# Policy Preferences or Policymakers' Beliefs: What caused the Great Inflation in the US?

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## Abstract

This paper studies the causes of the rise and fall of inflation during the 1970s and 1980s, considered under the term of the "Great Inflation," in the United States. The model incorporates policymakers that learn about the state of the economy in real time, representing policymakers' beliefs, as well as a potential shifts in policymakers' preferences. Policymakers' preferences are portrayed by the estimates of the parameters in the policymakers' objective function. Preferences are allowed to vary before and after the appointment of chairman Volcker to the Federal Reserve. The empirical results show that in order to characterize the Great Inflation, policymakers had to observe distorted beliefs about the state of the economy, in addition to a change in policymakers' preferences for inflation relative to the output gap at the beginning of the disinflation era.

# 1. Introduction

The inflation dynamics experienced by the U.S. during the 1970s and into the 1980s denominated the Great Inflation, have been subject of much research. Several authors have different hypotheses on what caused the hump-shaped behavior of U.S. inflation during the late 1960s into the 1980s. These authors arrive at different conclusions ranging from bad policy to bad luck, to lack of commitment, to a change in policy beliefs, to an overly optimistic estimate of potential output and to a change in policy preferences. Ceccetti et al. propose that none of these factors fully explain the drastic and sudden disinflation process experienced in the U.S. in the 1980s. They explain that although deviations from potential and policy learning may have contributed to the Great Inflation, they are not sufficient to account for the whole phenomenon. Ceccetti et al. conclude that monetary policy regime changes were important to large movements in the trend of inflation in the U.S. and other countries. De Long (1995) also supports the view of a change in preferences between the late 60's and the appointment of Volcker as chairman of the Fed. He concludes that there was significant evidence supporting the view that the Federal Reserve between the late 60's to the late 70's "lacked the mandate to fight inflation by inducing a significant recession" (De Long 1995 p. 34). Politicians had fresh in their memories the Great Depression, therefore the sole purpose of the Federal Reserve was to reduce unemployment to its minimun.

Romer and Romer (2002), Sargent (1999), and Primiceri (2006) advocate for policy learning as possible explanation for the Great Inflation. While Orphanides et al. (2005), Romer and Romer (2002), and Primiceri (2006) believe that policy misperception of potential output is also a key part of the puzzle.

This paper studies the Great Inflation in a model that embeds both a possible change in policymakers' preferences from the Great Inflation into the Inflation Stabilization era, and changing beliefs about the state of the economy. I let the data speak in order to disentangle whether or not it was a change in preferences that lead to the prolonged inflationary period, or if the episode was due to distorted policymakers' beliefs.

One of the precursors of the literature that studies the influence of beliefs on policy is Romer and Romer (2002). They investigate policymakers' understanding of the United States' aggregate demand policies by looking at the Fed's narrative evidence and its internal forecasts. They examine policymaker's beliefs on a model of the economy underlying the actions of monetary policy. Moreover, they look at the Fed's internal forecast errors for inflation, and they estimate the natural rate of unemployment implicit in the forecast behavior of inflation and unemployment. They explain the

1970s as being a period of "overoptimism" characterized by an underestimated natural rate of unemployment followed by a period of "overpessimism" distinguished by a very high sacrifice ratio associated with a very costly disinflation policy. They conclude that the fundamental source of changes in policy has been changes in policymakers' beliefs about how the economy functions. Sargent (1999) contributes to the literature on policymakers' understanding of inflation policy in a model where policymakers are learning adaptively. Policymakers are assumed to estimate a popular but misspecified model of inflation: the Phillips curve. Under constant gain leaning the equilibrium is consistent with high inflation, however, the time paths sporadically deviate from the equilibrium. These "escape routes" coincide with low inflation. Sargent performs simulations under decreasing gain learning that simulate Volcker's disinflation. This paper follows Sargent (1999) in that it studies the Great Inflation in a model that uses constant gain learning to form beliefs about the state of the economy. In addition, the parameters of a New Keynesian Phillips curve are estimated overtime in order to shed some light on policymakers' real time understanding of the economy.

This paper is more in line with the contribution made in Primiceri (2006). Primiceri (2006) builds on the literature on policymakers' beliefs about the coefficients of the Phillips curve from a quantitative and statistical perspective. Primiceri introduces learning dynamics in a model where agents are assumed to be optimizing. He presents a model that supports the view of an overoptimistic period of the state of the economy proposed by Romer and Romer (2002) and by Orphanides (2005). Moreover, he explains that inflation remained high due to the wrong estimate of the natural rate of unemployment, as well as a downward biased estimate of the persistence of inflation, resulting in a delayed response to high inflation. His model, explains the overpessimism period of the state of the economy that translates into a very costly disinflation episode, addressed by Romer and Romer (2002) and Cogley and Sargent (2004). Primiceri concludes that a change in the perceived inflation-unemployment tradeoff was what put end to the Great inflation. The model presented in this paper builds on Primiceri's (2006) in that rational policy makers learn about the behavior of the economy in real time and set stabilization policy optimally, conditional on their current beliefs. The resulting optimal policy is integrated in the actual model of the economy. In that fashion, central bankers' beliefs will be incorporated in the model as a possible explanation for the run up of inflation.

Ceccetti et al. (2007) points to a change in policy preferences where "inflation proved so damaging that -even in the face of overestimated sacrifice ratio -the central bankers acted to disinflate and keep inflation low." The central bankers, at the beginning of the Inflation Stabilization era, were willing to disinflate even if that translated

into a "painful" unemployment episode. During the Great inflation, regimes were more accommodative to inflation shocks or they observed higher inflation targets. They propose a change in political influence or a shift in policymakers' preferences as the main contributor of the rise and fall of inflation in the U.S. This line of explanation of the Great Inflation coincides with De Long's study on America's only peacetime inflation, meaning the Great Inflation. De Long (1992) concludes that the Great Depression predisposed political opinion on the left and center making any unemployment rate too high. Therefore, the Federal Reserve lacked the mandate to control inflation by risking unemployment in the late 1960s and most of the 1970s. He explains that policymakers were worried "about what the transformation of every business venture into a speculation on monetary policy" would do to the progress of the US economy. Policymakers by 1979 feared that expectations were about to become unanchored and there would be permanent double digit inflation. Therefore, by 1979 and with the appointment of Volcker to the Federal Reserve the mandate to fight inflation by inducing a significant recession was put in place. This paper also incorporates a potential change in policymakers' preferences from pre-Volcker's appointment into post-Volcker's appointment as a possible explanation of the Great Inflation. This is done specifically by estimating the parameters in the objective function that specify the different goals of the central banks. Doing so allows me to identify the loss-minimizing weights given in the loss function to price and wage inflation, the interest rate smoothing parameter, and the relative weight in output stabilization.

I estimate the weights of the loss function for the period pre- and post 1979 that is the year that Paul Volcker was appointed Chairman of the Board of Governors of the Federal Reserve System. As outlined in Clarida et al. (2000) it has been of conventional wisdom that monetary policy in the United States has been relatively well managed after the appointment of Paul Volcker into the Greenspan years. While the previous period's monetary policy was poorly managed. The change in preferences or lack thereof between the two periods will be distinguished through the change in the weights of the central bank loss function. In Primiceri (2006) the parameters in the objective function are fixed except for the interest rate smoothing parameter. Furthermore, the parameters in the objective function are assumed to be fixed and talking the same value between 1960:I to 2002:IV; while Dennis (2006) acknowledges that there was a policy regime change after Volcker became chairman of the Federal Reserve.

Under the assumption that policymakers behave optimally, this paper estimates the parameters in the policy loss function along with the parameters in the "true" model of the economy. A contribution of this paper is to use likelihood-based Bayesian methods

for the estimation of a structural model along with the weights of the central bank's completely microfounded loss function . This approach builds on literature by Dennis (2004,2006) and Salemi (1995) that estimate parameters in the objective function jointly with parameters in the optimizing constraint using maximum likelihood methods. Furthermore, Ozlale's (2003) scope is similar to the work by Dennis (2006) but the estimation performed uses a two-step approach in which the policy regime parameters are estimated conditional on the estimates of the parameters in the constraints. Salemi (1995), Ozlale (2003), and Dennis (2006) conclude that there have been "qualitatively" significant changes in the policy loss function estimated for different chairmen of the Federal Reserve. They conclude that the appointment of different chairmen is consistent with policy regime changes or changes in policy preferences.

The estimation procedure was performed using a Bayesian approach. Bayesian methods aid at estimating together the policymakers' preference parameters and the "true" model parameters. Lubik and Schorfheide (2004, 2007) among others estimate DSGE models using Bayesian methods under the rational expectations paradigm. Moreover, Milani (2007, 2008) revisits the expectation formation of the agents and allows for learning in an estimated DSGE models using Bayesian methods. The Bayesian approach followed in this paper is akin to Lubik and Schorfheide (2004,2007) and to Milani (2007,2008), however, in this setting, agents are assumed to form expectations rationally while policymakers are learning about the state of the economy.

