Bad Luck, Bad Policy, and Learning? A Markov-Switching Approach to Understanding Postwar U.S. Macroeconomic Dynamics

Gabriela Best* Joonyoung Hur†

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Abstract

In this paper we analyze changes in the Federal Reserve behavior and objectives since the 1960s justified by potentially evolving beliefs—through a real-time learning process—about the structure of the economy and shifts in policymakers' preferences in the late 1970s. In addition, we allow for changes in the volatility of the structural shocks in a medium scale Markov-switching DSGE model. We evaluate the relative contribution of each narrative to the explanation of the Great Inflation and the Great Moderation. We argue that the interplay between central bank learning and a shift in policy makers' preferences explains movements in the monetary instrument. In addition, the model captures non-policy related high volatility periods clustered around the late 1960s through the 1970s, specifically supply side shocks that behaved as destabilizing forces driving macroeconomic fluctuations. To conclude, we observe that a change in monetary policy objectives, assumptions about policymakers' learning process, and Markov-switching volatility are key to fit the model to the U.S. post-war data.

Keywords: Great Inflation; Policy Preferences; Policymakers' Beliefs; Constant Gain Learning; Markov-switching DSGE Models

JEL Classifications: C11; D83; E31; E50; E32; E44

*Department of Economics, Steven G. Mihaylo College of Business and Economics, California State University Fullerton, Fullerton, CA 92834, USA. Tel: +1-657-278-2387, E-mail: gbest@fullerton.edu.

†Corresponding author. Division of Economics, Hankuk University of Foreign Studies, 107, Imun-ro, Dongdaemun-gu, Seoul, Republic of Korea. Tel: +82-2-2173-8813, E-mail: joonyhur@gmail.com.

1 INTRODUCTION

The evolution of U.S. post-war macroeconomic dynamics and its possible sources have been the subject of extensive research. Starting with the Great Inflation, or the period of rising inflation in the 1970s and its subsequent fall in the early 1980s, followed by the period of remarkable economic stability—The Great Moderation—until the events leading to the Great Recession, have sparked considerable interest on the role played by U.S. monetary policy. In fact, monetary policy has often been perceived as an important driver of the U.S. economic performance in the period described; notable examples are Taylor (1999) and Clarida et al. (2000). However, understanding the determinants that explain shifts in the monetary policy instruments is an area of research that deserves further attention. Best (2016) investigates if shifts in the policy instrument were due to changes in the structure of the macroeconomy through a continual learning process [e.g. Sargent (1999) and Primiceri (2006)] or if they were due to changes in policymakers preferences toward output gap vs inflation stabilization at key turning points in the conduction of monetary policy [e.g. Dennis (2006) and Lakdawala (2016)]. On the other side of the Great Inflation and Great Moderation debate has been the contribution of "luck" or the sequence of adverse vs. favorable shocks that hit the economy in the post-war period. Sims and Zha (2006) find evidence of time variation in the disturbance variances as the main determinant of U.S. macroeconomic performance. Bianchi (2013) makes an important addition to this literature by considering not only regime changes in the volatilities of the structural shocks, but also time-variation in the Taylor rule parameters—as the expression of the evolution of monetary policy. Bianchi (2013) finds that both, changes in the monetary policy stance and the volatilities of the shocks contribute to the U.S. macroeconomic dynamics. In Bianchi (2013), monetary policy is contextualized in a Markov-switching interest rate rule, with the advantage of being able to pick up changes in the Fed behavior over time. However, as discussed in Debortoli and Nunes (2014), the interest rate responses are reduced-form representations of policymakers' behavior and their responses often hide the difference between policymakers' objectives: factors that the central bank can control and those it cannot control.

