Price Stability vs. Output Stability: Tales From Three Federal Reserve Administrations

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Abstract

This study disentangles the policy parameters from those describing the behavior of the private sector by simultaneously estimating an empirical model for inflation and output along with a loss function for the monetary policy for the last three Federal Reserve administrations. There are three important results: First, the Federal Reserve appears to put more emphasis on price stability than output stability when the entire sample is considered. Second, and more importantly, the loss function parameters exhibit a structural break at the time Paul Volcker was appointed as the chairman. The accommodative characteristics of monetary policy were replaced with a more active policy towards controlling inflation. Finally, interest rate smoothing is found to be an important feature of the monetary policymaking process for all three administrations.

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1 INTRODUCTION

Since the late 1960's, the United States economy experienced two different sorts of macroeconomic performances. Until the early 1980's, high and volatile inflation existed with several recessions. However, in the last two decades, inflation remained low and steady, with favorable output growth. The studies that offer answers for these two different episodes can be classified in two groups. First, some economists view supply shocks as the main determinant of the two different macroeconomic performances. As pointed out by Hamilton (1983), the two major oil shocks in 1973 and 1979 could be the driving forces of the high inflation and the recessions. After the 1980's, the supply shocks were mostly positive, which helped the policymakers to sustain low and stable inflation, with high output growth. However, recent studies cast some doubt on this view. DeLong (1997) argues that high inflation was already a problem before the oil crises. Even though the increases in oil prices may explain the transitory movements in inflation, they can not explain the persistent inflationary environment of the

1970's. Bernanke, Gertler and Watson (1997) examine the post-1980 era and find that the decrease in inflation in this period appears to lead the decrease in the real oil price.

The second view stresses the importance of the conduct of the monetary policy. Recent empirical studies find substantial differences in the conduct of monetary policy between the pre-1979 and post-1979 eras. Clarida, Gali and Gertler (2000) estimate a forward looking monetary policy reaction function and find significant differences in the estimated policy rule across periods. Judd and Rudebusch (1998) estimate a Taylor-type reaction function and report that monetary policy may have changed in significant ways over time. A common feature of these studies is that the response of the interest rate, which is the main monetary policy instrument, to an increase in inflation was relatively weak during Arthur Burns administration and the short tenure of G. William Miller. However, interest rate policy in the Volcker and Greenspan periods seems to be much more sensitive to changes in both actual and expected inflation.

Another common characteristic of these two empirical studies is that they focus only on the estimation of ad hoc monetary policy reaction functions. These studies leave open the question of whether the instabilities will continue to appear when the reaction function is estimated as part of a complete macroeconometric model. To answer this question, this study takes a broader view and adopts the model of inflation and output by Rudebusch and Svensson (1998, 1999) as its starting point. It goes beyond their studies by simultaneously estimating the empirical model for the macroeconomy and a loss function for the monetary policy for each of the three Federal Reserve administrations. Such an estimation method identifies independently the behavior of the private economy from those describing the Federal Reserve policy parameters, and it addresses the Lucas' Critique by testing stability directly for policy parameters and structural parameters[1].

There are three important results to be drawn from this paper. First, it is found that more emphasis has been put on price stability than output stability when the entire sample is considered. Second, and more importantly, the pa-

[1] Another study in this field is done by Favero and Rovelli (2000).

rameters of the loss function are not stable between the Burns period and the Volcker-Greenspan period. During the Burns administration, output stability was a superior goal in the monetary policymaking process. However, during the Volcker and Greenspan period, price stability has been much more important[2]. The implied monetary policy reaction functions for the different administrations also reflect these findings. Finally, it has been found that interest rate smoothing has always been an important goal for the Federal Reserve, regardless of the administrations.

The closest study to this paper is produced by Salemi (1995), where the results obtained are similar. However, the model presented here adds restrictions to an unconstrained vector autoregression (VAR) model that give each equation a structural interpretation. Therefore, such a methodology allows us to focus not only on the possibility of instability in the Federal Reserve's policy preferences, but also on the possibility of instability in the structural equations describing the behavior of the private sector. In other words, our model can do a more

[2] The Miller administration has been excluded because of his short tenure.

careful job of disentangling instability in the Federal Reserve's preferences from instability in the behavior of private-sector agents.

The plan of this paper is as follows. Next section introduces the empirical model of inflation and output along with a loss function for the monetary policymaker. Section 3 presents the estimation procedure and the optimization problem used in this study. Section 4 presents the parameter estimates, the policy function and the empirical fit of the model. Then, parameter stability tests are performed, and differences in the parameters of the loss function are analyzed. Section 5 summarizes the findings. Finally, technical details about optimization problem, estimation procedure and the stability tests are displayed in the Appendix.

