation need not be different, since the shock will be reflected in both measures. However, in case of a transitory shock, these two measures of inflation will differ from each other. Now the optimal policy choices may not be straightforward. Therefore, this scenario may create incentives for the Fed to deviate from a precommitted rule and implement discretionary policies. In order to explore the possible effects of different measures of inflation on policy discretion, we include headline and core measures of inflation in the variance equation.

Another potential determinant for policy discretion may be the uncertainty in the economy. When uncertainty is high, the central bank may find it optimal to deviate from the committed rule, with the objective of implementing temporarily optimal policies. On the other hand, uncertainty in financial markets may cause large policy shocks. To take into account these effects, we use stock market volatility index (VIX) as a measure of uncertainty in the economy. Nevertheless, uncertainty in the economy and financial markets may itself be a result of monetary policy shocks. Unexpected policy choices can *deteriorate* the outlook of the economy and increase uncertainty in financial markets. To take into account this, we use the one period lag of the VIX in the variance equation.

We estimate the model with additional regressors for the variance equation, keeping the variables in the mean equation unchanged[10]. In particular, we include headline inflation and VIX as determinants of the volatility of policy shocks. the results are reported in Table 5.

Table 5: The estimation results of the model with additional variance regressors for Alan Greenspan's era

Variable	**Parameter**	**Baseline**	**Extended-1**	**Extended-2**
Mean equation				
Fed funds rate	ρ	0.761***	0.789***	0.800***
Core inflation	ϕ_π	1.763***	1.810***	1.767***
Output gap	ϕ_x	0.789***	0.775***	0.770***
Variance equation				
Headline inflation	δ_π^h		-1.254***	-0.826**
Core inflation	δ_π^c		1.628***	1.220***
Output gap	δ_x		-0.049	-0.133
VIX	δ_v			0.073**
AIC		9.85	2.48	-2.10
BIC		23.67	23.22	20.94

Significance levels : * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

Note: The table presents estimation results for Baseline, Extended-1 and Extended-2 models estimated for Alan Greenspan's period 1987Q3 to 2005Q4.

[10] We discuss alternative specifications with additional regressors in the mean equation in the Robustness section.

The estimation results provide some interesting insights about the determinants of the policy discretion. In the model Extended-1, the coefficients on headline and core inflation have statistically significant but opposite signs. However, as in the baseline specification, the output gap has an non-significant coefficient.

In the model Extended-2 we also include VIX as a variance regressor. Not-surprisingly, the lag of VIX appears to have some explanatory power for the volatility of policy shocks with a statistically significant coefficient. On the other hand, after controlling for the VIX, the coefficients of core and headline inflation have smaller magnitude, but remain significant at conventional levels. This model is also preferred over the other models by the AIC and BIC criteria.

We use our preferred model Extended-2 to decompose policy actions in form of changes in the Fed funds rate into rule-based and discretion components, as defined in Equation 2, for Alan Greenspan's period of chairmanship. We plot the contributions of the two components to changes in the Fed funds rate in Figure 3.