I conclude that policymakers distorted beliefs about the state of the economy, in addition to a change in policymakers' preferences at the beginning of the disinflation era were the main contributors to the rise and fall of inflation in the U.S. Policymakers in the model do not react strongly enough to inflation at the initial stages of the Great Inflation because they perceive that inflation is stationary and that is will revert to its mean value at any time. Even though policymakers eventually learn the true persistence of inflation, they do not act on it because they perceive a very low tradeoff between output gap and inflation. They act on inflation once they perceive that this tradeoff has improved. These two views are consistent with the results presented in Primiceri (2006). Moreover, there was an important change in preferences for stabilizing inflation relative to output after Volcker's appointment as chairman of the Federal Reserve. The weight that central bankers in this model put on stabilizing the output gap approaches zero in the post-Volcker's appointment period. This claim supports Ceccetti's et (2007) argument that monetary policy regime changes were important to observe large movements in trend of inflation in the U.S. In addition, it shows that the memory of the Great Depression was still too fresh on policymakers' minds during the 1970s as proposed by De Long (1995). The model shows that even though there

was no mandate to fight inflation by allowing the unemployment rate to rise during the late 1960s and most of the 1970s, this changed by the 1979. The mandate to fight inflation by inducing a significant recession was put in place as a result of fears about the cost of inflation.

# 2. The environment

## 2.1. The model

The following optimizing model is a dynamic stochastic general equilibrium model in the spirits of Erceg et al. (2000), Woodford(2003), Giannoni and Woodford (2003). This model includes internal habit persistence, wage stickiness, and inflation inertia, which have proven to improve the empirical properties of the model giving more realism to the transmission mechanisms.

The structural equations that give the aggregate dynamics of output, price, and wage inflation are specified as follows:

### 2.1.1. Optimal consumption decisions

The economy is composed by a continuum of households $h$ distributed uniformly on the [0,1] interval, each of which supplies a differentiated labor service to the production sector. Thus, firms regard each household's labor as an imperfect substitute of the other household's labor. A labor aggregator bundles the household's labor hours in the same proportions as firms would choose. Each household $h$ maximize a lifetime expected utility that can be written as follows.

$$E_t \sum_{T=t}^{\infty} \beta^{T-t}[u(C_T^h - \eta C_{T-1}^h; \zeta_T) - v(H_T^h; \zeta_T)] \tag{1}$$

where $\beta$ is the household's discount factor, $C_T^h$ is a Dixit-Stiglitz index of household's consumption of each of the differentiated goods supplied at time t, and $H_t^h$ is the amount of labor (type $h$) supplied by the household $h$ at time t. The parameter $0 \leq \eta \leq 1$ represents the degree of habit formation. Each household obtains utility from the excess consumption at date t relative to some habit stock $\eta C_{t-1}$. $\zeta_T$ is a vector of exogenous preference shocks. The function $u(\cdot; \zeta_T)$ is increasing and concave for each value of $\zeta_T$, while $v(\cdot; \zeta_T)$ is increasing and convex. This model assumes that capital is fixed and cannot be instantaneously relocated among firms in order to equalize the return to capital services across firms that change their prices at different

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prices. In this model the financial markets are complete so that risks are efficiently shared. As a result, each household faces a single intertemporal budget constraint. CES Dixit-Stiglitz consumption index:

$$C_t^h \equiv \left[ \int_0^1 c_t^h(j)^{\frac{\theta_p-1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p-1}} \tag{2}$$

and the price index is:

$$P_t \equiv \left[ \int_0^1 p_t(j)^{1-\theta_p} dj \right]^{\frac{1}{\theta_p-1}} \tag{3}$$

where $c_t^h(j)$ aggregates consumption of each good and $\theta_p > 1$ stands for the elasticity of substitution between differentiated goods. Optimal consumption of good $j$ is given by $c_t^h(j) = C_t^h(p_t(j)/P_t)^{-\theta_p}$, where $p_t(j)$ is the price of good $j$ at date t.

Risks are efficiently shared since financial markets are complete. Therefore, each household faces the same intertemporal budget constraint given by:

$$P_t C_t^h + E_t[Q_{t,t+1} A_{t+1}^h] \le A_t^h + w_t(h) H_t^h + \Pi_t(h) - T_t \tag{4}$$

where $A_t^h$ is the nominal value of the household's beginning-of-period financial wealth, $w_t(h)$ denotes nominal wage of labor $h$, $\Pi_t(h)$ stands for the profits from sales of good $h$, and $T_t$ represents the nominal value of (net) lump-sum taxes. $Q_{t,T}$ is the stochastic discount factor that defines the market valuations of alternative random income streams. Taking into consideration that the riskless one-period nominal interest rate, $i_t$ must satisfy

$$(1+i_t)^{-1} = E_t Q_{t,t+1} \tag{5}$$

The first order conditions for the optimal choice of consumption is given by

$$\Lambda_t P_t = u_c(C_T - \eta C_{T-1}; \zeta_T) - \beta \eta u_c(C_{T+1} - \eta C_t; \zeta_{T+1}) \tag{6}$$

$\Lambda_t$ that denotes the representative household's marginal utility of real income at time t[1].

The marginal utilities of income at different dates and states must satisfy

$$\Lambda_t Q_{t,T} = \beta^{T-t} \Lambda_T \tag{7}$$

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[1]As in Giannoni and Woodford (2003) the problem is the same for each household since the initial level of wealth is assumed to differ among households in a way that it compensates for any differences in their expected labor incomes. All households choose identical state-contingent plans of consumption, thus, I drop the $^h$ in the consumption variable.

for any possible state at any date $T \geq t$. Merging equations (7) and (5) results in the Euler equation for optimal timing of consumption. The Euler equation links the interest rate to the evolution of the marginal utility of income in the following equilibrium relationship:

$$\Lambda_t P_t = \beta E_t[(1+i_t)\frac{P_t}{P_{t+1}}\Lambda_{t+1}P_{t+1}] \tag{8}$$

Log-linear approximations of these relationships were performed about a steady state equilibrium with no inflation. Log-linearizing equations (8) yields

$$\hat{\lambda}_t = E_t[\hat{\lambda}_{t+1} + \hat{i} - \pi_{t+1}] \tag{9}$$

where $\hat{\lambda}_t \equiv log\frac{\Lambda_t P_t}{\bar{\lambda}}, \hat{i}_t \equiv log(\frac{1+i_t}{1+\bar{i}})$, and $\pi_t \equiv log(\frac{P_t}{P_{t-1}})$ Using equation (9) and log-linearizing equation (6) yields:

$$\widetilde{C}_t = E_t\widetilde{C}_{t+1} - (1-\beta\eta)\sigma(\hat{i}_t - E_t\hat{\pi}_{t+1}) + g_t - E_t g_{t+1} \tag{10}$$

where
$$\widetilde{C}_t \equiv (\hat{C}_t - \eta\hat{C}_{t-1}) - \beta\eta E_t(\hat{C}_{t+1} - \eta\hat{C}_t) \tag{11}$$

$\sigma$ is the intertemporal elasticity of substitution of consumption in the absence of habit formation, exogenous preference shocks are represented by $g_t$, and $\hat{C}_t, \hat{i}_t$,and$\hat{\pi}_t$ represent log-deviations of consumption, nominal interest rates, and inflation from their steady-state values[2]. Aggregate demand $Y_t = C_t$, rewriting relationship (11) in terms of the output gap $x_t \equiv Y_t - Y_t^n$ where $Y_t^n$ indicates log deviations from in the natural rate of output [3] I obtain the intertemporal IS relation:

$$\widetilde{x}_t = E_t\widetilde{x}_{t+1} - (1-\beta\eta)\sigma[i_t - E_t\pi_{t+1} - r_t^n] \tag{12}$$

where
$$\widetilde{x}_t \equiv (x_t - \eta x_{t-1}) - \beta\eta E_t(x_{t+1} - \eta x_t) \tag{13}$$

and $r_T^n \equiv [(1-\eta\beta)\sigma]^{-1}[(Y_{t+1}^n - g_{t+1}) - (Y_t^n - g_t)]$ is the flexible price real interest rate that represents the real interest rate when $x_t = 0$ at all times.

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[2] The superscript ˆ will be omitted in the rest of the paper for conciseness.

[3] The natural rate of output means the equilibrium level of output under flexible prices, flexible wages, and constant levels of distorting taxes and of desired markups in the labor and product markets.

## 2.1.2. Optimal Wage Setting

This model incorporates optimal wage setting in a DSGE context, as well as a measure of wage inflation in the policymakers' loss function. This segment of the model is important because the behavior of wages and wage inflation provides information about the rate of core inflation during the late 1960s and most of the 1970s as in De Long (1995). He proposes that historically there had been a 1.5 percentage point gap between wage and price inflation in the 1950s and 1960s (wages always higher). Moreover, he compares the patterns of wage and price inflation and notices an ambiguity in the character of inflation in the 1970s. In prices, inflation happened after 1968, from 5 percent in 1968 to over 10 percent in 1981. In wages, inflation occurred by 1968, went from 6.5 percent to a peak of a little more than 8 percent at the end of the 1970s. Thus, he suggests that while the "magnitude of the inflation control problem" changed between the late 1960s, when policymakers realized the problem, to the beginning of Volcker's disinflation, the "qualitative nature of the problem did not." Paul Volcker at the end of the 1970s and Arthur Burns at the beginning of the 1970s had to confront the same issue of how to slow the wage inflation, and therefore the core of inflation. These issues make it relevant for the study of the Great Inflation to include wage and wage inflation into the model of the economy.