2 THE MODEL AND THE LOSS FUNCTION

2.1 *The Empirical Model of Inflation and Output*

As mentioned above, this study adopts the empirical model used in Rudebusch and Svensson (1998 and 1999). The two equations for output and inflation are:

$$\pi_{t+1} = \alpha_{\pi 1}\pi_t + \alpha_{\pi 2}\pi_{t-1} + \alpha_{\pi 3}\pi_{t-2} + \alpha_{\pi 4}\pi_{t-3} + \alpha_y y_t + \varepsilon_{t+1} \tag{1}$$

$$y_{t+1} = \beta_{y1} y_t + \beta_{y2} y_{t-1} - \beta_r(\bar{i}_t - \bar{\pi}_t - \bar{r}) + \eta_{t+1} \tag{2}$$

π_t is the annualized quarterly inflation, i.e., $\pi_t = 4(p_t - p_{t-1})$ and $p_t = 100\ln(P_t)$, where P_t is the chain-weighted price index. $\bar{\pi}_t$ is the four-quarter average inflation. y_t is the output gap which is the detrended log of real GDP using a quadratic trend. Such a measure is previously used by Clarida, Gali and Gertler (1997)[3]. Furthermore, the sum of the lagged inflation coefficients in equation 1 is assumed to be equal to one (*i.e.* $\sum_{i=1}^{4} \alpha_{\pi i} = 1$), since such an assumption will imply that there is no long-run trade-off between output and inflation[4]. Besides, i_t is the quarterly average funds rate, $\bar{i}_t$ is the four-quarter average funds rate, and $\bar{r}$ is the average real interest rate. All the variables are de-meaned, therefore no constants appear, and average real interest rate is set

[3] See Cogley (1997) for various measures of potential output and output gap.

[4] The results did not change when this constraint was relaxed.

to zero. The sample period is 1970:Q1 and 1999:Q1, and the data is taken from International Financial Statistics[5].

Equation (1) can be viewed as an Aggregate Supply curve, while equation (2) is an Aggregate Demand curve. As it can be seen from the two equations above, the model is a backward-looking Keynesian model, in which the monetary policy affects the real economy only with a lag. In explaining output gap, the lagged variables are also used. Inflation is explained by its lagged values and lagged output gap. Although the empirical fit of the model is convincingly supported by Rudebusch and Svensson (1998 and 1999), it is useful to discuss the advantages and disadvantages of the model.

Backward looking models receive support from both academic world and policymakers. Fuhrer (1997) tests a backward looking model against a forward-looking version, and his results are in favor of the former. Moreover, Blinder (1998) states his preferences in favor of backward-looking models.

[5] The starting date coincides with the appointment of Arthur Burns as the chairman of the Federal Reserve.

The model is a simple linear one, which consists of two basic equations. Yet, it must be noted that it is rich enough to capture the dynamics of output and inflation. Actually, the model can be thought as two restricted equations from a trivariate Vector Autoregression (VAR) model with four lags. Also, the model is similar to the empirical models that are actually used by the Central Banks, which are of primary interest in this study[6]. Its empirical fit is discussed by Rudebusch and Svensson (1998 and 1999). In the fourth section, after the parameters are estimated, the Akaike Information Criteria (AIC) and Schwarz Information Criteria (SIC) of the model are compared with an unrestricted VAR model, and it is shown that the model employed here seems to be favored by the information criteria. One interesting result is that the model also fits for other industrialized countries' data surprisingly well. This feature of the model makes it attractive to employ it for cross-section analysis.

The model's implications are consistent also with previous studies. The op-

[6] Actually, the model presented here is within the same spirit with the 11 Central Bank models analyzed in Bank for International Settlements (1995).

erating procedure for the US monetary authority is through the federal funds rate, which is consistent with the findings of Bernanke and Mihov (1998). Goodfriend (1991) also argues that, the funds rate had been the implicit target for the Federal Reserve even under the period of official reserve targeting. Taylor's rule is also implicitly captured in this model: when the output gap is positive and puts an upward pressure on inflation, the Federal Reserve can increase the nominal interest rate sufficiently enough to push up the real interest rate[7].

The model can be criticized for being too simplistic, and glossing over many important characteristics of the monetary transmission mechanism. Also, Lucas' Critique may apply since it is a backward-looking model. Therefore, it is necessary to apply econometric stability tests[8]. In this context, two stability tests -the Likelihood Ratio Test and Wald Statistic- are performed, and it is

[7] Clarida, Gali and Gertler (2000) finds that, in the pre-Volcker years, the Federal Reserve was accommodative in the sense that it increased the nominal interest rates by less than the increase in the expected inflation. However, during Volcker-Greenspan period, the Federal Reserve had increased both nominal and the real interest rates in response to higher expected inflation.

[8] Rudebusch and Svensson (1998 and 1999) show that the model employed in this study passes the stability tests easily for United States.

shown that the empirical model presented above is stable across periods.

2.2 *The Loss Function for the Monetary Authority*

In this section, a simple loss function for the monetary authority is defined as:

$$L_t = \lambda_\pi(\bar{\pi}_t)^2 + \lambda_y(y_t)^2 + \lambda_i(i_t - i_{t-1})^2 \tag{3}$$

where all the weights are assumed to be greater than zero, i.e., $\lambda_\pi > 0$, $\lambda_y > 0$ and $\lambda_i > 0$. Furthermore, the sum of the weights is assumed to be equal to one, i.e., $\lambda_\pi + \lambda_y + \lambda_i = 1$.

The first two terms imply that the monetary authority is penalized when the average inflation and output gap deviate from their target levels, which are zero. The third term represents the interest rate smoothing incentive for the policymaker. Since Barro and Gordon (1986), such a loss function formulation has become quite common. After Rogoff (1985) proved that it is better for the society to appoint a conservative Central Banker who puts more emphasis on price stability than output stability ($\lambda_\pi > \lambda_y$), an independent Central Banker has been associated with a high λ_π/λ_y ratio[9].