This paper estimates a Markov-switching dynamic stochastic general equilibrium (MS-DSGE) to bridge the gap between two narratives that are at the opposite ends of the debate on the causes of the Great Inflation and the Great Moderation. We combine the roles played by (i) the Fed in response to their evolving understanding about the structure of the U.S. economy and a possible change in preference regarding their stabilization policy after 1979 and (ii) time-varying changes in the *volatility* of the structural shocks modeled as Markov-switching processes [e.g., Bianchi (2013) and Davig and Doh (2014)], to the post-war dynamics of output, inflation, and the monetary policy instrument. In fact, the later element is essential because as noted in Fernández-Villaverde and Rubio-Ramírez (2007) and Justiniano and Primiceri (2008) on an estimated DSGE economy, models that move away from the homoscedastic structural shocks approach fit the data considerably better. We contribute to Bianchi's approach of integrating these two narratives, by attempting to disentangle the role of the Fed's time-varying macroeconomic beliefs from changes in monetary policy preferences, and their implications for the propagation and ending of the Great Inflation and the unravelling of the Great Moderation. We evaluate the relative contribution of each narrative to the explanations of the Great Inflation—specifically to the disinflation process—and to the Great Moderation.

Results show that learning, monetary policy preferences, and volatility changes played an important role at explaining macroeconomic dynamics for the United States from the 1960s to 2008. In fact, the model that includes all three elements has a superior fit to the post-war data. We add each element piece by piece and conclude that one of the reasons why we obtain a superior fit is because our model can reproduce closely the behavior of the Fed's monetary policy instrument. Policymakers' learning about the structure of the economy along with a change in the stance of U.S. policymakers toward inflation in 1979 with the appointment of chairman Volcker, can characterize the time varying response to inflation by the Fed. We find support to the widespread belief that U.S. monetary policy history can be described by a regime change pre- and post-Volcker that is the main contributor to the disinflation strategy of the late-1970s and early-1980s. Through the time-varying changes in the Fed's understanding about the structure of the economy we are able to capture the accommodative response to inflation during parts of the 1960s and 1970s and before the Great Recession.

We also find shifts in the volatility of monetary policy and non-policy shocks as tantamount contributors to the Great Inflation and the Great Moderation. We document periods of high volatility of the non-policy shock clustered around the late 1960s through the 1970s—coincident with the energy crises—and before the Great Recession; while the U.S. economy experienced long periods of high volatility of policy shock during the "Volcker experiment" and in the second half of the 1990s that extended until the 2001 recession. Furthermore, we disentangle the relative contribution of the various shocks to the output gap, inflation, and the policy rate. We find that supply shocks were definitely destabilizing forces driving inflation and the output gap during the 1970s, supporting the "bad luck" hypothesis, but demand and monetary policy shocks had key contributions to output and inflation dynamics after 1975; especially during Volckers' experiment. Therefore, monetary policy determinants and non-monetary policy shocks explain the Great Inflation and the Great Moderation.

We test Hakkio (2013) hypothesis that better monetary policy was a key contributor to the period of relative calm after the volatility of the Great Inflation—the Great Moderation. As Bernanke (2004) noted, each of the three classes of explanation of the Great Moderation—changes in the structure of the economy, good luck and good policy—most likely "contains element of truth." This point is further illustrated by Sims (2012) kitchen fire analogy: effective monetary policy or structural change in the economy—like a good fire extinguisher—may limit the adverse impact of even a major shock. We conduct a series of counterfactual experiments under alternative

Fed's learning assumptions about the state of the economy, monetary policy preferences, and shock volatilities to assess the role of better policy on the Great Moderation period.[1]

One source of monetary policy variation by the Federal Reserve have been explained in the literature in the following context: The central bank has experience a continual evolution of beliefs about how the structure of the U.S. economy operates and has set policy responding to its real time understanding. Romer and Romer (2002) provide narrative evidence, while Primiceri (2006) and Orphanides and Williams (2005) perform a quantitative analysis of Fed's changing perceptions through a perpetual *learning* process about the structure of the economy. Best (2016) and Lubik and Matthes (2016) build on the aforementioned literature and study optimal monetary policy under central bank learning, assuming a forward-looking private sector model. In this paper we build on both approaches and we study the role played by the shift in preference with the appointment of Chairman Volcker to the Federal Reserve, along with the effect of different learning assumptions—i.e. changes in the speed of learning about the structure of the economy.

