Policy Preferences and Policymakers' Beliefs: The causes of the Great Inflation in the U.S.

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Abstract

The monetary policy literature has proposed two potential channels through which monetary policy played a role in the rise and fall of inflation in the U.S. during the 1970s and 1980s. One approach holds that monetary policymakers during the 1970s preferred stabilizing output while post 1979 they preferred inflation stabilization (Cecchetti, et al. 2007). An alternative explanation contends that the Federal Reserve held misperceptions about the state of the economy and the transition equations for the economy. Erroneous beliefs about the state of the economy and the transition equations could lead policymakers into creating excessive inflation that will be reversed once beliefs are aligned with outcomes via an adaptive learning process. To disentangle the effects of these two hypotheses, this paper develops a medium scale macroeconometric model that incorporates real-time learning by policymakers as well as a (potential) shift in policymakers' preferences. Empirical results support both views: distorted beliefs led policymaker's to underestimate the persistence of inflation and to incorrectly perceive an unfavorable tradeoff between inflation and the output gap; these misperceptions were accompanied by a stronger preference for output stabilization during the 1970s than the 1980s. Combined these two channels illustrate the role played by monetary policy in propagating and ending the Great Inflation.

Keywords: Great Inflation, policy preferences, policymakers beliefs, constant gain learning, Bayesian econometrics, optimal monetary policy.

JEL classification: C11, D83,E31, E50, E52, E58.

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1. Introduction

The rise and subsequent fall of inflation in the United States during the 1970s and 1980s –the "Great Inflation"– has been subject to extensive research. There are a number of hypotheses on the causes: bad monetary policy, bad luck due to the sequence of shocks, lack of commitment to low inflation policies, overly optimistic view of potential output and erroneous beliefs about the structure of the economy through a policy learning process, or a change in policymakers' preferences towards inflation stabilization. Cecchetti et al. (2007) argue that none of these factors fully explain the drastic and sudden disinflation process experienced in the United States in the 1980s. They acknowledge that deviations from potential output and policy learning contribute to the Great Inflation but they are not sufficient to account for the whole phenomenon. Cecchetti et al. (2007) propose that a key factor in explaining the Great Inflation was a change in preferences towards output gap stabilization by officials at the Federal Reserve. In this paper I combine two potential channels through which monetary policy plays a role in the rise and fall of inflation in the U.S. during the 1970s and the 1980s.

One approach holds that monetary policymakers during the late 1960s and throughout the 1970s preferred stabilizing output, while post 1979 they preferred inflation stabilization. This change in *preferences* between the late 1960s and the appointment of Paul Volcker as chairman of the Federal Reserve view was supported by De Long (1995). He argues that the Federal Reserve between the late 1960s to the late 1970s, with the Great Depression fresh in their memories, "lacked the mandate to fight inflation by inducing a significant recession" (De Long 1995 p. 34).

An alternative explanation contends that the Federal Reserve held misperceptions about the state of the economy and the transition equations for the economy. Erroneous *beliefs* about the state of the economy and the transition equation for the economy could lead policymakers into creating excessive inflation that will be reversed once beliefs are aligned with outcomes via an adaptive *learning* process. Previous literature such as Romer and Romer (2002), Sargent (1999), and Primiceri (2006) have argued that misperceptions regarding the standard features of the U.S. economy such as how to measure the natural rate of unemployment, or the existence of a Phillips curve and its coefficients were important factors in the Great Inflation. In the models by Sargent (1999) and Primiceri (2006), policymakers learn about the parameters overtime, updating their beliefs through constant-gain learning (CGL).