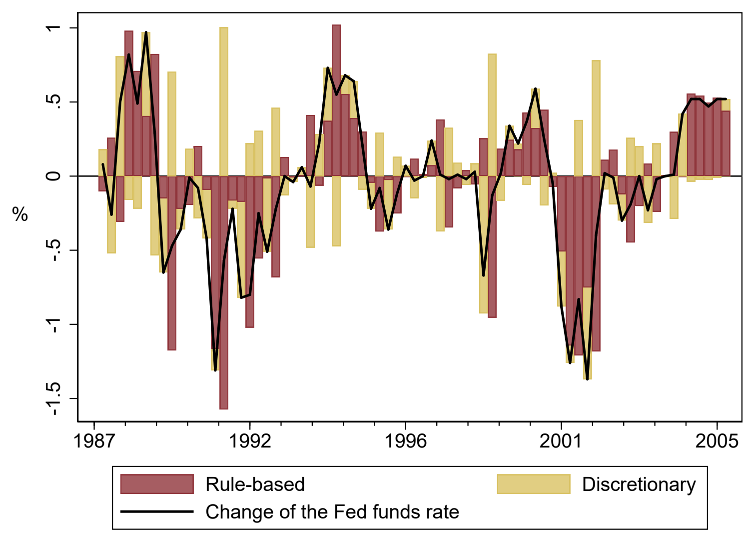
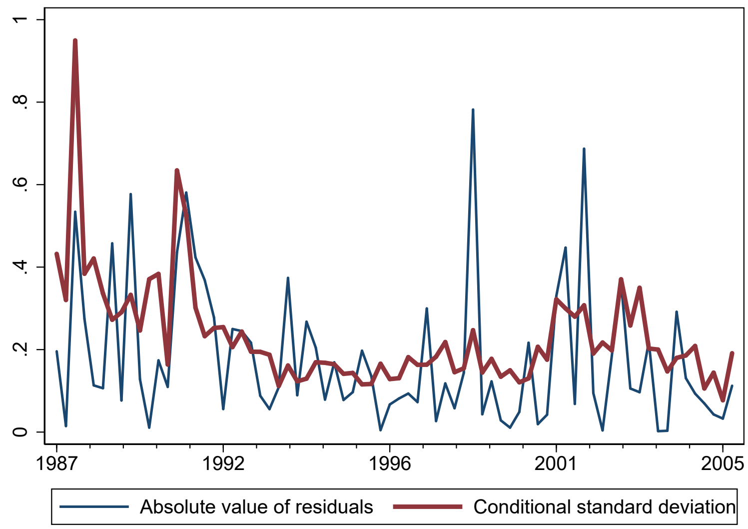


Figure 3: Rule-based and discretionary components of changes in the Fed Funds Rate during Alan Greenspan's era

An interesting result of this decomposition is that the rule-based and discretionary components are not independent of each other, but rather are negatively correlated with a correlation coefficient of -0.51. Nevertheless, about 66 percent of the variability of changes in the Fed funds rate is due to the rule-based component, while the discretionary component accounts for about 34 percent of it.

Figure 4 plots the deviations (in absolute value) from the rule and the implied volatility from the Extended model. As it can be seen from the figure, our model identifies a period if active policy discretion in the beginning of Greenspan's chairmanship described by high predicted volatility of policy shocks. Another period with relatively high degree of discretion is the bursting of the dot com bubble in the beginning of 2000s.



Note: The blue line represents the absolute value of deviations from the estimated policy rule ε_t and the red (thicker) line represents the conditional standard deviation of the error terms $\sigma_{\varepsilon,t}$ from the model Extended-2 estimated for Alan Greenspan's era from 1987Q3 to 2005Q4.

Figure 4: Actual and fitted volatility of policy shocks during Alan Greenspan's era

5.3 Optimal policy with heteroskedastic policy shocks

Our estimation results provide interesting evidence on the policy implementation of the Fed. We get a negative relationship with the degree of discretion and the headline inflation, but positive relationship with the core inflation. This means that the degree of discretion is the highest, when the economy experiences negative cost-push shock and positive output gap. In a standard New-Keynesian model economy, this situation is a likely outcome of positive technology shock or a negative oil price shock. Clarida et al. (1999) advocate for accommodative policies in response to these kind of shocks shocks.

However, if, consistent with our model specification, the degree of discretion depends on inflation, output gap and possibly on past discretion, the optimal policy may not be the same, as in standard textbook models. To study the effectiveness of monetary policy with time-varying discretion, one can study the contributions of possible determinants(inflation, output gap, etc.) to the volatility of policy shocks.

For example, due to the persistence of discretion (if there is), current policy choices might be harmful in terms of lost credibility in the future, and this can be a serious reason to reconsider ongoing policies. For example, if there is high inflation due to a cost-push shock, then the optimal monetary policy implies that the policy rate should respond to the deviation from the targeted inflation rate more than one to one. Then, if inflation has a significant positive contribution to the variance of the policy shocks, it will result in a larger deviation from the rule and hence will lead to a loss of credibility. Thus, a credible policy that is otherwise optimal within the New-Keynesian framework, may have certain negative effects with persistent discretion.