We find an essential role to the central bank learning assumption. To begin, we find that improved economic understanding through a continual central bank learning process in the post-1979 era, as described in Romer and Romer (2002), Orphanides and Williams (2005), and Primiceri (2006) would have not been enough to explain the decrease in volatility associated with the Great Moderation. A shift in policy objectives by the Fed directed to stabilize inflation, like a good fire extinguisher, was necessary to reproduce post-Volcker macroeconomic dynamics. Moreover, inspired by Bianchi (2013), we believe that the distinction between learning and changes in policy preferences is useful because it allows us to investigate the counterfactual scenario of appointing of a hawkish policymaker during the Great Inflation. We find that having a central bank where policymakers exhibit a preference for inflation stabilization would have fallen short at reducing inflation; at least given the economic understanding about the structure of the economy present during the Great Inflation and represented by our learning assumption. Thus, although not an "Eagle," a hawkish policymaker with a preference for inflation stabilization in the 1970s would have been ineffective at combating inflation. We also note that in the post-Volcker period and during the Great Moderation, only the combination of post-Volcker policy preferences along with the matching learning speed produce the right combination for "good policy." We find support to Sims (2012) kitchen fire analogy in the sense that alternative combinations of policy preferences and structural change, i.e. pre-Volcker policy preferences and learning speed during the Great Moderation period, would have led to undesirable amplified economic fluctuations and intuitively implausible macroeconomic dynamics.

Lastly, we attempt to quantify the effect of alternative policy preferences, learning assumptions, and volatilities of the shock by estimating the conditional standard deviations of counter-factual

[1] Although we admit that this paper abstracts from modelling elements that would capture specific structural change in the economy, we believe that it can still shed light on the contribution of possible improvements in monetary policy and "good luck" to the decline in macroeconomic volatility.

output gap and inflation series. Our analysis reveals that pre-79 policy preferences present through the whole period would have resulted in five times the volatility of inflation. Although the mean effect of imposing alternative learning speeds not consistent with the time period in question is not large, it creates a non-zero probability that the standard deviations of the output gap or inflation could become considerably large (up to seven times its actual size). While a stream of bad luck, or high volatility of the non-policy shock would have had the strongest impact on output's standard deviation, good luck or a low volatility of the non-policy shock prevailing through the whole sample would have cut output gap's volatility by 7% and inflation's volatility by 12%.

2 THE MODEL

The model estimated builds on Erceg et al. (2000), and Woodford (2003). This model is a New Keynesian medium scale model with internal habit persistence, wage stickiness, and inflation inertia. It has been used as the basis for the study of monetary policy in the literature [e.g., Christiano et al. (2005); Smets and Wouters (2007)]. The feature of wage rigidity is important to enhance the realism of the transmission mechanisms resulting from the model and is considered to be key element in explaining output and inflation dynamics (e.g., Christiano, Eichenbaum, and Evans (1999 and 2005), Smets and Wouters (2003), and Altig et al. (2011). In addition, the central bank has the potential to respond to wage inflation in its policy objective function; DeLong (1997) documents its importance during the 1960s and 1970s specially because if provides information about the core of inflation which attests to the qualitative nature of the Great Inflation.

The economy can be represented by the following system of equations:

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

where

$$\widetilde{x}_t \equiv (x_t - \eta x_{t-1}) - \beta\eta E_t(x_{t+1} - \eta x_t). \tag{2}$$

and $\varphi^{-1} \equiv [(1-\eta\beta)\sigma]$ captures the sensitivity of output to changes in the interest rate.[2] The log-linearized Euler equation (1) includes x_t that represents output gap, π_t is price inflation, and i_t is the nominal interest rate set by the central bank (determined within the model), and E_t represents rational expectation.