This paper studies the Great Inflation in a medium scale macroeconometric model that embeds both a possible change in policymakers' preferences from the Great Inflation into the inflation stabilization era and changing beliefs, through learning, about the state of the economy. I is left to disentangle whether a change in preferences contributed to the prolonged inflationary period, or if the episode was solely due to policymakers' beliefs. Specifically, this paper combines the policymakers' (potential) shift in preferences view of Cecchetti et al (2007) and Dennis (2006), and the learning hypothesis in Primiceri (2006). By combining both elements, the learning hypothesis with the policymakers' shift in preferences, the empirical results illustrate the extent to which changes in the *perceived* inflation – output tradeoff or the *preferred* inflation – output tradeoff can help explain the Great Inflation.

In order to gauge to what extent these two hyptoheses contribute to explain the Great Inflation I estimate a New Keynesian DSGE model that includes wage and price stickiness as the 'true model' of the economy. I assume, moreover, that policymakers have imperfect information about the model of the economy and its parameters. Policymakers use historical data to learn the parameters over time, updating their beliefs through constant gain learning (CGL). Subsequently, policymakers solve the optimal control problem using beliefs derived from their model in order to obtain and implement a policy variable. The preference parameters and the coefficients of the 'true' model written are jointly estimated using Bayesian methods.

One contribution of this paper is to use likelihood-based Bayesian methods to estimate the weights of the central bank's loss function along with a structural model for the U.S. economy. I estimate the weights of the loss function for the period pre- and post 1979, 1979 being the year that Paul Volcker was appointed Chairman of the Board of Governors of the Federal Reserve System. The change in *preferences* or lack thereof between the two periods will be represented by the change in the weights of the central bank loss function. This approach builds on Dennis (2004, 2006) and Salemi (1995) who estimate parameters in the objective function jointly with parameters in the optimizing constraint using maximum likelihood methods. They conclude that the appointment of a different chairman of the Federal Reserve is consistent with policy regime changes or changes in policy preferences.

The empirical results show 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 illustrate the role played by monetary policy in propagating and ending the Great Inflation in the United States. Policymakers in the model do not react strongly enough to inflation during the Great Inflation because they perceive that inflation is stationary and that it will revert to its mean value at any time. Moreover, policymakers perceive an unfavorable tradeoff between output gap and inflation for most of the 1970s. Thus, policymakers did not fight inflation because they did not believe that it would work at a reasonable cost. The perceived tradeoff between the output gap and inflation did not improve until 1980s.

Most importantly, there was a 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. Therefore, as pointed out in Cecchetti et al. (2007) even in the face of an overestimated sacrifice ratio, inflation proved so damaging that central bankers acted to disinflate. This claim supports Cecchetti's et al (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. 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.

1.1. Discussion of existing literature

This paper builds on the work that studies the impact of distorted policymakers' beliefs on policy and its effect on the Great Inflation. One of the precursors of this literature 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 regarding a model of the economy designed to serve as the basis for the actions of monetary policy. At the same time, they look at the Fed's internal forecast errors for inflation, and estimate the natural rate of unemployment implicit in the forecast behavior of inflation and unemployment. Their analysis views the 1970s as being a period of "overoptimism" characterized by an underestimated natural rate of unemployment followed by a period of "overpessimism" characterized by a very high sacrifice ratio implying 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. However, this paper specifically combines the fundamental insights in Primiceri (2006), and Cecchetti et al. (2007) and De Long (1995).

The model presented in this paper builds on Primiceri's (2006) in that rational policymakers 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.

This analysis not only includes policymakers' real time learning but it also includes a possible change in policymakers' preferences from before to after 1979. Proponents of a change in preferences from before to after 1979 as the missing part in the analyses that include learning as explanations of the Great Inflation are Cecchetti et al. (2007). They point to a change in policy preferences where "inflation proved so damaging that even in the face of an 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. Cecchetti et al. suggest that during the Great inflation, the regime was more accommodative to inflation shocks or that policymakers had higher inflation targets. The authors propose a change in political influence or a shift in policymakers' preferences as the main source 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 of 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.

Owyang et al. (2004) conducts a study of the use of regime switching for estimating monetary policy preferences. The estimates display switches to dove regimes that Granger-cause the Romer dates. The Romer dates demarcate the Fed's intent to exert contractionary monetary policy to reduce inflation, thus supporting the view that there have been changes in policymakers' preferences, especially around 1979.