There are several reasons to include an interest rate smoothing incentive in the loss function. In practice, it has been observed that the Federal Reserve adjusts interest rates more smoothly than the conventional monetary models would predict. As an example, the FRB-US model predicts a more volatile interest rate path than the policymakers would choose. This is also confirmed in Rotemberg and Woodford (1997). Although the smoothing incentive for the policymakers remain relatively unsolved, there are several explanations in this context. As Clarida, Gali and Gertler (1999) explains, model and parameter uncertainty may induce policymakers to have a smoothing incentive. Rotemberg and Woodford (1997) analyze the lagged dependence of interest rates and find that such a behavior enables Central Banks to manipulate aggregate demand with more modest movements in the short term interest rate. Another reason for a smoothing incentive is to ensure the existence of well-functioning capital

[9] One extension to this study could be to compare this ratio for several countries and generate an empirical Central Bank Independence index.

markets. Volatile interest rates may result in capital losses, which would be disruptive for the financial sector.

3 ESTIMATION AND OPTIMIZATION

As it is mentioned in the first section, there are two purposes of this study. The first goal is to estimate the parameters of the loss function and the empirical model represented in the previous section. The second purpose is to see whether there have been structural breaks for the parameters of the model and the loss function between Federal Reserve administrations. This section and the first two appendices introduce the optimization procedure and the estimation method used to obtain these parameters.

3.1 *The Optimization Problem for the Policymaker*

The intertemporal loss function for the policymaker at time t is:

$$E_t(1-\beta)\sum_{\tau=0}^{\infty}\beta^{\tau}L_{t+\tau}$$

where β is the discount factor and L_t is the period loss function for the policymaker. As $\beta \rightarrow 1$, the intertemporal loss function approaches $E(L_t)$ which will be equal to $\lambda_\pi(\bar{\pi}_t)^2 + \lambda_y(y_t)^2 + \lambda_i(i_t - i_{t-1})^2$.

As it can be seen in Appendix 1, the empirical model can be written in state space form. Then, given the state equation and the loss function, the problem for the policymaker can be represented in the form of a stochastic optimal linear regulator, as discussed by Sargent (1987) and Ljungqvist and Sargent (2000). Minimizing the objective function with respect to the state equation will result in a policy reaction function

$$i_t = -fX_t + \xi_t \tag{4}$$

where f is a row vector and X_t is the state variables vector. ξ_t can be thought as the policy shock, which is there to pick up movements in the interest rate that can not be explained by the model. Common sense tells us that Federal Reserve officials have not, at any time in the past, followed a mechanical rule for setting the short-term nominal interest rate. In addition, including a policy shock will allow us to obtain impulse responses for each of the three shocks: the policy shock, the aggregate supply shock, and the aggregate demand shock. Therefore, we will better evaluate the model's overall fit, and see whether the obtained impulse responses will display the "prize puzzle" - increasing prices in response to a monetary policy contraction, as documented by Gordon and Leeper (1994), Leeper, Sims and Zha (1996), Christiano, Evans and Eichenbaum (1998).

As it can be seen in Appendix 1, substituting the feedback rule into the state equation and the equation for the goal variables, an optimal closed-loop system is obtained, which shows the evolution of the state variables under the optimal control.

3.2 *The Estimation Procedure*

After deriving the optimal closed-loop system, the parameters of the model and their standard errors can be estimated by initializing the Kalman Filter and maximizing the log-likelihood function, as discussed in Hamilton (1994). The standard errors of the parameters can be obtained by taking the square roots of the diagonal elements of the inverse of the information (Hessian) matrix. Appendix 2 represents the estimation procedure in detail.

4 PARAMETER ESTIMATES

4.1 *Estimation of the Empirical Model*

As explained above, the sample period is 1970:Q1-1999:Q1. The parameter estimates for the empirical model of inflation and output along with their standard errors are presented in Table 1 and Table 2.

Table 1. Parameter Estimates of the Inflation Equation

Parameter	Estimate	Standard Error
$\boldsymbol{\alpha}_{\pi 1}$	0.76	0.081
$\boldsymbol{\alpha}_{\pi 2}$	-0.40	0.103
$\boldsymbol{\alpha}_{\pi 3}$	0.42	0.097
$\boldsymbol{\alpha}_{\pi 4}$	0.22	0.065
$\boldsymbol{\alpha}_{y}$	0.17	0.026
$\boldsymbol{\sigma}_{\varepsilon}$	0.67	0.053
$\boldsymbol{\sigma}_{\varepsilon\eta}$	0.11	0.039

Table 2. Parameter Estimates of the Output Equation

Parameter	Estimate	Standard Error
$\boldsymbol{\beta}_{y1}$	1.19	0.081
$\boldsymbol{\beta}_{y2}$	-0.16	0.076
$\boldsymbol{\beta}_{r}$	-0.09	0.024
$\boldsymbol{\sigma}_{\eta}$	0.17	0.086
$\boldsymbol{\sigma}_{\varepsilon\eta}$	0.11	0.039

When the parameter estimates are compared to Rudebusch and Svensson (1998 and 1999), there are only slight differences. One obvious reason is the difference in the sample period used. The second factor may be the estimation technique. They estimate each equation by OLS. In this study, the parameters of the model and the loss function are simultaneously estimated so that the log-likelihood function is maximized[10]. Overall, the parameter estimates of the two studies are close, and each parameter has the expected sign.

After deriving the estimates, it is necessary to evaluate the empirical fit of the model. Comparing the model with an unrestricted VAR model can fulfill this purpose. Although VAR models are criticized for their lack of structure, they can provide a useful benchmark for the empirical performance of the models. Actually, the model presented in this paper can be seen as two restricted equations from a trivariate VAR with four lags. Table 3 represents the Akaike Information Criteria (AIC) and Schwarz Information Criteria (SIC) of the two

[10] The log-likelihood function is derived after generating an optimal closed-loop system and evaluating the updating equations.

models.