The supply-side model is given by the following equations:

$$\pi_t^w - \gamma_w\pi_{t-1} = \xi_w[\omega_w x_t + \varphi\widetilde{x}_t] + \xi_\omega(w_t^n - w_t) + \beta E_t(\pi_{t+1}^w - \gamma_w\pi_t) + u_t^w \tag{3}$$

$$\pi_t - \gamma_p\pi_{t-1} = \kappa_p x_t + \xi_p(w_t - w_t^n) + \beta E_t(\pi_{t+1} - \gamma_p\pi_t) + u_t^p, \tag{4}$$

[2] $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution, $\beta \in (0,1)$ is the household's discount factor, and $0 \leq \eta \leq 1$ is the measure of habit persistence in consumption. As in Giannoni and Woodford (2003), the parameter φ has been estimated instead of σ.

where $\kappa_p \equiv \xi_p \omega_p$ and (3) and (4) are New Keynesian Phillips curves for price and wage inflation, and

$$w_t = w_{t-1} + \pi_t^w - \pi_t \tag{5}$$

is an identity for the real wage $(w_t = W_t/P_t)$ expressed in logs and rearranged to provide a law of motion for the log of nominal wages. Here w_t is the log of the real wage, w_t^n represents exogenous variation in the natural real wage, and π_t^w is nominal wage inflation. This is a cashless economy as in Woodford (2003). The parameters $0 \leq \gamma_p \leq 1$ and $0 \leq \gamma_w \leq 1$ represent the degree of indexation to past inflation for price and wage inflation, respectively. Prices and wages are adjusted $\grave{a}$ la Calvo (1983). The parameter ξ_p represents the sensitivity of goods-price inflation to changes in the average gap between the 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). The expression $\omega_p > 0$ represents the elasticity of the marginal cost 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.

We substitute the law of motion for wages (5), into the Phillips curve for wages (3) and rewrite the Phillips curve for prices and wages in terms of $W_t = w_t - w_t^n$, where the model consistent shock in the Phillips curve for wages becomes $u_t^w = -w_t^n - w_{t-1}^n + \beta E_t w_{t+1}^n - \beta E_t w_t^n$.

For estimation purposes, we assume that the demand shock, r_t^n, and the supply shocks, u_t^p and u_t^w follow AR(1) processes:

$$r_t^n = \rho_r r_{t-1}^n + v_t^r, \tag{6}$$

$$u_t^p = \rho_p u_{t-1}^p + v_t^p, \tag{7}$$

$$u_t^w = \rho_w u_{t-1}^w + v_t^w, \tag{8}$$

where $v_t^r \sim iid(0, \sigma_r^2)$, $v_t^p \sim iid(0, \sigma_p^2)$, and $v_t^w \sim iid(0, \sigma_w^2)$.

3 POLICYMAKERS' BELIEFS

In order to disentangle the potential role that the evolution of policymaker's understanding of the economy on the post-war macroeconomic dynamics, we assume that policymakers have an imperfect model of the economy. Policymakers approximate the true model of the economy by estimating a vector autoregressive (VAR(2)) model as in Primiceri (2006).[3] Policymakers estimate

[3] We also estimated a VAR(1) model for the central bank, which would better match the structure and dynamics present in our medium scale DSGE model, however we found that the VAR(2) has a better fit to the data. Results with VAR(1) beliefs are available upon request.

their parameter values using constant gain least-squares learning (CGL). The resulting evolving policymakers' beliefs about the economy are then used to minimize the central bank's loss function.