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.

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); however, in this setting, agents are assumed to form expectations rationally while policymakers are learning about the state of the economy.

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 described in the following section.

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 household 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 β 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 ηC_{t-1}. ζ_T is a vector of exogenous preference shocks. The function $u(\cdot;\zeta_T)$ is increasing and concave for each value of ζ_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 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. The CES Dixit-Stiglitz consumption index is given by:

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

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 (j) 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.

Under the assumption of complete financial markets, this economy is characterized by efficient risk sharing. Each household faces the same intertemporal budget constraint given by:

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

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. 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

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

Λ_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

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

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 steady state equilibrium with no inflation. Log-linearizing equation (8) yields

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

where $\hat{\lambda}_t \equiv \log \frac{\Lambda_t P_t}{\bar{\lambda}}, \hat{i}_t \equiv \log\left(\frac{1+i_t}{1+\bar{i}}\right)$, 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

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

σ 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

[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 index "h'' in the consumption variable.

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.

2.1.2. Equilibrium 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),

[2] The ˆ designation 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.

and Giannoni and Woodford (2003) I assume that there is a single labor market in the economy. Firm j is a monopolistic supplier of good j, which produces according to the production function

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

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 $H_t(j)$ used to produce each good j has the Dixit-Stiglitz form:

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

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 is obtained by the maximizing of index (15) for a given level of wage payments. 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

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

The monopolistic supplier of each type of labor sets the wage for each type of labor. Each monopolistic suplier is ready to supply as many hours of work to be demanded at that wage. Integrating accross firms, the demand for labor faced by households h is $H_t^h(j) = H_t \left(\frac{w_t(h)}{W_t} \right)^{-\theta_w}$ where $H_t \equiv \int_0^1 H_t(z) dz$. Each monopolisticly competitive worker of type h , sets wage $w_t(h)$ assuming that it has a negligible impacto on the wage index W_t. In addition, analogous to the Calvo model of staggered pricing, each wage is reoptimized with a fixed probability $1 - \alpha_w$ each period. 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 $\log w_t(h) = \log\, w_{t-1}(h) + \gamma_w \pi_{t-1}$ 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 α^{T-t} at any time $T \geq t$. Facing such a wage, the worker will face a demand of

$$H_T(\frac{w_t(h)\frac{P_{T-1}}{Pt-1}^{\gamma_w}}{W_T}))^{-\theta_w} \tag{17}$$

for its work. Newly optimized wages take effect immediately w_t^*, is chosen at the end of period t-1, with information available at t-1. A new wage w_t^* adjusted in period t should be selected to maximize

$$E_t \sum_{T=t}^{\infty} (\alpha_w \beta)^{T-t} [\Lambda_T (1+\tau_w) w_t(h) \left(\frac{P_{T-1}}{P_{t-1}}\right)^{\gamma} H_T \left(\frac{w_t(h)\left(\frac{P_{T-1}}{P_{t-1}}\right)^{\gamma_w}}{W_T}\right)^{-\theta_w} \tag{18}$$

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

A subsidy $0 \leq \tau < 1$ for employment that offsets the effect on imperfect competition in labor markets on the steady- state level of output. where Λ_T is the representative household's marginal utility of nominal income at date T. The solution to this problem satisfies the first order condition

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

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

where v_t is the geometric average of the marginal rate of substitution (MRS) between work and consumption for the supplier of a given type of labor, and $\mu_w = \theta_w/(\theta_w - 1) > 1$ is the desired markup of household's real-wage demand over its marginal rate of substitution owing to its monopoly power. 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. The optimal wage w_t^* is determined impicitly by the previous equation. 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 $\overline{w}$,1, and 1 respectively. 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

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

where $\nu \equiv \frac{v_h h \overline{H}}{v_h}$, $\hat{H} \equiv \log H_t/\overline{H}$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