The role central bank credibility for monetary policy implementation has been studied extensively in the literature. The majority of these papers, studies committed(rule-based) and discretionary policies independent from each other. Moreover, whether or not the central bank implements committed or discretionary policy in certain point in time is given exogenously.

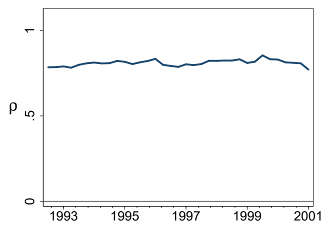
In this context, our empirical findings suggest that the degree of discretion can depend on different macroeconomic variables. That is, the degree to which a central bank implements committed or discretionary policies can be determined *endogenously* in a model, as a function of the state of the economy. Hence our findings open a potential research area for studying optimal monetary policy in a framework with endogenous policy strategies.

6 Robustness of the model

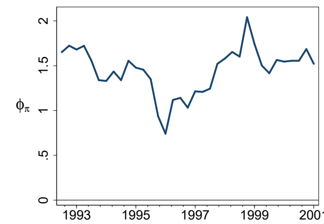
We check the robustness of our model to a number of possible model misspecification issues. In particular, we consider specifications with alternative measures of inflation in the policy rule, rolling window estimation of the model to check for time-varying coefficients as well as possibly non-linear policy responses to inflation and output gap.

Throughout the main text of the paper, we have been using core inflation in the monetary policy rule. This specification is commonly used in the literature, since the monetary policy is believed to respond to core rather than headline inflation. Nevertheless, in the extended version of the model we include both measures of inflation to study their effects on policy discretion. Hence, we consider a version of the model, where we include headline inflation also in the mean equation to allow for different responses to them in the policy rule.

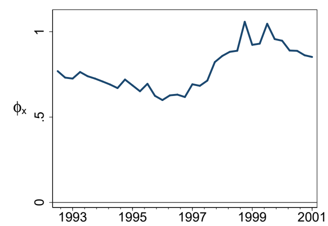
Next, to check for potential structural changes in the policy behavior, that could take place in form of time-varying coefficients, we perform rolling window estimation of the model Extended-2 over the sample period. The results, plotted in Figure 5, in general indicate no significant instability in the coefficients of the policy rule.



(a) lagged fed funds rate



(b) core inflation

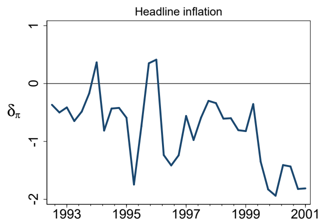


(c) output gap

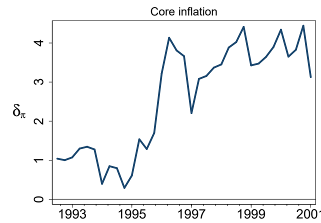
Note: Results of rolling window estimation of the model Extended-2 using window length of 40 quarters. The midpoint of estimation window is on the horizontal axis

Figure 5: Structural stability in estimated parameters of the mean equation

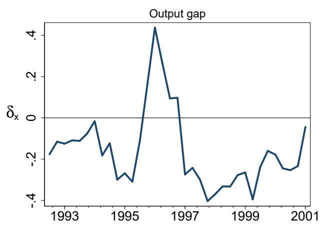
At the same time, estimates of the variance equation plotted in Figure 6 are relatively unstable. The coefficient of headline inflation is in the negative territory, in spite of sometimes being not significantly different from zero. On the other hand, the coefficient on core inflation displays increasing pattern, which indicates strengthening association between the degree of policy discretion and core inflation over the sample period. The relationship between the output gap and the volatility of policy shocks seems to be non-significant both in full sample and rolling window estimates. The effects of the lag of VIX on policy discretion seem to be strong throughout the sample period except for the beginning of 1990s.