3.1 The Policy Objective Function under Imperfect Information

The policy objective function takes the standard quadratic form with a preference for interest-rate smoothing as in Dennis (2006) and Best (2016). In this model, the central bank's objective is to minimize a quadratic loss function that reflects the goals of stabilizing the output gap, wage inflation, and deviations of the nominal interest rate from its lagged value relative to inflation stabilization.

$$E_t \left\{ \sum_{j=0}^{\infty} \beta^j [(\pi_{t+j})^2 + \lambda_w (\pi^w_{t+j})^2 + \lambda_x (x_{t+j})^2 + \lambda_i (i_{t+j} - i_{t+j-1})^2] \right\}. \tag{9}$$

Policy preference parameters are illustrated by the weights assigned to the different stabilizing objectives represented by λ = $[\lambda_w,\ \lambda_x,\ \lambda_i]$. Dennis (2006) outlines the reasons why interest rate smoothing is a desirable feature of the loss function, however, in this setting it allows us to obtain a monetary policy instrument that embeds both, policymakers' beliefs and preferences about the structure of the economy. The weight assigned to inflation stabilization has been normalized to 1 following the convention of the previous literature.

Policymakers minimize their welfare loss function (9) subject to the following perceived constraints, written in VAR form:

$$y_t = \hat{\mu}_s + \hat{\Gamma}_s(L) y_{t-1} + \hat{\Xi}_s(L) i^f_{t-1} + \epsilon_t, \tag{10}$$

for t $\geq$ s+1 where $y_t = [x_t, \pi_t, W_t]'$ and i^f_t is the actual short-term interest rate.[4] We assume that the central bank has imperfect information about the private sector model and uses a VAR(2) approximation to it that includes the same set of variables. A VAR(2) learning model for the Fed is desirable due to its good empirical properties documented in the literature, and because it produces intuitively plausible time-varying Fed beliefs about the state of the economy [e.g. Primiceri (2006)]. Slobodyan and Wouters (2014) evaluate the empirical relevance of learning by private agents in an estimated medium-scale DSGE model. They find that allowing agents to form their expectations under VAR learning produces the best marginal likelihood and outperforms substantially the REE model.

The matrices $\hat{\mu} = [\hat{c}_y, \hat{c}_\pi, \hat{c}_w]'$, $\hat{\Gamma} = [\hat{b}_1, \hat{b}_2, \hat{b}_3, \hat{b}_5, \hat{b}_6, \hat{b}_7; \hat{c}_1, \hat{c}_2, \hat{c}_3, \hat{c}_5, \hat{c}_6, \hat{c}_7; \hat{d}_1, \hat{d}_2, \hat{d}_3, \hat{d}_5, \hat{d}_6, \hat{d}_7]$, and $\hat{\Xi} = [\hat{b}_4, \hat{c}_4, \hat{d}_4, \hat{b}_8, \hat{c}_8, \hat{d}_8]'$ contain the coefficients that represent the **policymakers' beliefs** about the reduced-form parameters in the econometric model of the economy for the output gap, price inflation, and wage inflation, respectively.

[4] In the estimation, the lagged federal funds rate was used as a proxy for the previous short-term interest rate.

The optimization constraints have the following state-space representation:

$$z_{t+1} = C_t + A_t z_t + B_t i_t + e_{t+1} \tag{11}$$

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 control variable.[5] **Policymakers' beliefs** about the model's coefficients are represented by circumflexes. This imperfect model of the economy is estimated on inflation, output gap, detrended wages, and lagged short-term interest rate data.

3.2 Learning

Policymakers estimate the parameters of the VAR model by CGL. CGL is a form of discounted recursive least-squares learning sensitive to environments with structural change of unknown form.[6] The constant gain parameter **g** governs how strongly past data are discounted; the larger the gain coefficient, the more rapid is the learning of structural breaks, and the more volatile are the learning dynamics.