Following Erceg et al. (2000), Amato and Laubach(2003), Woodford (2003), and Giannoni and Woodford (2003) I assume that there is a single labor market in the economy. The producers of all goods hire the same kind of labor and face the same wages. Firm $j$ is a monopolistic supplier of good $j$, which produces according to the production function

$$y_t(j) = A_t F(\overline{K}, H_t(j)) \equiv A_t f(H_t(j)) \tag{14}$$

where $A_t$ is an exogenous technology factor, the function $f$ is increasing and concave, and capital is fixed so that labor is the only variable input. The labor index $H_t(j)$ has the Dixit-Stiglitz form:

$$H_t(j) \equiv \left[ \int_0^1 H_t^h(j)^{\frac{\theta_w - 1}{\theta_w}} dh \right]^{\frac{\theta_w}{\theta_w - 1}} \tag{15}$$

for some elasticity of substitution $\theta_w > 1$ where $H_t^h(j)$ is the labor of type $h$ that is hired to produce a given good $j$. The demand for labor type $h$ by firm $j$ results from the maximization of index (15) for a given level of wage and it is characterized by $H_t^h(j) = H_t(j) \left( \frac{w_t(h)}{W_t} \right)^{-\theta_w}$, where $w_t(h)$ is the nominal wage of labor of type $h$, and

$W_t$ is a wage index

$$W_t \equiv \left[ \int_0^1 w_t(h)^{1-\theta_w} dh \right]^{\frac{1}{1-\theta_w}} \tag{16}$$

The monopoly supplier sets the wage for each type of labor. Each type of labor is ready to supply as many hours of work to be demanded at that wage. In addition, analogous to the Calvo model of staggered pricing, each wage is reutilized with fixed probability $1 - \alpha_w$ each period. Moreover, as in Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003), Altig et al. (2004), and Giannoni and Woodford (2003, ch. 3) if a wage is not reoptimized, it is adjusted according to the indexation rule

$$log w_t(h) = log w_{t-1}(h) + \gamma_w \pi_{t-1} \tag{17}$$

for some $0 \leq \gamma_w \leq 1$ that represents the degree of indexation to past inflation. A worker of type $h$ who chooses a new wage $w_t(h)$ at date t, expects to have a wage $w_t(h)(P_{T-1}/P_{t-1})^\gamma$ with probability $\alpha^{T-t}$ at any time $T \geq t$. Newly optimized wages take effect immediately, thus, a new wage $w_t(h)$ adjusted in period t should be selected to maximize

$$E_t \sum_{T=t}^{\infty} (\alpha\beta)^{T-t} [\Lambda_T w_t(h) \left( \frac{P_{T-1}}{P_{t-1}} \right)^\gamma H_T \left( \frac{w_t(h) \left( \frac{P_{T-1}}{P_{t-1}} \right)^{\gamma_w}}{W_T} \right)^{-\theta_w}$$

$$- v \left( H_T \left( \frac{w_t(h) \left( \frac{P_{T-1}}{P_{t-1}} \right)^\gamma}{W_T} \right)^{-\theta_w} ; \xi_T \right) ] \tag{18}$$

where $\Lambda_T$ is the representative household's marginal utility of nominal income at date T. The solution to this problem satisfies the first order condition

$$0 = E_t \{ \sum_{T=t}^{\infty} (\alpha_w\beta)^{T-t} \left[ H_T (w_t^*)^{-\theta_w-1} \left( \frac{P_{T-1}/P_{t-1}^{\gamma_w}}{W_T} \right)^{-\theta_w} (1 - \theta_w) \right] \tag{19}$$

$$\left[ \Lambda_T w_t^* \left( \frac{P_{T-1}}{P_{t-1}} \right)^\gamma_w - \mu_w v_h \left( H_T \left( \frac{w_t^* (P_{T-1}/P_{t-1})^{\gamma_w}}{W_T} \right)^{-\theta_w} ; \xi_T \right) \right] \}$$

where $\mu_w = \theta_w/(\theta_w - 1) > 1$ is the desired markup of household's real wage demand over its marginal rate of substitution (MRS) owing to it's monopoly power, and $v_t$ is the geometric average of the MRS between work and consumption across different types of labor. The optimal wage $w_t^*$ is equal across all $h$, since the function $v(H, \xi)$ is the same across all $h$, and the optimization problem solved by the each household is the same. Given the choice of $w_t^*$ each period, the overall wage index evolves according to

$$W_t = \left[ (1 - \alpha_w) w_t^{*1-\theta_w} + \alpha \left( W_{t-1} \left( \frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_w} \right)^{1-\theta_w} \right]^{\frac{1}{1-\theta_w}} \tag{20}$$

The Log-linearization will be performed under the assumption that $W_t/P_t$, $P_t/P_{t-1}$, and $w_t^*/W_t$ will remain close to their steady state values. Log-linearizing equation (20) results in

$$\hat{w}_t^* = \frac{\alpha_w}{1 - \alpha_w} (\pi_t^w - \gamma_w \pi_{t-1}) \tag{21}$$

where $\hat{w}_t^* \equiv log(w_t^*/W_t)$, $\pi_t^w \equiv log(W_t/W_t - 1)$. A log-linear approximation to the first-order condition yields

$$0 = E_t \left\{ \sum_{T=t}^{\infty} (\alpha_w \beta)^{T-t} \left[ (1 + v\theta_w)) \left( \hat{w}_t^* - \sum_{\tau=t+1}^{\infty} (\pi_\tau^w - \gamma_w \pi_{\tau-1}) + \hat{\omega}_T - \hat{v}_T \right] \right\} \tag{22}$$

where $v \equiv \frac{v_h h \overline{H}}{v_h}$, $\hat{H} \equiv log H_t/\overline{H}$ and $\hat{\omega}_t \equiv log \left( \frac{W_t/P_t}{\overline{\omega}} \right)$ is the percent deviation of the real wage from steady-state, and

$$\hat{v}_t \equiv v \hat{H}_t + \frac{v_h \xi}{v_h} \xi_t - \hat{\lambda}_t \tag{23}$$

is the geometric average of the deviation from steady state of the MRS between work and consumption across different types of labor. Solving the log-linearized first-order condition results in

$$\hat{w}_t^* = E_t \left\{ \left[ \sum_{T=t}^{\infty} (\alpha_w \beta)^{T-t} \left[ (\pi_T^w - \gamma_w \pi_{T-1}) + \frac{1 - \alpha_w \beta}{1 + v\theta_w} (\hat{\omega}_T - \hat{v}_T) \right] \right] - (\pi_t^w - \gamma_w \pi_{t-1}) \right\} \tag{24}$$

Quasi-differencing this equation and making use of equation (21) yields

$$\pi_t^w - \gamma_w \pi_{t-1} = \xi_w (\hat{v}_t - \hat{\omega}_t) + \beta E_t (\pi_{t+1}^w - \gamma_w \pi_t) + u_t^w \tag{25}$$

Expressing equation (23) as log deviations of the MRS form its steady state values as a function of fluctuations in aggregate output can be written as

$$\hat{v}_t = \omega_w (\hat{Y} - a_t) + \frac{v_h \xi}{v_h} \xi_t - \hat{\lambda}_t \tag{26}$$

The parameter $\omega_w \equiv v\phi > 0$ indicates the degree to which higher economic activity increases workers' desired wages for given prices. The expression of the natural rate of

output is given by

$$\omega \hat{Y}_t^n = (1+\omega)a_t - \frac{v_h \xi}{v_h}\xi_t + \hat{\lambda}_t^n \tag{27}$$

Taking into consideration the previous equation, the marginal rate of substitution between labor and consumption can be expressed as

$$\hat{v}_t = \omega_w x_t + [((1-\beta\eta)\sigma)^{-1}\widetilde{x} + \hat{w}_t^n] \tag{28}$$

where

$$\hat{w}_t^n \equiv (1+\omega_p)a_t - \omega_p \hat{Y}_t^n \tag{29}$$

represents percent deviation from the steady state natural real wage. Lastly, wage-inflation equation (25) can be written as an aggregate-supply relation of the form

$$\pi_t^w - \gamma_w \pi_{t-1} = \xi_w[\omega_w x_t + [(1-\eta\beta)\sigma]^{-1}\widetilde{x}_t] + \xi_\omega(w_t^n - w_t) + \beta E_t(\pi_{t+1}^w - \gamma_w \pi_t) + u_t^w \tag{30}$$

where $\xi_w = \frac{(1-\alpha_w)(1-\alpha_w\beta)}{\alpha_w(1+v\theta_w)}$ is a function of the degree of wage stickiness, the elasticity of marginal disutility of labor supply at the steady state, $v \equiv \frac{v_{hh}\overline{H}}{v_h}$ and the elasticity of substitution for different types of labor.