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

is the geometric average of the deviation from steady state of the MRS between work and consumption. Solving the log-linearized first-order for $\hat{w}_t^*$ yields

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

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

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

where $\xi_w \equiv \frac{(1-\alpha_w)(1-\alpha_w\beta)}{\alpha_w(1+\nu\theta_w)>0}$ The production function was loglinearized, and taking into consideration that the steady-state value of A_t is 1 results in

$$\hat{y}_t(j) = a_t + \phi^{-1} \hat{H}_t(j),$$

where $\hat{y}_t(j) \equiv \log(y_t(j)/\overline{Y})$, $a_t \equiv$log(A_t), $\hat{H}_t \equiv$log$(H_t(j)/\overline{H})$, and $\phi \equiv \frac{f(\overline{H})}{\overline{H} f'(\overline{H})} > 1$. Solving for $\hat{H}_t$ yields

$$\hat{H}_t = \phi(\hat{Y}_t - a_t).$$

Substituting this into equation (23) the following is obtained

$$\hat{\upsilon}_t = \omega_w(Y_t - a_t) + \frac{\upsilon_h\xi}{\upsilon_h}\xi_t - \hat{\lambda}_t. \tag{26}$$

The parameter $\omega_w \equiv \upsilon\phi > 0$ 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

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

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

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

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

2.1.3.Equilibrium Price Setting

Similarly, the suppliers of goods are monopolistically competitive and each price is chosen optimally with probability $1-\alpha_p$ in a given period. 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

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

Each firm selects its new price p_t^* in order to maximize the expected present discounted value of future profits

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

where $Q_{t,T}$ is the stochastic discount factor that defines the market valuations of alternative randome income streams. Nominal profits Π_T 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

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

ω_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

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

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

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

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

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

Writting the previous equation in terms of deviations from steady state output and the natural rate of output gives

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

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

$\hat{w}_t^n$ represents the percent deviation from steady state value of the natural real wage and 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:

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

where

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

$\varphi \equiv (1-\eta\beta)\sigma$ 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:

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

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

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 ($w_t = \mathtt{W}_t/P_t$) 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, π_t and π_t^w are nominal price and wage inflation, w_t is the log of the 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 φ that has been called the pseudo-elasticity of intertemporal substitution will be estimated instead of σ. φ measures the sensitivity output to changes in the interest rate. The terms ξ_p, ξ_w, are all positive. Prices and wages are adjusted a la Calvo, where $1-\alpha_p$ $(1-\alpha_w)$ is the probability that 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 ξ_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 (α_p). The parameter ξ_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 (α_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 is the minimum state variable solution when shocks are unobserved 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 the monetary policy variable 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. Policymakers expect that parameters remain the same in the future, having no room for experimentation.

Policymakers set monetary policy optimally according to the quadratic loss function described below. In this case $x_t \equiv Y_t - Y_t^n$.

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

Policymakers' preferences parameters are λ_p, $\gamma_p f$, λ_w, $\gamma_w f$, λ_x, and λ_i and δ 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. The 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 policymakers 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.

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

where $y_t = [x_t, \pi_t, W_t]'$. The matrices μ,Γ, 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.

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 $e_{t+1} = [e^y_{t+1}, 0, e^\pi_{t+1}, 00, e^w_{t+1}, 0, 0, 0, 0]'$ is the shock vector, and i_t is the policy instrument or control variable and the matrices in the state-space form are $C = \begin{bmatrix} \hat{c}_y & 0 & \hat{c}_\pi & 0 & 0 & \hat{c}_w & 0 & 0 & 0 & 0 \end{bmatrix}$
$B = \begin{bmatrix} \hat{b}4 & 0 & \hat{c}4 & 0 & 0 & \hat{d}4 & 0 & 0 & 1 & 0 \end{bmatrix}$

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

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:

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

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

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:

$$i_t = F_1 x_t + F_2 x_{t-1} + F_3 \pi_t + F_4 \pi_{t-1} + F_5 \pi_{t-2} + F_6 W_t + F_7 W_{t-1} + F_8 W_{t-2} + F_9 i_{t-1}. \quad (56)$$

Furthermore, i_t will be used to estimate the parameters of the model of the economy including the preference parameters. The structural model is composed by equations (44)-(48) along with the solution to the optimal policy problem expressed in structural form given by equation (56). In order to solve and estimate the model some assumptions are made in regards to the private sector's expectation formation process. As in Primiceri (2006) and Sargent (1999), the private sector knows policymakers' actions. In particular, private agents in the economy know policymakers' model given by equation (50) as well as policymakers loss minimizing problem that yields the policy variable i. I follow Primiceri (2005) and most of the adaptive learning literature in that the private sector assumes that policymakers will not revise their future estimates of the parameters in the model. Agents think that policymakers will continue to implement policy based on their last estimate of equation (50)[4]. Therefore, assuming that estimates $F(\hat{\phi}_t)$ in (53) will remain fixed into the future, equations (44)-(48) along with the solution to the optimal policy problem given by equation (56) are a linear rational expectations model[5]. Since the parameters in $F(\hat{\beta}_t)$ are estimated and therefore change every period as more information becomes available, the 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.

[4] An alternative specifications would be to have a "fully rational" private sector that takes into account that policymakers revise their estimates about the model on the base of future data. However, Primiceri (2005) concludes that having fully rational agents is probably too strong and at odds with the data on the disinflation period

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

3.3. Learning

Policymakers estimate the parameters of the policymaker's model by Constant Gain Learning (CGL). CGL 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 these drifts 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. The larger is the gain coefficient the faster is learning of structural breaks. However, a larger coefficient also implies greater volatility around the steady state.

The VAR coefficients will be computed by updating previous estimates as additional data on output, inflation, and wages become available. Policymakers estimate their model using constant gain learning algorithms. The formulas used are specified 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 $j = \{x, \pi, W\}$
$\widehat{\phi}_t^{x_t} = [\widehat{c}_y, \widehat{b}1, \widehat{b}2, \widehat{b}3, \widehat{b}4]'; \zeta_t^x = x_t$
$\widehat{\phi}_t^{\pi_t} = [\widehat{c}_\pi, \widehat{c}1, \widehat{c}2, \widehat{c}3, \widehat{c}4]'; \zeta_t^\pi = \pi_t$
$\widehat{\phi}_t^{w_t} = [\widehat{c}_w, \widehat{d}1, \widehat{d}2, \widehat{d}3, \widehat{d}4]'; \zeta_t^\pi = W_t$
$x_t = [1, x_{t-1}, \pi_{t-1}, W_{t-1}, i_{t-1}]$.

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 correspond to the MSV solution to the "true" model of the economy. Policymakers 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 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 and 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 1960:II to 2008:I. However, to characterize the change in policymakers' preferences I estimate the policy parameters for two samples: the first sample runs from 1960: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 endogenously generate time-varying macroeconomic volatility. The initial beliefs correspond to ols estimates of the policymakers' model using data from 1954:II to 1960:I.

The parameters are represented in a vector of 27 x 1 parameters denoted θ. The vector θ 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, π_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:

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

I estimate the posterior distribution through a Metropolis Hastings algorithm[6]. 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, which 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.