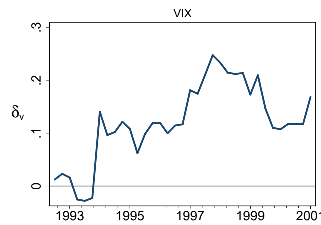
(a) headline inflation



(b) core inflation



(c) output gap



(d) VIX

Note: Results of rolling window estimation of the model Extended-2 using window length of 40 quarters. The midpoint of estimation window is on the horizontal axis

Figure 6: Structural stability in estimated parameters of the variance equation

Monetary policy rules are potentially very complex and can represent nonlinear policy reactions to inflation and output. If such a policy behavior is in place, then omitting the non-linear factors from the policy rule specification will bias estimated coefficients in both mean and variance equation. In the mean equation, we will have a omitted variables problem. In the variance equation, omission of non-linear effects may distort the coefficients on the inflation and output gap.

Table 6: The estimation results of non-linear specifications

Variable	Baseline		Extended		Extended-2	
Mean equation						
Fed funds rate	0.761***	0.756***	0.771***	0.768***	0.800***	0.800***
Core inflation	1.763***	2.370***	1.773***	2.020***	1.767***	1.973**
Core inflation sq		-0.088		-0.038		-0.032
Output gap	0.789***	0.794***	0.788***	0.790***	0.770***	0.771***
Output gap sq		0.009		0.014		0.006
Variance equation						
Headline Inflation					-0.826**	-0.834**
Core inflation			0.349**	0.346**	1.220***	1.238***
Output gap			-0.060	-0.049	-0.133	-0.130
VIX					0.073**	0.073**
AIC	9.85	13.03	8.99	12.65	-2.10	1.76
BIC	23.67	31.47	27.42	35.70	20.94	29.41

Significance levels : * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

Note: The table presents estimation results for Baseline and Extended-2 models augmented with non-linear (square) terms of inflation and output gap and estimated for Alan Greenspan's period 1987Q3 to 2005Q4.

To check for nonlinear policy reaction to inflation and output and its effects on the estimates of the variance equation, we include quadratic terms of inflation and output gap in the mean equation. The results presented in Table 6 show that the model is robust to nonlinear specifications. In particular, we find statistically significant effects of both measures of inflation, output gap and stock market volatility of the policy discretion. In the meantime, there is no evidence of nonlinear policy response to inflation and output gap. Moreover, the linear form is preferred over nonlinear specifications by Akaike's and Bayes's information criteria.

7 Conclusions

In this paper we propose a new framework for characterizing monetary policy to measure the strength of commitment versus discretion in the monetary policy by decomposing policy actions into commitment and discretion components. For this purpose, we use Taylor-type of policy rules with conditional heteroskedasticity. Deviations from the committed rule, in form of volatility of a policy shock, are linked to the key determinants of the policy rule, disclosing the nature and strength of discretion of a central banker. We estimate the U.S. monetary policy rule for the period 1967-2005. We extend the model by introducing headline and core inflation available from Greenbook datasets, as well as VIX volatility index, for Alan Greenspan's period of chairmanship.

Overall, suggested heteroskedastic model provides a better fit to the data than the standard model does, represented by the mean equation. Inflation has positive significant effects on volatility of shocks, except for Alan Greenspans period of chairmanship. The output gap is statistically significant only in Alan Greenspans period. During Greenspan's era, the degree of discretion is decreasing in headline inflation, but increasing in core inflation, suggesting that monetary policy has been more tied to the rule in times of positive temporary shocks and more flexible in times of negative shocks. Also, monetary policy tended to deviate from the rule after high stock market volatility periods, and follow the rule after low volatility periods. We find no relationship between the shock volatility and output gap. Finally, there is no evidence of discretion persistence in the sample period.

We check the robustness of our results in two ways. First, we perform rolling window estimation of the benchmark model for the Greenspan's period of chairmanship. The estimates of the variance equation, our primary interest, are relatively stable and preserve the expected signs. Next, we estimate similar models allowing for non-linear response of monetary policy to output gap and inflation. Importantly, the parameter estimates in both rule-based and discretionary components of our model are robust to nonlinear specifications.

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