## 2.1.3. Optimal Price Setting

Similarly, the suppliers of goods are monopolistically competitive and each price is maximized with probability $1 - \alpha_p$ in a given period. Moreover, as in Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003), Altig et al. (2004), Giannoni and Woodford (2003), and Woodford (2003, ch. 3) if a price is not reoptimized, it is adjusted according to the indexation rule

$$logp_t(j) = logp_{t-1}(j) + \gamma_p \pi_{t-1} \tag{31}$$

Every firm solves the same decision problem, and when thy change their price, they set a common price at $p_t^*$. The aggregate price evolves according to

$$P_t = \left[\alpha_p \left(P_{t-1}\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p}\right)^{1-\theta_p} + (1-\alpha_p)p_t^{*1-\theta_p}\right]^{\frac{1}{1-\theta_p}} \tag{32}$$

for some $0 \leq \gamma_p \leq 1$. Log-linearizing equation (29) results in

$$\hat{p}_t^* = \frac{\alpha_p}{1-\alpha_p}(\pi_t - \gamma_p \pi_{t-1}) \tag{33}$$

Firms select its new price $p_t^*$ in order to maximize the expected present discounted value of future profits

$$E_t \left\{ \sum_{T=t}^{\infty} \alpha^{T-t} Q_{t,T} [\Pi_T(p_t)] \right\} \tag{34}$$

where $\Pi_T$ nominal profits are given by

$$\Pi_T(p) = p \left( \frac{P_{T-1}}{P_{t-1}} \right)^{\gamma_p} \left( \frac{p(P_{T-1}/P_{t-1})^{\gamma_p}}{P_T} \right)^{-\theta_p} Y_T - W_t f^{-1} \left( \left( \frac{p(P_{T-1}/P_{t-1})^{\gamma_p}}{P_T} \right)^{-\theta_p} \frac{Y_T}{A_T} \right) \tag{35}$$

The solution to this problem satisfies the first order condition

$$0 = E_t \{ \sum_{T=t}^{\infty} (\alpha_p \beta)^{T-t} \left[ \frac{\Lambda_T}{\Lambda_t} (p_t^*)^{-\theta_p - 1} \left( \frac{(P_{T-1}/P_{t-1})^{\gamma_p}}{P_T} \right)^{-\theta_p} (1 - \theta_p) P_T Y_T \right] \tag{36}$$

$$\left[ \frac{p_t^*}{P_T} \left( \frac{P_{T-1}}{P_{t-1}} \right)^{\gamma_p} - \mu_p \frac{W_T/P_T}{A_T f' \left( f^{-1} \left( \left( \frac{p_t^* (P_{T-1}/P_{t-1})^{\gamma_p}}{P_T} \right)^{-\theta_p} \frac{Y_T}{A_T} \right) \right)} \right] \}$$

where $\mu_w = \theta_w/(\theta_w - 1) > 1$. The optimization problem is the same for all firms, therefore the optimal price $p_t^*$ is the same for all firms. Log-linearizing the previous equation around a steady state results in

$$0 = E_t \left\{ \sum_{T=t}^{\infty} (\alpha_p \beta)^{T-t} \left[ (1 + \omega_p \theta_p) \left( \hat{p}_t^* - \sum_{\tau=t+1}^{T} (\pi_t - \gamma_p \pi_{t-1}) \right) - \hat{\omega}_T - \hat{\psi}_T \right] \right\} \tag{37}$$

$\omega_p$ indicates the degree to which higher economic activity increases producers' desired prices given wages, $\hat{p}_t^* \equiv log(\hat{p}_t^*/P_t), \hat{\omega}_t \equiv log(\frac{W_t/P_t}{\overline{w}})$ and

$$\hat{\psi}_t \equiv \omega_p \hat{T}_t - (1 + \omega_p) a_t \tag{38}$$

$\hat{\psi}_t$ represents minus the average deviation of log marginal product of labor across firms from its steady state. Solving the log-linearized first-order condition equation (37) yields

$$\hat{p}_t^* = E_t \left\{ \left[ \sum_{T=t}^{\infty} (\alpha_w \beta)^{T-t} \left[ (\pi_T - \gamma_p \pi_{T-1}) + \frac{1 - \alpha_p \beta}{1 + \omega_p \theta_p} (\hat{\omega}_T - \hat{\psi}_T) \right] \right] - (\pi_t - \gamma_p \pi_{t-1}) \right\} \tag{39}$$

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Quasi differencing this equation and making use of equation (33) gives

$$\pi_t - \gamma_p \pi_{t-1} = \xi_p(\hat{\omega}_T + \hat{\psi}_T) + \beta E_t(\pi_{t+1} - \gamma_p \pi_t) + u_t^p \tag{40}$$

Witting the previous equation in terms of output and the natural rate of output

$$\pi_t - \gamma_p \pi_{t-1} = \kappa_p(\hat{Y}_t - \hat{Y}_t^n) + \xi_p(\hat{w}_t - \hat{w}_t^n) + \beta E_t(\pi_{t+1} - \gamma_p \pi_t) + u_t^p \tag{41}$$

$$\hat{w}_t^n \equiv (1 + \omega_p)a_t - \omega_p \hat{Y}_t^n \tag{42}$$

$\hat{w}_t^n$ represents the percent deviation from steady state value of the natural real wage. Moreover, $w_t^n$ is defined as the log of the natural real wage and $w_t$ is the log real wage. Therefore, equation (38) can be further expressed as relation of the form

$$\pi_t - \gamma_p \pi_{t-1} = \kappa_p x_t + \xi_p(w_t - w_t^n) + \beta E_t(\pi_{t+1} - \gamma_p \pi_t) + u_t^p \tag{43}$$

where $\kappa_p = \xi_p \omega_p$, $\xi_p = \frac{(1-\alpha_p)(1-\alpha_p\beta)}{\alpha_p(1+\omega p\theta_p)}$ is a function of the degree of price stickiness.

The structural model is composed by equations (12), (13), (30), and (43) reproduced here for convenience. The demand block is represented by:

$$\tilde{x}_t = E_t \tilde{x}_{t+1} - \varphi[i_t - E_t\pi_{t+1} - r_t^n] \tag{44}$$

where

$$\tilde{x}_t \equiv (x_t - \eta x_{t-1}) - \beta\eta E_t(x_{t+1} - \eta x_t) \tag{45}$$

$\varphi \equiv (1 - \eta\beta)\sigma$ and $r_T^n \equiv [(1 - \eta\beta)\sigma]^{-1}[(Y_{t+1}^n - g_{t+1}) - (Y_t^n - g_t)]$
The supply side model is given by equations:

$$\pi_t^w - \gamma_w \pi_{t-1} = \xi_w[\omega_w x_t + \varphi^{-1}\tilde{x}_t] + \xi_\omega(w_t^n - w_t) + \beta E_t(\pi_{t+1}^w - \gamma_w \pi_t) + u_t^w \tag{46}$$

$$\pi_t - \gamma_p \pi_{t-1} = \kappa_p x_t + \xi_p(w_t - w_t^n) + \beta E_t(\pi_{t+1} - \gamma_p \pi_t) + u_t^p \tag{47}$$

and the identity

$$w_t = w_{t-1} + \pi_t^w - \pi_t \tag{48}$$

Equation (45) is the log-linearized Euler equation. Equations (46) and (47) are Phillips curves for prices and wages. Equation (48) is an identity for the real wage ($w_t = W_t/P_t$) expressed in logs and it was rearranged in this form to provide a law of motion for the log of nominal wages. Here $x_t$ represents the output gap, $\pi_t$ and $\pi_t^w$ are nominal price and wage inflation, $w_t$ is the log real wage, $w_t^n$ represents exogenous variation in the natural real wage and $E_t$ represents rational expectations. $\sigma > 0$ is

the inverse of the inter-temporal elasticity of substitution. However, as in Giannoni and Woodford (2003) the parameter $\varphi$ that has been called the pseudo-elasticity of intertemporal substitution will be estimated instead of $\sigma$. $\varphi$ measures the sensitivity output to changes in the interest rate. The terms $\xi_p$, $\xi_w$, are all positive. Prices and wages are adjusted a la Calvo, where $1 - \alpha_p (1 - \alpha_w)$ is the probability that each of the price (wage) is adjusted each period, where the probability is independent of the time since a given price (wage) was last adjusted. The parameter $\xi_p$ represents the sensitivity of goods-price inflation to changes in the average gap between marginal cost and current prices; it is smaller as prices are stickier ($\alpha_p$). The parameter $\xi_w$ indicates the sensitivity of wage inflation to changes in the average gap between households "supply wage" (the marginal rate of substitution between labor supply and consumption) and current wages, and it is a function of the Calvo parameter that denotes wage stickiness in the economy ($\alpha_w$). $\omega_p > 0$ represents the elasticity of supply wage with respect to the quantity supplied at a given wage; while $\omega_w > 0$ measures the elasticity of the supply wage with respect to the quantity produced, holding fixed households' marginal utility of income. In order to estiamte the system of equations, I substitute the law of motion for wages, equation (48), into the Phillips curve for wages, equation (46). In addition, I rewrite the Phillips curve for prices and wages in terms of $W_t = w_t - w_t^n$ where the shock in the Phillips curve for wages becomes $u_t^w = -w_t^n - w_{t-1}^n + \beta E_t w_{t+1}^n - \beta E_t w_t^n$.

# 3. Policymaker's Beliefs

## 3.1. The Policy Objective Function under Imperfect Information

Policymakers have imperfect information about the model of the economy and about the model's parameters. For that reason, policymakers approximate the true model of the economy by estimating a vector autoregressive (VAR) model every period. The VAR model takes the form of the minimun state variable solution yielded by the model of the economy. After estimating the value of the parameters in the VAR model every period, they implement optimal monetary policy to obtain i. Policymaker's beliefs about the state of the economy are characterized by their estimate for the parameters in the VAR. As in Primiceri (2006), policymakers estimate the coefficients of the model every period and they expect to remain the same in the future, having no room for experimentation.