[6]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	φ	Gamma	1.00	0.50	[0.27,2.19]
Habit formation	η	Beta	0.50	0.22	[0.09,0.90]
Function price stick.	ξ_p	Normal	0.01	0.01	[-0.00,0.03]
Function wage stick	.ξ_w	Normal	0.01	0.01	[-0.00,0.03]
H.Econ.Inc.Price	ω_p	Gamma	0.89	0.40	[0.28,1.83]
H.Econ.Inc.Wage	ω_w	Gamma	0.89	0.40	[0.28,1.83]
Infl. index price	γ_p	Beta	0.50	0.22	[0.09,0.90]
Infl. index wage	γ_w	Beta	0.50	0.22	[0.09,0.90]
Weight x	λ_x	Gamma	0.30	0.25	[0.02,0.95]
Weight π	λ_p	Gamma	1.00	0.50	[1.14,3.09]
Weight π^w	λ_w	Gamma	0.30	0.25	[0.02,0.95]
Weight int.smooth.	λ_i	Gamma	4.52	3.50	[0.39,13.5]
Infl index price	γ_{pf}	Beta	0.50	0.22	[0.09,0.90]
Infl index wage	γ_{wf}	Beta	0.50	0.22	[0.09,0.92]
Autoregr. dem.	ρ_r	Beta	0.50	0.20	[0.13,0.87]
Autoregr. sup.	ρ_p	Beta	0.50	0.20	[0.13,0.87]
Autoregr. wag.	ρ_w	Beta	0.50	0.20	[0.13,0.87]
MP shock	σ_{mp}	InvGamma	0.40	0.1	[0.25,0.64]
Demand shock	σ_r	InvGamma	0.50	0.51	[0.04,0.81]
Supply Shock	σ_p	InvGamma	0.50	0.51	[0.04,0.82]
Wage Shock	σ_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 φ^{-1} in Milani (2007) and Giannoni and Woodford (2003). The prior for the parameter φ^{-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 of 0.50 and standard deviation of 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 ξ_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, ω_p and ω_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	φ	2.79	[2.28,3.35]
Habit formation	η	0.85	[0.64,0.98]
Function price stick.	ξ_p	0.09	[0.08,0.11]
Function wage stick.	ξ_w	0.004	–
H.Econ.Inc.Price	ω_p	9.20	[7.96,10.40]
H.Econ.Inc.Wage	ω_w	0.72	[0.37,1.17]
Infl. index price	γ_p	0.87	[0.75,0.97]
Infl. index wage	γ_w	0.62	[0.59,0.65]
Weight x^1	λ_x^1	0.68	[0.56,0.84]
Weight π^1	λ_p^1	1.98	[1.41,2.48]
Weight $\pi^w 1$	λ_w^1	1.24	[1.04,1.43]
Weight int. smooth. ^{1}	λ_i^1	0.37	[0.33,0.41]
Infl. index price^1	γ_{pf^1}	0.9	–
Infl. index wage^1	γ_{wf^1}	0.96	[0.91,0.99]
Weight x^2	λ_x^2	0.01	[0.00,0.02]
Weight π^2	λ_p^2	2.21	[2.12,2.27]
Weight $\pi^w 2$	λ_w^2	0.08	[0.01,0.22]
Weight int.s.^{2}	λ_i^2	0.01	[0.00,0.01]
Infl. index price^2	γ_{pf^2}	0.5	–
Infl. index wage^2	γ_{wf^2}	0.42	[0.25,0.57]
Autoregr. dem.	ρ_r	0.06	[0.01,0.09]
Autoregr. sup.	ρ_p	0.05	[0.01,0.14]
Autoregr. wag.	ρ_w	0.1	–
MP shock	σ_{mp}	0.47	[0.42,0.52]
Demand shock	σ_r	2.87	[2.60,3.20]
Supply Shock	σ_p	2.81	[2.35,3.23]
Wage Shock	σ_w	0.88	–

Note: ξ_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 the absolute value of 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 $\hat{c2}$. During 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 $\hat{c1}$. Policymakers do not react strongly to the rise of inflation because they perceive a very unfavorable output gap – inflation tradeoff during 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. The perceived tradeoff between the output gap and inflation did not improve until the 1980s. It is clearly depicted in *Figure 2* that only *after* policymakers start to purse policy devoted to bringing inflation down that the perceived cost of fighting inflation decreases; implying that policies to stabilize inflation were put in place *before* the perceived output gap - inflation tradeoff improved.