Table 3. Model Selection Criteria

	Inflation Equation			Output Equation	
	VAR	**The Model**		**VAR**	**The Model**
SIC	2.55	2.37	**SIC**	9.78	9.36
AIC	2.35	2.30	**AIC**	9.56	9.23

For both of the equations, the model presented here has lower SIC and AIC values. As a result, the model represented here seems to be favored by the information criteria[11].

A second method used in this context was to perform an F-test to test the restrictions of the model presented here. The results are in favor of our model: the restrictions implied by the model fail to be rejected. The F-statistic is smaller than the critical value at 95 percent significance level. As mentioned in the first section, Lucas' Critique can apply for backward looking models, which makes it necessary to perform stability tests. The two tests which will be applied for this purpose is the Likelihood Ratio Test described in Andrews and Fair (1998), and the Wald statistic. The procedures for both of these tests

[11] This result is found also by Rudebusch and Svensson (1998) for inflation equation. The AIC value for the output equation in their study is higher, however.

can be found in Appendix 3. After performing the two procedures for all of the possible break points, the null hypothesis can not be rejected for the estimated parameters[12]. Both the Likelihood Ratio Test statistic and Wald statistic had lower values than 21.03, which is the critical value at 95 percent significance level with 11 degrees of freedom. Therefore, the model's parameters are reasonably stable across the sample period.

4.2 *Estimation of the Loss Function*

The loss function for the monetary authority was as follows:

$$L_t = \lambda_\pi(\bar{\pi}_t)^2 + \lambda_y(y_t)^2 + \lambda_i(i_t - i_{t-1})^2$$

λ_π, λ_y,and λ_i reflect the weights on price stability, output stability and interest rate smoothing, respectively.

The parameter estimates of the function can be seen below.

[12] Rudebusch and Svensson (1998 and 1999) finds the same result. Although they employ a larger sample, they find that the model is stable accross periods.

Table 4. Parameter Estimates of the Loss Function

Parameter	Estimate	Standard Error
$\boldsymbol{\lambda}_\pi$	0.39	0.016
$\boldsymbol{\lambda}_y$	0.26	0.012
$\boldsymbol{\lambda}_i$	0.35	0.017

As Table 4 presents, the Federal Reserve has put more weight on price stability than output stability when the entire sample period is considered. The interest rate smoothing incentive for the policymaker has been almost as important as the price stability.

The stability of the loss function parameters can also be tested with the same methods used to test the empirical model. Here, possible break points are chosen according to the date of appointments of the chairmen of the Federal Reserve. These dates are 1979:3, which is the beginning of the Volcker period, and 1987:Q3, the appointment of Alan Greenspan.

Both Likelihood Ratio test suggested by Andrews and Fair (1988) and the Wald statistic reveal the same result: there was a structural break for the loss function parameters between Burns period and Volcker period. The Likelihood Ratio test statistic is 19.31 while the Wald test statistic is 14.12. The critical value at the 95 percent significance level with three degrees of freedom is 7.82. Therefore, the null hypothesis of stability is rejected. On the other hand, when the beginning of the Greenspan period is chosen as the possible break point, the Likelihood Ratio test statistic is 3.11 while the Wald statistic is 2.92, which are both smaller than the critical value 7.82. Therefore, the null hypothesis can not be rejected[13]. Consequently, the stability tests for the loss function parameters imply that there was a significant change in the weights attached to goal variables after the appointment of Paul Volcker.

4.3 *Parameter Estimates Under Three Administrations*

The results in the previous sections imply that the price stability has been a more important goal for the Federal Reserve than output stability in the last three decades, and interest rate smoothing has been an important factor. More importantly, even though the empirical model and its parameters are found to be stable across periods, there was a structural break in the loss function

[13] Another tested breakpoint was 1982:Q4, since from the start of the Volcker administration to this date, the Federal Reserve targeted non-borrowed reserves, and this period was characterized by a sharp disinflation. However, there were no signs of instability.

parameters at the time when Paul Volcker was appointed as the chairman.

As it was mentioned in the first section, several studies attempted to explain the different inflation performances of the United States in the last three decades. Some economists like Hamilton (1983) mentioned that the existence of negative supply shocks in 1970's resulted in high and volatile inflation while the positive supply shocks helped the Federal Reserve to sustain low inflation with high economic growth rate. Other studies including Clarida, Gali and Gertler (2000), and Judd and Rudebusch (1998) found important differences in the way monetary policy had been conducted in the pre-Volcker and post-Volcker period. Based on these studies and the findings of the previous section about the structural break for the loss function parameters, it may be a useful exercise to compare the weights that each Federal Reserve administration attached to the goal variables in their loss function. This section estimates the parameters of the loss function under three administrations: Burns (1970:Q1-1978:Q1), Volcker (1979:Q3-1987:Q2) and Greenspan (1987:Q3-1999:Q1).

The loss function parameter estimates along with their standard errors for the three periods are presented in Table 5.