Policymakers set monetary policy optimally according to the quadratic loss function

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described below. In this case $x_t \equiv Y_t - Y_t^n$.

$$E_t\left\{\sum_{j=0}^{\infty}\beta^j[\lambda_p(\pi_{t+j}-\gamma_{pf}\pi_{t+j-1})^2+\lambda_w(\pi_{t+j}^w-\gamma_{wf}\pi_{t+j-1})^2+\lambda_x(x_{t+j}-\delta x_{t+j-1}-\hat{x}^*)^2+\lambda_i(i_{t+j}-i_{t+j-1})^2]\right\}$$
(49)

Policymakers' preferences parameters are $\lambda_p$, $\gamma_pf$, $\lambda_w$, $\gamma_wf$, $\lambda_x$, and $\lambda_i$ and $\delta$ is the smaller root of the quadratic equation $\eta\varphi(1+\beta\delta^2)=[\omega+\varphi(1+\beta\eta^2)]\delta$.

The model of the economy was derived from the optimizing behavior of the agents and gives policymakers the objective of maximizing the expected utility of the representative household, as described in Giannoni and Woodford (2003). Therefore, the objective is represented by a quadratic function of wage and price inflation, the output gap and the nominal interest rate. Moreover, loss-minimizing weights given in the loss function to price and wage inflation are determined by lagged inflation rates and indexation coefficients. These are mainly due to the inflation indexation properties of the model of the economy. In this quadratic loss function I also include a term that gives room for policymaker's interest rate smoothing. There are several reasons why interest rate smoothing is a compelling property of the loss function. One reason is that maturity mismatches between banks' assets and volatilities make financial volatility an undesirable property ass addressed by Cukierman (1989). In addition, if policy makers have to retract from a large interest rate movement it may lead to lost credibility and reputation as described by Brainard (1967). These and other reasons why interest rate smoothing is a desirable feature of the loss function are outlined in Dennis (2006).

Policymakers optimize subject to the following constraints written in VAR form.

$$y_t = \mu + \Gamma y_{t-1} + Ti_{t-1} + \epsilon_t \tag{50}$$

where $y_t = [x_t, \pi_t, W_t]'$. The matrices $\mu$, $\Gamma$, and $T$ contain the coefficients $\hat{c}_y$, $\hat{c}_\pi$, $\hat{c}_w$, $\hat{b}1, \hat{c}1, \hat{d}1, \hat{b}2, \hat{c}2, \hat{d}2, \hat{b}3, \hat{c}3, \hat{d}3$, and $\hat{b}4, \hat{c}4, \hat{d}4$ that represent the policymakers' beliefs and can be distinguished by their circumflexes.

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## 3.2. State Space Form and Optimal Policy

The optimization constraints have the following state space representation.

$$z_{t+1} = C_t + A_t z_t + B_t i_t + e_{t+1} \tag{51}$$

where $z_t = [x_t, x_{t-1}, \pi_t, \pi_{t-1}, \pi_{t-2}, W_t, W_{t-1}, W_{t-2}, i_{t-1}, i_{t-2}]'$ is the state vector $e_{t+1} = [e_{t+1}^y, 0, e_{t+1}^\pi, 00, e_{t+1}^w, 0, 0, 0, 0]'$ is the shock vector, and $i_t$ is the policy instrument or control variable and the matrices in the state-space form are $C = \begin{bmatrix} \hat{c}_y & 0 & \hat{c}_\pi & 0 & 0 & \hat{c}_w & 0 & 0 & 0 & 0 \end{bmatrix}$

$B = \begin{bmatrix} \hat{b}4 & 0 & \hat{c}4 & 0 & 0 & \hat{d}4 & 0 & 0 & 1 & 0 \end{bmatrix}$

and $A = \begin{bmatrix} \hat{b}1 & 0 & \hat{b}2 & 0 & 0 & \hat{b}3 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hat{c}1 & 0 & \hat{c}2 & 0 & 0 & \hat{c}3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hat{d}1 & 0 & \hat{d}2 & 0 & 0 & \hat{d}3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$

The quadratic loss functions is characterized in terms of the state and control vectors in the following form:

$$E_t \left\{ \sum_{j=0}^{\infty} \beta^j [(z_{t+j})' Q(z_{t+j}) + (i_{t+j})' R(i_{t+j}) + 2(z_{t+j})' U(i_{t+j})] \right\} \tag{52}$$

In this representation the matrices Q,U, and R contain the policy preference parameters represented as below:

$$Q = \begin{bmatrix} \lambda_x & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & (\lambda_p + \lambda_w) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -2(\gamma_p^f \lambda_p) + (\gamma_w^f \lambda_w)) & (\lambda_p \gamma_p^{f2}) + (\lambda_w \gamma_w^{f2}) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2\lambda_w & -2\lambda_w \gamma_w & 0 & \lambda_w & 0 & 0 & 0 & 0 \\ 0 & 0 & -2\lambda_w & 2\lambda_w \gamma_w & 0 & -2\lambda_w & \lambda_w & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_i & 0 \end{bmatrix}$$

$$R = \begin{bmatrix} \lambda_i \end{bmatrix} \quad U' = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_i & 0 \end{bmatrix}$$

Following Sargent (1987) the solution to this stochastic linear optimal regulator problem is the optimal policy rule:

$$i_t = F(\hat{\phi}_t) z_t \tag{53}$$

where

$$F = -(R + \beta BPB)^{-1}(V + \beta B'PA) \tag{54}$$

$$P = Q + \beta A'PA - (\beta A'PB + U')(R + \beta B'PB)^{-1}(\beta B'PA + U) \tag{55}$$

Equation (55) is a matrix Riccati equation. In order to obtain a solution for P it was iterated to convergence. $i_t$ will be implemented every period. The solution to the problem is a function of the parameters from the VAR estimated by the policymakers every period $\hat{\phi}_t = [\hat{c}_y, \hat{b}1, \hat{b}2, \hat{b}3, \hat{b}4, \hat{c}_\pi, \hat{c}1, \hat{c}2, \hat{c}3, \hat{c}4, \hat{c}_w, \hat{d}1, \hat{d}2, \hat{d}3, \hat{d}4]'$. $i_t$ will also be determined by the pertinent state variables. The value for $i_t$ will embed the policymakers' beliefs about the state of the economy. The policy solution's structural form representation is the equation:

$$i_t = F_1 x_t + F_3 \pi_t + F_6 W_t + F_9 i_{t-1} \tag{56}$$

Furthermore, $i_t$ will be used to estimate the parameters of the model of the economy including the preference parameters. The structural model composed by equation (44)-(48) along with the solution to the optimal policy problem expressed in structural form (56) are a linear rational expectations model[4]. Since the parameters in $F(\hat{\beta}_t)$ are estimated and therefore change every period, the

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[4]The rational expectations model was solved using Sims (2002)

linear rational expectations model must be solved every period; this in order to find the time varying data generating process. I estimate jointly the full set of structural, non-structural and policy preference parameters along with the standard deviations of the shocks.

## 3.3. Learning

Policymakers estimate the parameters of the policymaker's model by Constant Gain Learning. Constant Gain Learning gives less value to past and more value to current observations. As addressed in Milani (2004) it represents a simple way to model learning when we know that there could be coefficient drifts, but we do not know when did they happen. The economy will converge to an ergodic distribution around the rational expectations equilibrium unlike recursive squares learning where it would converge to the actual equilibrium. If the gain coefficient possess a large value, then there would be faster learning of structural breaks, however, it will also imply higher volatility around the steady state.

The VAR coefficients will be computed by updating previous estimates as additional data on output, inflation, and wages becomes available. Policymakers estimate their model using constant gain learning algorithms. The formulas used are described below.

$$\widehat{\phi}_t^j = \widehat{\phi}_{t-1}^j + gR_{j,t-1}^{-1}\chi_t(\zeta_t^j - \chi_t'\widehat{\phi}_{t-1}^j) \tag{57}$$

$$R_{j,t} = R_{j,t-1} + g(\chi_t\chi_t' - R_{j,t-1})$$

where $j = \{x, \pi, W\}$
$\widehat{\phi}_t^{x_t} = [\widehat{c}_y, \widehat{b1}, \widehat{b2}, \widehat{b3}, \widehat{b4}]'; \zeta_t^x = x_t$
$\widehat{\phi}_t^{\pi_t} = [\widehat{c}_\pi, \widehat{c1}, \widehat{c2}, \widehat{c3}, \widehat{c4}]'; \zeta_t^\pi = \pi_t$
$\widehat{\phi}_t^{w_t} = [\widehat{c}_w, \widehat{d1}, \widehat{d2}, \widehat{d3}, \widehat{d4}]'; \zeta_t^\pi = W_t$
$x_t = [1, x_{t-1}, \pi_{t-1}, W_{t-1}, i_{t-1}]$

We have an updating formula for the coefficients in the VAR model where $g$ is the gain coefficient and $R_{j,t}$ is the matrix of second moments of the regressors $\chi_t = [1, x_{t-1}, \pi_{t-1}, W_{t-1}, i_{t-1}]$.

## 3.4. Model Procedures

Policymakers utilize the time series data on the variables in the economy in order to estimate beliefs of the parameters in the their model. The policymakers model's parameters are estimated over time by CGL. Policymakers use estimated coefficients of their model that corresponds to the MSV solution to the "true" model of the economy. Policymaker's solve the optimal control problem using the beliefs derived from their model in order to obtain and implement the policy variable $i_t$. The preference parameters, that are the parameters in the loss function, and the coefficients of the true model written in state space form, are jointly estimated using Bayesian methods. The policymaker's preference parameters are estimated for the period before and after the appointment of Paul Volcker as the chairman of the Federal Reserve.