But most importantly, there was a change in preferences for stabilizing inflation relative to output after Volcker's appointment as chairman of the Federal Reserve. 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. Therefore, as pointed out in Cecchetti et al. (2007) even in the face of an overestimated sacrifice ratio, inflation proved so damaging that central bankers acted to disinflate.

As addressed in Cecchetti et al. (2007) central bankers at the Inflation Stabilization era were willing to disinflate 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 Cecchetti's et al. (2007) argument that monetary policy regime changes were important to large movements in the trend of inflation in the U.S.

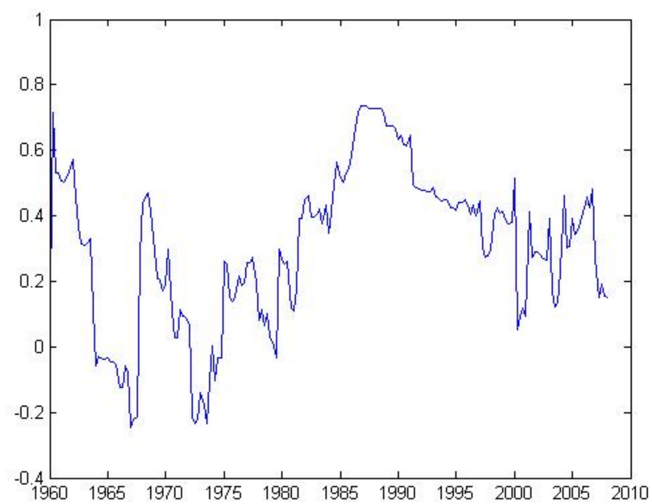

Figure 1: *Policymakers' Beliefs about the Persistence of Inflation in the Phillips Curve*

In order to grasp the monetary policy followed by the policymakers in the model, *Figure 4* 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

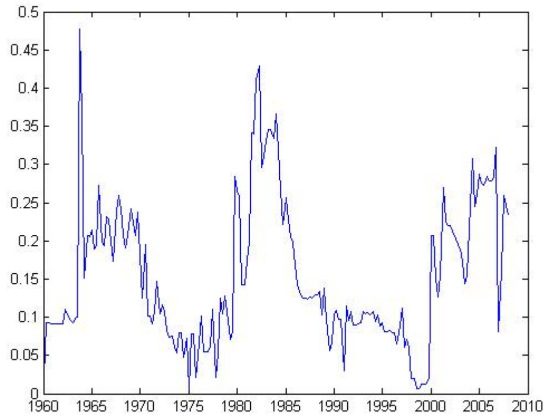

Figure 2: *Policymakers' Beliefs about the Slope of the Phillips Curve*

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 η the habit formation in consumption, and γ_p and γ_w the degrees of indexation in wage and price inflation are closely related to the estimates in Milani (2007) and Giannoni 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 ξ_p that represents price stickiness,is not identified in the estimation; it takes the value of the prior assigned to the parameter. Furthermore, ω_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 9 %.