Table 5. Loss Function Parameter Estimates Under Three Administrations

	$\boldsymbol{\lambda}_\pi$	$\boldsymbol{\lambda}_y$	$\boldsymbol{\lambda}_i$
Burns Period (1970:1-1978:1)	0.33 (0.019)	0.37 (0.038)	0.30 (0.036)
Volcker Period (1979:3-1987:2)	0.45 (0.012)	0.21 (0.009)	0.34 (0.018)
Greenspan Period (1987:3-1999:1)	0.42 (0.026)	0.22 (0.044)	0.36 (0.037)
Volcker-Greenspan Period (1979:3-1999:1)	0.43 (0.022)	0.21 (0.016)	0.36 (0.025)
Whole Sample (1970:1-1999:1)	0.39 (0.016)	0.26 (0.012)	0.35 (0.017)

Table 5 displays a very important result: More emphasis was placed on output stability during Burns administration. However, price stability was a superior goal in the post-Volcker period. This can be better seen if λ_π/λ_y ratios for each period are shown: the ratio is 0.89 for the Burns period, 2.14 for the Volcker period and 1.91 for the Greenspan period. This result confirms the findings of the previous studies which found a significant change in the way that monetary policy is implemented. An accommodative policy had been followed under Burns administration, while achieving price stability had been the main focus of monetary policy under Volcker and Greenspan administrations. Another important finding is that interest rate smoothing incentive has been an important goal in monetary policymaking under every administration.

4.4 The Policy Functions

After getting the parameter estimates of the model and the loss function, the feedback instrument rule mentioned in the previous section will be as follows:

$$
\begin{aligned}
i_t &= 0.77\pi_t + 0.24\pi_{t-1} + 0.21\pi_{t-2} + 0.19\pi_{t-3} + 1.19y_t \\
&\quad -0.17y_{t-1} + 0.70i_{t-1} - 0.13i_{t-2} - 0.06i_{t-3}
\end{aligned}
$$

The above equation implies that federal Reserve both responds to current inflation and output gap in a very active way. A one percent increase in inflation leads to a 0.77 percent increase in interest rate. Also, the Federal Reserve increases the rate by 1.19 percent due to a one percent increase in output gap. Federal Reserve also takes into account the past values of inflation, however, its response is smaller compared to the response of current inflation and output gap. Another important result is the lagged dependence of the interest rate.

It is useful to compare the reaction function obtained above with a generalized Taylor rule presented in Rudebusch and Svensson (1999), in which the weights in the loss function are $\lambda_\pi = 0.4$, $\lambda_y = 0.4$ and $\lambda_i = 0.2$. Such a reaction function will be as:

$$\begin{aligned} i_t &= 0.86\pi_t + 0.31\pi_{t-1} + 0.37\pi_{t-2} + 0.12\pi_{t-3} + 1.34y_t \\ &\quad -0.35y_{t-1} + 0.50i_{t-1} - 0.06i_{t-2} - 0.03i_{t-3} \end{aligned}$$

In both of the reaction functions, the signs are the same. However, in their simulated reaction function, the Federal Reserve responds to inflation and output gap more vigorously. The main reason for this difference is the weights attached to goal variables in the loss function. This factor also explains the different lagged dependence of interest rates in the two reaction functions.

After finding out the weights of the goal variables in the loss function for three administrations, policy rules for the pre-Volcker and post-Volcker periods can easily be obtained as:

$$\text{pre-Volcker} \quad : \quad i_t = 0.63\pi_t + 0.19\pi_{t-1} + 0.11\pi_{t-2} + 0.20\pi_{t-3} + 1.29y_t$$

$$-0.12y_{t-1} + 0.64i_{t-1} - 0.06i_{t-2} - 0.08i_{t-3}$$

$$\text{post-Volcker} \quad : \quad i_t = 0.81\pi_t + 0.23\pi_{t-1} + 0.22\pi_{t-2} + 0.15\pi_{t-3} + 1.14y_t$$

$$-0.17y_{t-1} + 0.75i_{t-1} - 0.09i_{t-2} - 0.07i_{t-3}$$

As the two policy functions show, the interest rate response to current inflation is considerably higher in the post-Volcker regime. The Federal Reserve takes a more active role in controlling inflation in this period. The response of interest rate to output is slightly higher in Burns administration.

These results for the policy functions are consistent with Clarida, Gali and Gertler (2000). Other than their original forward-looking specification, they also represent backward-looking estimates for the monetary policy reaction function. Although the magnitudes of the interest rate response are different, both studies find a more active policy towards controlling inflation in the post-Volcker regime, and the response of interest rates to the output gap is slightly higher in Burns period.

4.5 *Simulations*

The simulations derived from the policy functions for the entire sample, the pre-Volcker period and the post-Volcker period can be seen in Figure 1 and Figure 2, which are at the end of the paper. In Figure 1, actual interest rate path is displayed with the policy function simulated according to the parameters of the entire sample. Although the two paths are similar, the policy function predicts a higher interest rate than the actual one in the pre-Volcker regime while the actual interest rate is higher than the simulated one for most of the post-Volcker regime.

Figure 2 presents the actual interest rate with the policy functions derived from parameters for the pre-Volcker regime and the post-Volcker regime. Before 1980, the policy function for the pre-Volcker regime and the actual interest rate are close to each other. The post-Volcker regime consistently predicts a higher interest rate for this period, which implies that monetary policy in this regime has been more aggressive. After 1980, this situation is almost reversed. Excluding the period between 1990 and 1994, the actual interest rate and the post-Volcker regime follow a similar path while the pre-Volcker regime predicts a lower interest rate. As a result, the two figures support the findings of the previous sections.