# 4. Bayesian Estimation Strategy

The estimation performed for this model is a Bayesian estimation following An and Schorfheide (2007). I estimate both, the set of private sector model parameters along with the policy preference parameters. The private sector model parameters include the structural and non-structural parameters, and corresponding standard deviations of the shocks. I estimate the private sector parameters for the whole sample from 1966:III to 2008:I. However, to characterize the change in policymakers' preferences I estimate the policy parameters for two samples: the first sample runs from 1966:III to 1979:II, and the second sample runs from 1979:III to 2008:I. The second sample begins with Volcker's appointment as the Federal Reserve chairman. The superscript 1 denotes the first sample of estimated policy parameters, and the superscript 2 represents the second sample. The gain coefficient for the VAR estimates ($g$) is fixed at 0.06. The gain coefficient is within the 95% posterior probability interval estimated by Milani (2007). This gain corresponds to the value estimated by Milani(2007) for a DSGE model in which agents' learning about the economy can endogenoulsy generate time-varying macroeconomic volatility.

The parameters are represented in a vector of 27 x 1 parameters denoted $\theta$. The vector $\theta$ is composed by:

$$\theta = [\varphi, \eta, \xi_p, \xi_w, \omega_p, \omega_w, \gamma_p, \gamma_w, \lambda_x^1 \lambda_p^1, \lambda_w^1, \lambda_i^1, \gamma_{pf}^1, \gamma_{wf}^1, \lambda_x^2, \lambda_p^2, \lambda_w^2, \lambda_i^2, \gamma_{pf}^2, \gamma_{wf}^2, \quad (58)$$

$$\rho_r, \rho_p, \rho_w, \sigma_{mp}, \sigma_r, \sigma_p, \sigma_w]'$$

The vector of observed variables is composed by the output gap, the inflation rate, and the deviation of log real wage from trend. $Y_T = [x_t, \pi_t, W_t]$.

A prior distribution is assigned to the parameters of the model and is represented by p($\theta$). The Kalman filter is used to evaluate the likelihood function given by $p(Y^T|\theta)$, where $Y^T = [Y_1, ..., Y_T]$. Lastly, the posterior distribution is obtained by updating prior beliefs through Bayes' rule taking into consideration the data reflected in the likelihood. Bayes' rule is represented by:

$$p(\theta|Y^T) = \frac{p(Y^T|\theta)p(\theta)}{p(Y^T)} \qquad (59)$$

I estimate the posterior distribution through a Metropolis Hastings algorithm[5]. The specific simulation method that I use is random walk Metropolis Hastings for which I ran 100,000 iterations, discarding the initial 20% as burn-in.

## 4.1. Data

The estimation was performed using quarterly data on output gap, inflation, real wage, and nominal inters rates. The data comprises two periods. The first period runs from 1966:III to 1979:II. The second period, that begins with Volcker's appointment as the Federal Reserve chairman, runs from 1979:III-2008:I. Inflation consists of the annualized rate of change of the GDP implicit price deflator. The output gap for the private sector model is the log difference of the GDP and potential GDP estimated by the CBO. Real wage is measured by the log of the Non-farm business sector real compensation per hour from the BLS. Lastly, the nominal interest rate is represented by the federal funds rate. All data used were taken from FRED.

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[5]For details on the specification of the Metropolis Hastings algorithm refer to Chib and Greenberg (1995)

**Table 1: Prior Distributions**

| Description | Name | Density | Mean | Standard Deviation | 95% Prior Prob. Interval |
|---|---|---|---|---|---|
| IES | $\varphi$ | Gamma | 1.00 | 0.50 | [0.27,2.19] |
| Habit formation | $\eta$ | Beta | 0.50 | 0.22 | [0.09,0.90] |
| Function price stick. | $\xi_p$ | Normal | 0.01 | 0.01 | [-0.00,0.03] |
| Function wage stick | $.\xi_w$ | Normal | 0.01 | 0.01 | [-0.00,0.03] |
| H.Econ.Inc.Price | $\omega_p$ | Gamma | 0.89 | 0.40 | [0.28,1.83] |
| H.Econ.Inc.Wage | $\omega_w$ | Gamma | 0.89 | 0.40 | [0.28,1.83] |
| Infl. index price | $\gamma_p$ | Beta | 0.50 | 0.22 | [0.09,0.90] |
| Infl. index wage | $\gamma_w$ | Beta | 0.50 | 0.22 | [0.09,0.90] |
| Weight x | $\lambda_x$ | Gamma | 0.30 | 0.25 | [0.02,0.95] |
| Weight $\pi$ | $\lambda_p$ | Gamma | 1.00 | 0.50 | [1.14,3.09] |
| Weight $\pi^w$ | $\lambda_w$ | Gamma | 0.30 | 0.25 | [0.02,0.95] |
| Weight int.smooth. | $\lambda_i$ | Gamma | 4.52 | 3.50 | [0.39,13.5] |
| Infl index price | $\gamma_{pf}$ | Beta | 0.50 | 0.22 | [0.09,0.90] |
| Infl index wage | $\gamma_{wf}$ | Beta | 0.50 | 0.22 | [0.09,0.92] |
| Autoregr. dem. | $\rho_r$ | Beta | 0.50 | 0.20 | [0.13,0.87] |
| Autoregr. sup. | $\rho_p$ | Beta | 0.50 | 0.20 | [0.13,0.87] |
| Autoregr. wag. | $\rho_w$ | Beta | 0.50 | 0.20 | [0.13,0.87] |
| MP shock | $\sigma_{mp}$ | InvGamma | 0.40 | 0.1 | [0.25,0.64] |
| Demand shock | $\sigma_r$ | InvGamma | 0.50 | 0.51 | [0.04,0.81] |
| Supply Shock | $\sigma_p$ | InvGamma | 0.50 | 0.51 | [0.04,0.82] |
| Wage Shock | $\sigma_w$ | InvGamma | 0.15 | 0.51 | [0.03,0.60] |

## 4.2. Priors

I estimated $\varphi \equiv [(1 - \beta\eta)\sigma]$ in this model which corresponds to $\varphi^{-1}$ in Milani (2007) and Giannoni and Woodford (2003). The prior for the parameter $\varphi^-1$ has a Gamma distribution with mean 1 and a standard deviation of 0.50 that is slightly lower than in Milani (2007). The priors for habit persistence, price and wage inflation indexation, and price and wage inflation indexation in the loss function, follow a Beta distribution with mean 0.50 and standard deviation 0.22. This prior aids at estimating the parameters because it prevents posterior peaks from being trapped at the upper corner of the interval. I use an Inverse Gamma as prior density for the shocks' standard deviation . The prior for $\xi_p$, that is a function of price stickiness, follows a Normal distribution centered at 0.015, which was the value assigned at Milani (2007). Furthermore, $\omega_p$ and $\omega_w$ follow a Gamma distribution with mean 0.89 and a large standard deviation; a

Gamma distribution was assigned in this case because the model assumes that this parameters take a positive value.

The priors for the weights on the stabilization objectives of the policymakers' loss function are informative, except for the weight on the interest smoothing parameter. They are centered at the values implied by the microfounded weights derived at Giannoni and Woodford (2003). The implied microfounded weights are functions of the underlying model parameters. The loss minimizing rates of wage and price inflation are determined by the lagged inflation rate and the indexation coefficients. The priors of the loss minimizing rates of wage and price inflation, deadweight loss, and interest smoothing parameter follow a gamma distribution. The loss minimizing rates of wage and price inflation, as well as the deadweight loss are centered at 0.30, 1.00, and 0.30. These are means approximated by taking the values of the structural estimates in the model and calculating the various stabilization objectives as functions of the underlying model parameters, implied by the microfounded loss function. The prior of the interest rate smoothing parameter finds its mean at the value obtained at Dennis (2006). The standard deviations of the priors for wage and price inflation are 0.25 and 0.50, while the standard deviation for the deadweight loss and the interest rate smoothing prior take the values of 0.25 and 3.50.