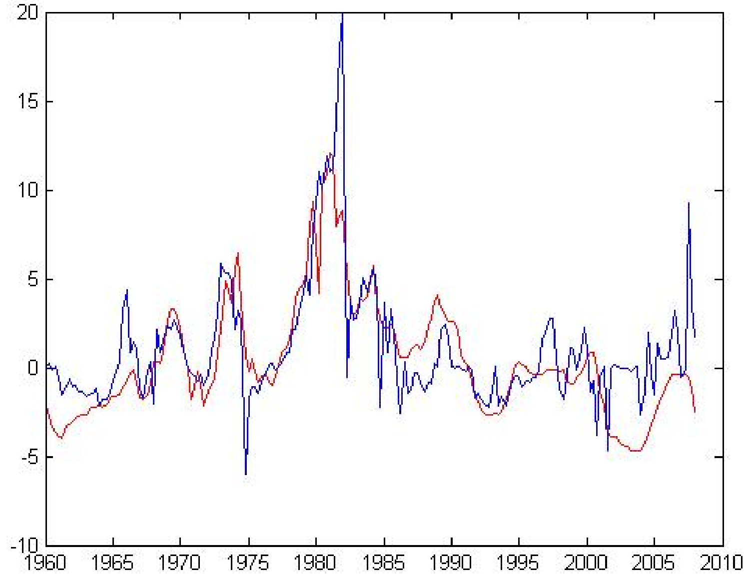

Figure 3: *Federal Funds Rate in Red and Estimated Optimal Monetary Policy Variable*

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 output 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.

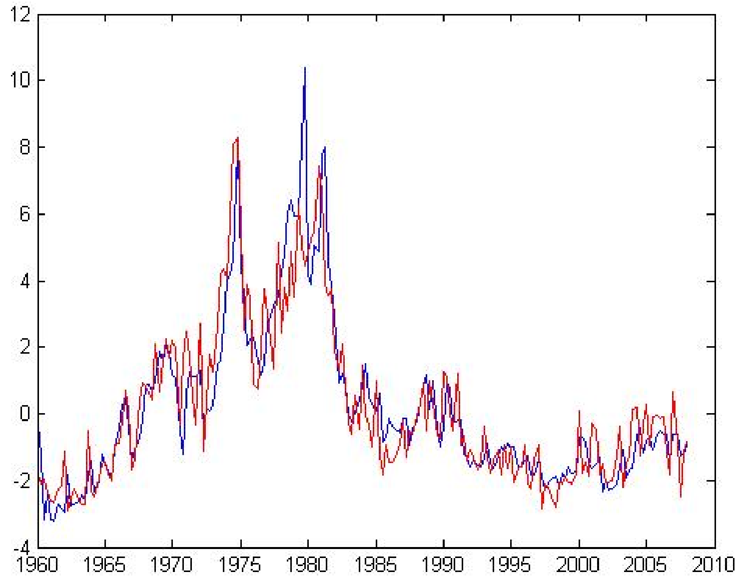

Figure 4: *Policymakers' Inflation Forecast in Blue*

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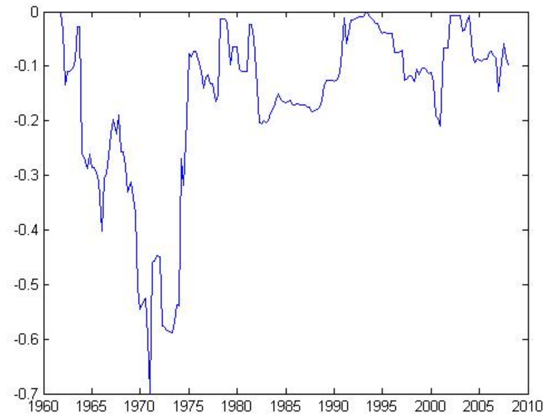

Figure 5: *Policymakers' Beliefs about the Response of the Output Gap to the Interest rate*

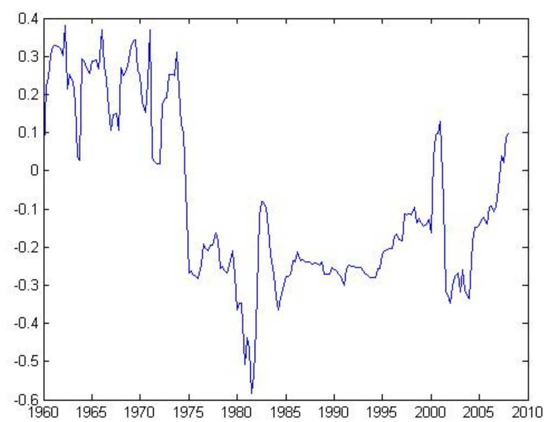

Figure 6: *Policymakers' Beliefs about the Response of the Output Gap to Inflation*