4.6 Impulse Responses and Variance Decompositions

As mentioned before, impulse response functions and variance decompositions will allow us to evaluate the model's overall fit. The impulse responses to each of the three shocks, the policy shock, the aggregate supply shock and the aggregate demand shock can be seen in Figure 3 at the end of the paper. One important result that the impulse response functions display is that there is no sign of a "prize puzzle" -increasing prices in response to a monetary policy contraction: a contractionary policy shock causes both inflation and output to fall, as expected. Also, a contractionary supply shock causes interest rates to increase and output to decrease over ten-year horizons. Finally, a positive aggregate demand shock causes all of the variables to increase, which is consistent with the literature.

Variance decompositions reveal the fact that policy behavior is endogenous. Over horizons of one to five years, around 25 percent of the fluctuations in the funds rate are due to aggregate demand shocks and 40 percent of the shocks are due to aggregate supply shocks. Another finding is that aggregate demand and policy disturbances are important sources of inflation variation, each causing around 30 percent over horizons of five years. Finally, policy shocks are very important determining aggregate demand fluctuations, accounting for 65 percent of the fluctuations.

5 CONCLUSION

Several studies attempted to explain two different macroeconomic outcomes in the United States in the last three decades. In the 1970's, the economy produced high and persistent inflation and was exposed to several negative supply shocks. From the beginning of 1980's, the story was completely different: low inflation was sustained with moderate levels of economic growth. Some studies, most recently Clarida. Gali and Gertler (2000) claimed that the conduct of monetary policy played a crucially important role for the two different inflation performances. Before the 1980's, monetary policy was characterized as being more accommodative. However, since the beginning of Volcker administration, controlling inflation and achieving price stability has been the most important goal.

This study adopts a simple empirical model of inflation and output from Rudebusch and Svensson (1998 and 1999), defines a loss function for the monetary authority, and simultaneously estimates the parameters for the model and the loss function. By doing so, the policy parameters are independently identified from those describing the behavior of the private economy. Also, monetary policy reaction functions associated with these estimated parameters are obtained both for the entire sample and the subsamples. It has been found that the empirical model's parameters are stable across the sample period, which is also consistent with Rudebusch and Svensson (1998 and 1999). More interesting results are obtained when the estimates of the loss function parameters are considered. First, price stability has been a superior goal for the monetary policy when the whole sample is considered. Second, and more importantly, the loss function parameters are not stable throughout the sample. There is a structural break after Paul Volcker is appointed as the chairman of the Federal Reserve. Output stability is found to play a more important role in the pre-Volcker era, while price stability has become much more dominant afterwards. The monetary policy reaction functions for the two periods also reflect these findings. The Volcker and Greenspan periods adopt a more active stance toward controlling inflation.

One extension to this study could be to reproduce the results using a forward looking IS and Phillips curves. However, several studies like Estrella and Fuhrer (1999) find that forward-looking models tend to perform worse in fitting the data than the backward-looking ones. Therefore, such a forward-looking specification need not improve the model's overall fit. For another reason, the optimization problem of the central bank in a forward-looking model is much more difficult to estimate and some special techniques described in Soderlind (1999) must be employed. Thus, such an exercise is left for further research.

Based on these findings, this study supports the view that there has been an important change in the monetary policymaking process after the end of the 1970's. However, the existence of positive supply shocks- or at least the absence of negative shocks- after the 1980's might ease the policymaking process for the monetary authorities.

Another explanation for the two different episodes may be the "learning story" as discussed by Taylor (1997) and Sargent (1997). The dynamics of inflation may have been better understood by both the policymakers and the academicians as the economics profession makes progress, and this may be a very important factor in achieving price stability.

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7 APPENDICES

7.1 Appendix 1. Optimization Problem

As $\beta \to 1$, the intertemporal loss function approaches $E\left[L_t\right]$, which will be equal to

$$\lambda_\pi(\bar{\pi}_t)^2 + \lambda_y(y_t)^2 + \lambda_i(i_t - i_{t-1})^2$$

Also, the inflation and output equation can be written in a state space form as:

$$X_{t+1} = AX_t + Bi_t + Vu_{t+1}$$

which can be shown as:

$$\begin{bmatrix} \pi_{t+1} \\ \pi_t \\ \pi_{t-1} \\ \pi_{t-2} \\ y_{t+1} \\ y_t \\ i_t \\ i_{t-1} \\ i_{t-2} \end{bmatrix} = \begin{bmatrix} \alpha_{\pi1} & \alpha_{\pi2} & \alpha_{\pi3} & \alpha_{\pi4} & \alpha_y & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{\beta_r}{4} & \frac{\beta_r}{4} & \frac{\beta_r}{4} & \frac{\beta_r}{4} & \beta_{y1} & \beta_{y2} & -\frac{\beta_r}{4} & -\frac{\beta_r}{4} & -\frac{\beta_r}{4} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \pi_t \\ \pi_{t-1} \\ \pi_{t-2} \\ \pi_{t-3} \\ y_t \\ y_{t-1} \\ i_{t-1} \\ i_{t-2} \\ i_{t-3} \end{bmatrix} +$$

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -\frac{\beta_r}{4} \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} i_t + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \varepsilon_{t+1} \\ \eta_{t+1} \end{bmatrix}$$

X_t is 9×1 vector of state variables, A is the 9×9 matrix, B is 9×1 column vector, V is the 9×2 matrix, and u_t is the 9×1 disturbance vector.