**Table 2: Posterior Estimates**

| Description | Parameter | Mean | 95% Posterior Prob. Interval |
|---|---|---|---|
| IES | $\varphi$ | 2.79 | [2.28,3.35] |
| Habit formation | $\eta$ | 0.85 | [0.64,0.98] |
| Function price stick. | $\xi_p$ | 0.09 | [0.08,0.11] |
| Function wage stick. | $\xi_w$ | 0.004 | – |
| H.Econ.Inc.Price | $\omega_p$ | 9.20 | [7.96,10.40] |
| H.Econ.Inc.Wage | $\omega_w$ | 0.72 | [0.37,1.17] |
| Infl. index price | $\gamma_p$ | 0.87 | [0.75,0.97] |
| Infl. index wage | $\gamma_w$ | 0.62 | [0.59,0.65] |
| Weight $x^1$ | $\lambda_x^1$ | 0.68 | [0.56,0.84] |
| Weight $\pi^1$ | $\lambda_p^1$ | 1.98 | [1.41,2.48] |
| Weight $\pi^w 1$ | $\lambda_w^1$ | 1.24 | [1.04,1.43] |
| Weight int. smooth. [1] | $\lambda_i^1$ | 0.37 | [0.33,0.41] |
| Infl index price[1] | $\gamma_{pf^1}$ | 0.9 | – |
| Infl index wage[1] | $\gamma_{wf^1}$ | 0.96 | [0.91,0.99] |
| Weight x$^2$ | $\lambda_x^2$ | 0.01 | [0.00,0.02] |
| Weight $\pi^2$ | $\lambda_p^2$ | 2.21 | [2.12,2.27] |
| Weight $\pi^w 2$ | $\lambda_w^2$ | 0.08 | [0.01,0.22] |
| Weight int.s.[2] | $\lambda_i^2$ | 0.01 | [0.00,0.01] |
| Infl index price[2] | $\gamma_{pf^2}$ | 0.5 | – |
| Infl index wage[2] | $\gamma_{wf^2}$ | 0.42 | [0.25,0.57] |
| Autoregr. dem. | $\rho_r$ | 0.06 | [0.01,0.09] |
| Autoregr. sup. | $\rho_p$ | 0.05 | [0.01,0.14] |
| Autoregr. wag. | $\rho_w$ | 0.1 | – |
| MP shock | $\sigma_{mp}$ | 0.47 | [0.42,0.52] |
| Demand shock | $\sigma_r$ | 2.87 | [2.60,3.20] |
| Supply Shock | $\sigma_p$ | 2.81 | [2.35,3.23] |
| Wage Shock | $\sigma_w$ | 0.88 | – |

*Note: $\xi_w$ is fixed at the value estimated in Giannoni and Woodford (2003)*

# 5. Results

Table 2 presents the estimation results. The weights on price and wage inflation on the policymakers' loss function for the period before the appointment of chairman Volcker to the Federal Reserve equal 1.98 and 1.24 respectively. After 1979, moreover, the weights that policymakers gave to the stabilization of price inflation increased to 2.21 and the wage inflation weight decreased to 0.08. The reported posterior probability intervals indicate that the estimates for the price

inflation stabilization weight are unlikely to be different from one another in the pre and post-Volcker appointment eras. Therefore, one can conclude that there was not a big change in preferences for inflation stabilization before and after the appointment of chairman Volcker to the Federal Reserve. However, the deadweight loss, the weight that policymakers give to wage inflation stabilization, and the interest rate smoothing weight do appear to be considerably different from the period before and after 1979. Policymakers' changed their preferences towards output stabilization form pre-Volcker's appointment to post-Volcker's appointment. Pre-Volcker the weight given to output stabilization was 0.68, this value decreased considerably in the post-Volcker's appointment period to 0.01. This change in preferences coincides with the results reported at Dennis (2006). Dennis estimates the parameters in the Federal Reserve's policy objective function along with the parameters in the optimizing constraints. Dennis concludes that the estimated weight on the output gap in the objective function is not significantly different from zero in the post-Volcker era. He suggests that the Federal Reserve does not have an output stabilization goal during this period and that the reason the output gap is significant is because it contains information about future inflation. However, in the pre-Volcker era, the value estimated for the weight on the output gap is higher than in the post-Volcker period. The parameter values for deadweight loss at Dennis (2006) take values of 2.94 before 1979 and it increases to 3.14 after 1979. The weight that policymakers give to wage inflation diminished from 1.24 to 0.08. Lastly, results show that the weight estimated for the interest rate smoothing parameter was much higher at the pre-Volcker period than at the post-Volcker period. The estimate went from 0.37 to 0.01. This reduction in the parameter value from pre to post-Volcker appointment is consistent with the results obtained in Dennis (2006). He obtains an interest rate smoothing parameter that goes from 37.17 in the pre-Volcker period to 4.52.

## 5.1. Policymakers' Beliefs and the Great Inflation

The Great Inflation that is the episode of high inflation that began at the late 1960s and ended in the early 1980s can be explained in part by a change in beliefs about the state of the economy as in Primiceri (2006). However, there was a also a change in preferences towards the weights given to output gap stabilization,

wage gap stabilization, and the interest rate smoothing parameter as suggested in Dennis (2006). The estimation suggests that there was a negligible change in preferences in the weight that central bankers in the US give to inflation stabilization. This implies that the beliefs of policymakers towards the persistence of inflation in the Phillips curve, and the beliefs towards the slope of the Phillips curve estimated in this paper support the "Overoptimistic" and "Overpessimistic" interpretation of the Great Inflation given by Primiceri (2006), and Romer and Romer( 2002). Figures 1 plots the estimates of the persistence of inflation in the policymakers' Phillips curve in real time starting from 1960. This figure plots the values of the beliefs obtained in parameter $\hat{c}2$. In the early stages of the Great Inflation, policymakers in the model do not react strongly to inflation because they perceive that inflation is stationary, and that it will revert to its mean value at any time. Policymakers slowly revise upward their estimates of the persistence of inflation. This period has been described as the "Overoptimistic" period of the Great Inflation by Primiceri (2006). In this paper however, underestimation of potential in the economy is not necessary to approximate an estimated policy variable that is similar to the instrument of monetary policy in the US. This is an important deviation from Primiceri (2006) and Romer and Romer (2002).

Figure 2 plots the estimates of the slope of the Phillips curve starting from 1960. This figure plots the values of the beliefs obtained in parameter $\hat{c}1$. Even when policymakers revise their estimates of the persistence of inflation upwards, they still do not react strongly to the rise of inflation because they perceive a very low output gap inflation tradeoff. During most of the 1970s policymakers perceived that pushing output below its potential will only reduce inflation slightly. As proposed by De Long (1997) the cost of fighting inflation was not acceptable.

It is clearly depicted in Figure 2 that at the beginning of the disinflation era the perceived cost of fighting inflation decreased and the output-gap inflation tradeoff "improved" as addressed in Primiceri (2006); making monetary policy more effective. In addition, the change in preferences from a deep concern to stabilize output during the Great Inflation years, changed into a more moderate almost insignificant concern for output stabilization. The weight on output gap stabilization in the loss function decreased from 0.62 in the pre-Volcker years to a weight of almost zero. As addressed in Ceccetti et al. (2007) central bankers at the beginning of the Inflation Stabilization era were willing to disin-

flate even if that translated into a "painful" unemployment episode. The results in this model imply that entering into the Inflation Stabilization era the central bank focus changed into stabilizing inflation relative to the output gap. This claim strengthens Ceccetti's et al. (2007) argument that monetary policy regime changes were important to large movements in the trend of inflation in the U.S. and other countries.
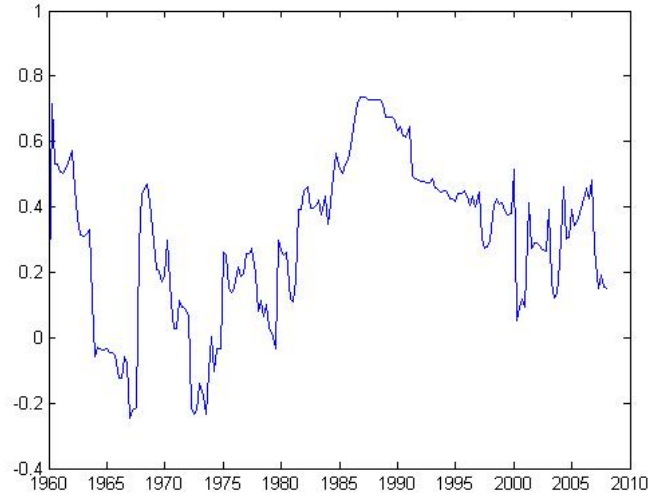


**Figure 1:** *Policymakers' Beliefs about the Persistence of Inflation in the Phillips Curve*
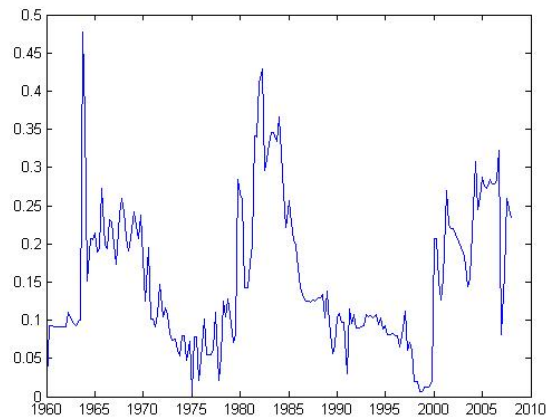


**Figure 2:** *Policymakers' Beliefs about the Slope of the Phillips Curve*

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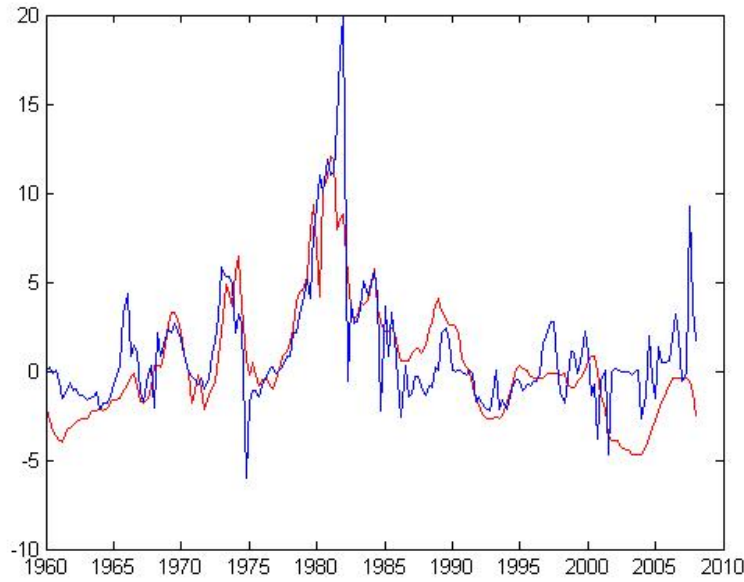
**Figure 3:** *Federal Funds Rate in Red and Estimated Optimal Monetary Policy Variable*

In order to grasp the monetary policy followed by the policymakers in the model, Figure 1 plots the evolution overtime of the model's policy variable. In addition, the federal funds rate was plotted for comparison. As we can observe, the model's policy variable follows quite closely the behavior of the federal funds rate in the period of study. However, the policy variable suggests a higher response to the policy variables being stabilized (inflation, output gap, and wage gap) at the beginning of the inflation stabilizing era. One reason for the higher value of the estimated policy variable in the beginning of the Volcker era is that the inflation forecast by the policymakers in the model entails higher inflation than actual at the beginning of the 1980s. Thus, the policy variable estimate could be responding to this higher forecast of inflation at the beginning of Volcker's appointment to the Federal Reserve.