Then, we can define the goal variables as:

$$Y_t = C_x X_t + C_i i_t$$

which can be shown as:

$$\begin{bmatrix} \bar{\pi}_t \\ y_t \\ i_t - i_{t-1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix} X_t + \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} i_t$$

Defining such a goal variables vector will let us write the loss function as $L_t = Y_t^T K Y_t$ where K can be written as:

$$K = \begin{bmatrix} \lambda_\pi & 0 & 0 \\ 0 & \lambda_y & 0 \\ 0 & 0 & \lambda_i \end{bmatrix}$$

Now, the optimization problem can be written in a stochastic linear regulator form as explained in Sargent (1987) and Ljungqvist and Sargent (2000). Minimizing the loss function in each quarter subject to the state equation and the current state of the economy will give a feedback rule in the form of:

$$i_t = -fX_t$$

where $f = (C_i^T K C_i + \beta B^T V B)^{-1}(C_x^T K C_i + \beta B^T V A)$ and

$$V = C_x^T K C_x + C_x^T K C_i f + f^T C_x^T K C_i + f^T C_i^T K C_i f + \beta(A + Bf)^T V(A + Bf)$$

V is known as the algebraic Riccati equation.

7.1.1 The Dynamics of The Model

Substituting the feedback rule in to the vectors for state variables and goal variables will result in an optimal closed loop system:

$$X_{t+1} = (A - Bf)X_t + Vu_{t+1}$$

and

$$Y_t = (C_x - C_i f)X_t$$

The system is stable for all $X_0 \in R^n$ if and only if the maximum modulus of the eigenvalue of $(A - Bf)$ is strictly less than unity, which holds in this study.

The optimal value for $E(L_t)$ can be found as:

$$X_t^T V X_t + (\frac{\beta}{1-\beta}) trace(V \sum_{\mathrm{u}\,u})$$

$\sum_{\mathrm{u}\,u}$ is the covariance matrix of the disturbance vector. When discount factor $\beta = 1$, then $E(L_t) = trace(V \sum_{u\,u})$.

7.2 Appendix 2. Estimation Procedure

Let $F = (A - Bf)$ and $H = (C_x - C_i f)$. Then the optimal closed loop system can be written as:

$$X_{t+1} = FX_t + Vu_{t+1}$$

and

$$Y_t = HX_t$$

Then, conditional on $\{Y_{t-1}, Y_{t-2}, ..., Y_1\}$, Y_t is normally distributed with mean $HX_{t|t-1}$ and variance $HP_{t|t-1}H^T$, where $\left\{X_{t|t-1}\right\}_{t=1}^{T}$ and $\left\{P_{t|t-1}\right\}_{t=1}^{T}$ may be constructed recursively using the initial conditions:

$$X_{1|0} = 0_{9\times 1}$$

and

$$vec(P_{1|0}) = (I_{81\times 81} - F \otimes F)^{-1} vec(Q \sum Q^T)$$

Next, we can initialize the Kalman Filter. The updating equations will be:

$$K_t = FP_{t|t-1}H^T(HP_{t|t-1}H^T)^{-1}$$

$$X_{t+1|t} = FX_{t|t-1} + K_t(Y_t - HX_{t|t-1})$$

$$P_{t+1|t} = (F - K_tH)P_{t|t-1}(F^T - H^TK_t^T) + Q \sum Q^T$$

Finally, we can derive the log-likelihood function as:

$$\Gamma = -T\ln(2\pi) + \sum_{t=1}^{T} \Gamma_t$$

where

$$\Gamma_t = -\frac{1}{2}\ln\left[\det(HP_{t|t-1}H^T)\right] - \frac{1}{2}(Y_t - HX_{t|t-1})^T(HP_{t|t-1}H^T)^{-1}(Y_t - HX_{t|t-1})$$

The model's parameters can be estimated by choosing values that maximize Γ.

7.3 Appendix 3. Stability Tests

Andrews and Fair (1988) describe some procedures which can be used to test for the stability of the model's estimated parameters. Let Θ^1 and Θ^2 be the estimated parameters from two disjoint samples. Let's assume that asymptotically,

$$\Theta^1 \sim N(\Theta^{10}, H^1)$$

and

$$\Theta^2 \sim N(\Theta^{20}, H^2)$$

Then, a Likelihood Ratio test statistic can be formed as:

$$LR = 2\left[\ln\Gamma(\Theta^1) + \ln\Gamma(\Theta^2) - \ln\Gamma(\Theta)\right]$$

where $\ln\Gamma(\Theta^1)$,$\ln\Gamma(\Theta^2)$ and $\ln\Gamma(\Theta)$ are the maximized log-likelihood functions from the first subsample, second subsample and the entire sample. This statistic is asymptotically distributed as a chi-square random variable. The number of estimated parameters is the degrees of freedom, and the null hypothesis is that the model is stable over the entire sample.

Another way to test the stability is to use the Wald statistic which is

$$W = g(\Theta^1, \Theta^2)^T (G\hat{H}G^T)^{-1} g(\Theta^1, \Theta^2)$$

and the stability restrictions are as:

$$g(\Theta^1, \Theta^2) = 0$$

where

$$G = \frac{\partial g(\Theta^1, \Theta^2)}{\partial(\Theta^1, \Theta^2)}$$

and

$$\hat{H} = \begin{bmatrix} H^1 & 0 \\ 0 & H^2 \end{bmatrix}$$

Let Θ_q^1 and Θ_q^2 be the subsets of Θ^1 and Θ^2, and if H_q^1 and H_q^2 are the covariance matrices of Θ_q^1 and Θ_q^2, then the Wald statistic can be written as:

$$W = (\Theta_q^1 - \Theta_q^2)^T (H_q^1 + H_q^2)^{-1} (\Theta_q^1 - \Theta_q^2)$$

Similar to the Likelihood Ratio test, this statistic will also be asymptotically distributed as a chi-square random variable. The null hypothesis is stability over the entire sample with the degrees of freedom equal to the number of estimated parameters.

FIGURE 1: INTEREST RATE AND POLICY FUNCTION

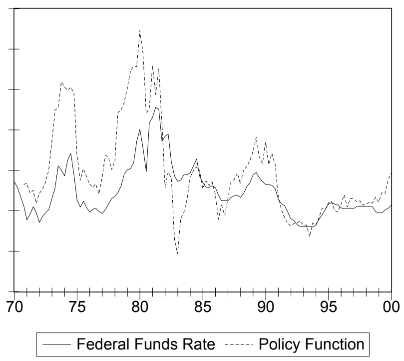


FIGURE 2: INTEREST RATE AND POLICY REGIMES

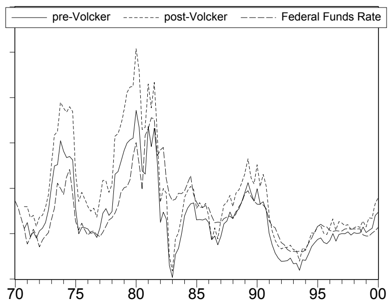
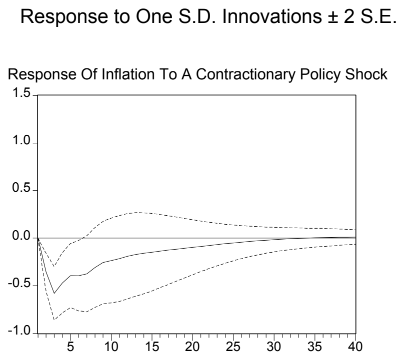
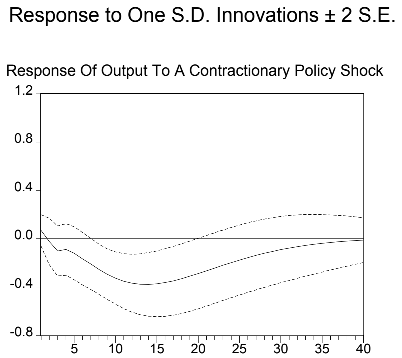
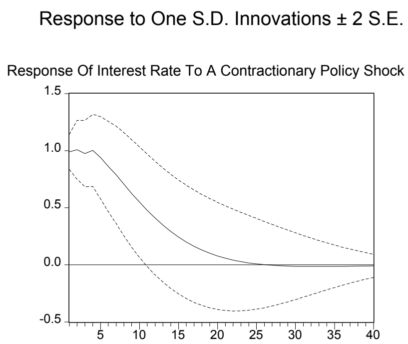


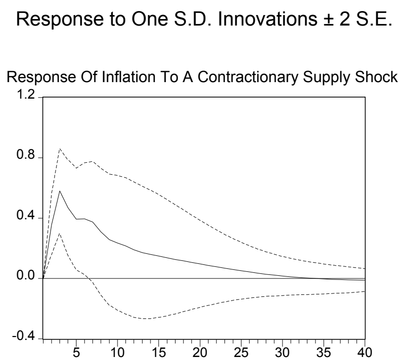
FIGURE 3: IMPULSE RESPONSE FUNCTIONS
3.1. TO A CONTRACTIONARY POLICY SHOCK

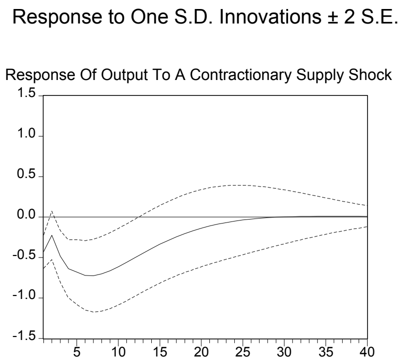


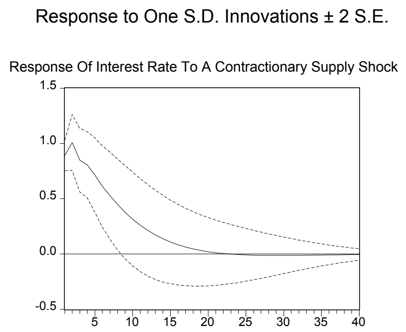




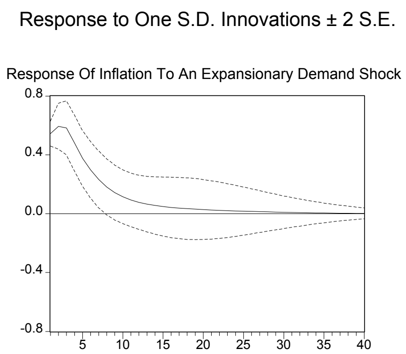
3.2. TO A CONTRACTIONARY SUPPLY SHOCK

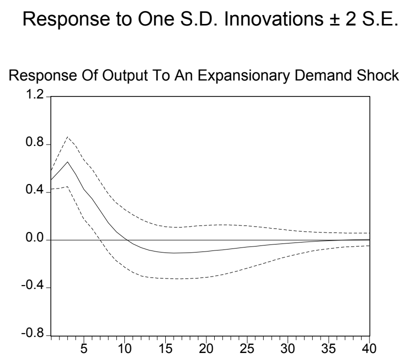






3.3 TO AN EXPANSIONARY DEMAND SHOCK





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