The contribution of this paper is to estimate the weights in the central bank loss function along with the structural parameters in a model that embeds policymakers' beliefs about the state of the economy. The estimates on $\eta$ the habit formation in consumption, and $\gamma_p$ and $\gamma_w$ the degrees of indexation in wage and price inflation are closely related to the estimates in Milani (2007) and Giannoni
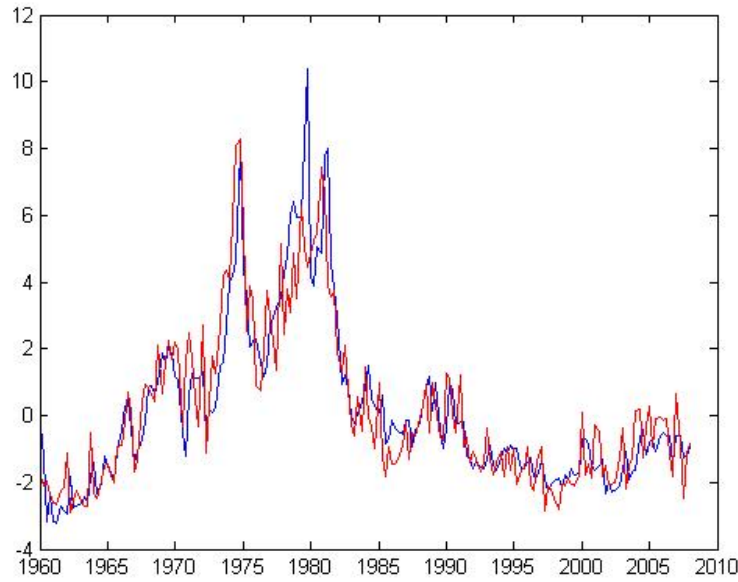
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***Figure 4:*** *Policymakers' Inflation Forecast in Blue*

and Woodford (2003). The value obtained for $\varphi = 0.35$, the pseudo-intertemporal elasticity of substitution, is somewhat lower than the value obtained at Giannoni and Woodford (2003) of 0.66. In addition, the parameter $\xi_p$ that represents price stickiness,is not identified in the estimation; it takes the value of the prior assigned to the parameter. Furthermore, $\omega_p$'s estimate is very high compared to previous estimates. One interpretation of the value of this parameters is that when there is a 1 % increase in economic activity firms ask for price increases of close to 20 %.

# 6. Conclusions

I conclude that there is evidence of a decline in the weight of output, wage gap, and interest rate stabilization after 1979 even in the presence of a model where policymakers are learning about the state of the economy over time. However, there is not much evidence that the weight toward inflation stabilization in the loss function changed from pre-Volcker to post-Volcker's appointment. Policymakers changed their preferences towards output stabilization from pre-Volcker's appointment to post-Volcker's appointment. Pre-Volcker the weight given to out-

put stabilization was 0.68, this value decreased considerably in the post-Volcker's appointment period to 0.01. The weight that central bankers in this model put on stabilizing the output gap approaches zero in the post-Volcker's appointment period. This shows that the memory of the Great Depression was still too fresh on policymakers' minds during the 1970s as proposed by De Long (1995). Even though there was no mandate to fight inflation by allowing the unemployment rate to rise during the late 1960s and most of the 1970s, this changed by the 1979. The mandate to fight inflation by inducing a significant recession was put in place as a result of fears about the cost of inflation.

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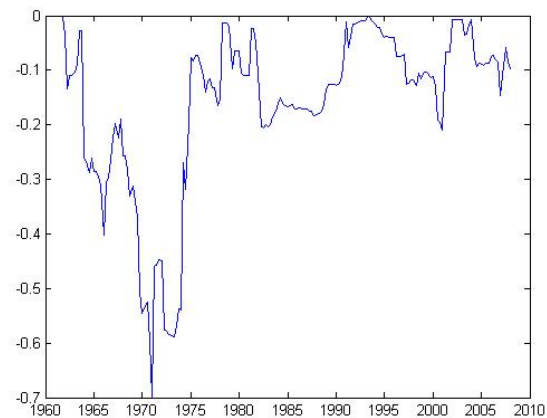Woodford, M., "Interest and prices: Foundations of a theory of monetary policy," Princeton U

**Figure 5:** *Policymakers' Beliefs about the Response of the Output Gap to the Interest rate*
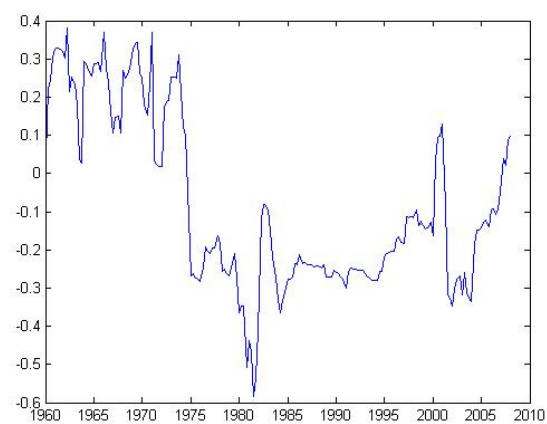


**Figure 6:** *Policymakers' Beliefs about the Response of the Output Gap to Inflation*
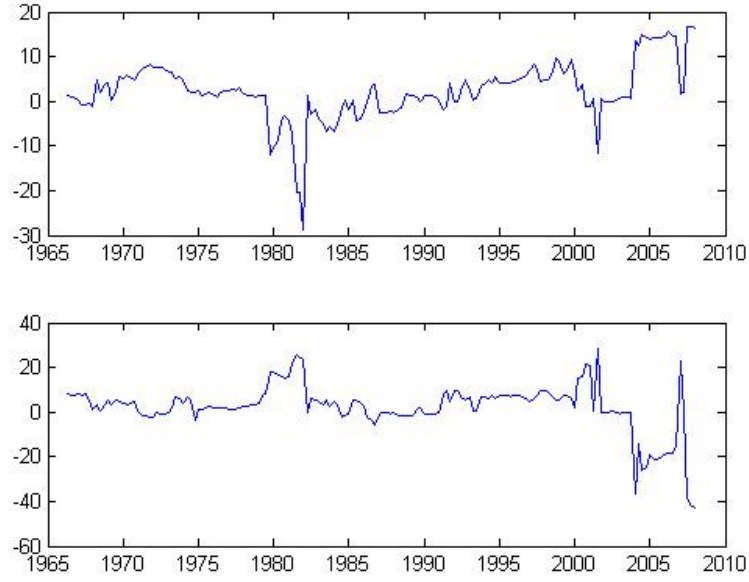
**Figure 7:** *Output Gap and Inflation Coefficients on Policy Solution Equation*
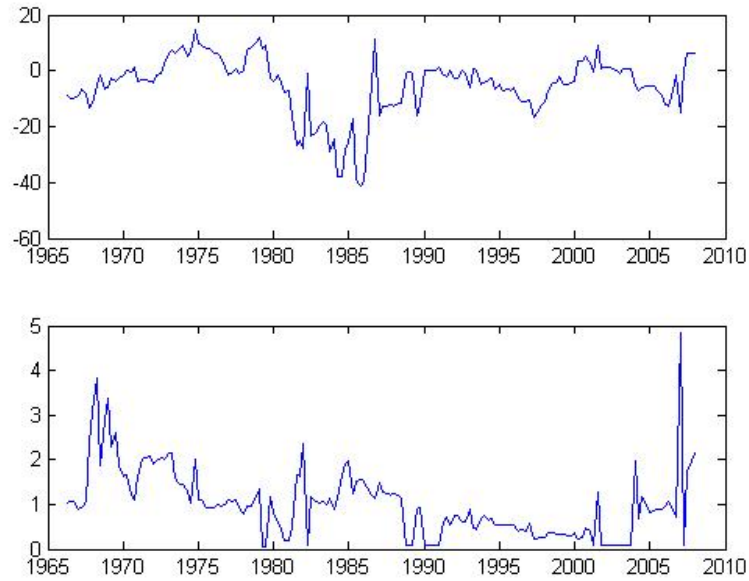


**Figure 8:** *Wage Gap and Lagged Interest Rate Coefficients on Policy Solution Equation*