The VAR(2) coefficients that constitute the **policymakers' beliefs** are computed by updating previous estimates as additional data on output, inflation, wages, and lagged short-term interest rates become available. The recursive formulas used are

$$\widehat{\phi}^j_t = \widehat{\phi}^j_{t-1} + \mathbf{g} R^{-1}_{j,t-1} \chi_t (\zeta^j_t - \chi'_t \widehat{\phi}^j_{t-1}) \tag{12}$$

$$R_{j,t} = R_{j,t-1} + \mathbf{g}(\chi_t \chi'_t - R_{j,t-1}), \tag{13}$$

where $j = \{x, \pi, W\}$, $\zeta_t \equiv [x_t, \pi_t, W_t]'$ is a vector of endogenous variables and $\chi_t \equiv [1, \zeta_{t-1}, \zeta_{t-2}, i_{t-1}, i_{t-2}]$ is a matrix of regressors, **g** is the gain coefficient, and $\widehat{\phi}^{x_t}_t = [\widehat{c}_y, \widehat{b}_1, \widehat{b}_2, \widehat{b}_3, \widehat{b}_4, \widehat{b}_5, \widehat{b}_6, \widehat{b}_7, \widehat{b}_8]'$, $\widehat{\phi}^{\pi_t}_t = [\widehat{c}_\pi, \widehat{c}_1, \widehat{c}_2, \widehat{c}_3, \widehat{c}_4, \widehat{c}_5, \widehat{c}_6, \widehat{c}_7, \widehat{c}_8]'$, $\widehat{\phi}^{w_t}_t = [\widehat{c}_w, \widehat{d}_1, \widehat{d}_2, \widehat{d}_3, \widehat{d}_4, \widehat{d}_5, \widehat{d}_6, \widehat{d}_7, \widehat{d}_8]'$ collect the reduced-form parameters. The updating rule for the central bank's beliefs is represented by (12), while (13) describes the updating formula for the precision matrix of the stacked regressors $R_{j,t}$. The updating formulas correspond to a discounted least-squares estimator.

3.3 Optimal Policy

Policymakers minimize their welfare loss function (9) subject to the VAR model of the central bank (10). Following Sargent (1987), the solution to this stochastic linear optimal regulator problem is the optimal policy rule:

$$i_t = F(\hat{\phi}_t, \lambda) z_t, \tag{14}$$

The solution to the policy problem is a function of the perceived VAR parameters $\hat{\phi}_t = [\hat{c}_y, \hat{b}_1, \hat{b}_2, \hat{b}_3, \hat{b}_4, \hat{b}_5, \hat{b}_6, \hat{b}_7, \hat{b}_8, \hat{c}_\pi, \hat{c}_1, \hat{c}_2, \hat{c}_3, \hat{c}_4, \hat{c}_5, \hat{c}_6, \hat{c}_7, \hat{c}_8, \hat{c}_w, \hat{d}_1, \hat{d}_2, \hat{d}_3, \hat{d}_4, \hat{d}_5, \hat{d}_6, \hat{d}_7, \hat{d}_8]'$, policy pref-

[5]The matrices in the state-space form are available upon request.

[6]Under CGL, learning dynamics will converge to a distribution around the rational expectations equilibrium.

erence parameters λ, and state variables z_t. The value for the optimal monetary policy variable i_t will embed the policymakers' beliefs and preferences about the state of the economy. Notice that they influence the direction of the economy through i_t.

The policy rule (14) can be rewritten as

$$i_t = F_{x1}x_t + F_{x2}x_{t-1} + F_{\pi 1}\pi_t + F_{\pi 2}\pi_{t-1}t + F_{w1}\pi_t^w + F_{w2}\pi_{t-1}^w + F_{il}i_{t-1}^f + v_t^{mp} \tag{15}$$

where $v_t^{mp} \sim iid(0, \sigma_{mp}^2)$ and σ_{mp} follows a Markov-switching process as described in Section 4.1. This monetary policy shock moves between high and low volatility regimes and can be interpreted as Fed's deviations from an optimal policy rule that varies over time, or policy mistakes.

The structural model consists of (1)-(5) along with the solution to the optimal policy problem expressed in structural form given by (15). To solve and estimate the model, some assumptions are made with regard to the private sector's expectation formation process. As in Primiceri (2006) and Sargent (1999), the private sector knows the policymakers' actions. In particular, private agents in the economy know the policymakers' model given by (10), as well as the policymakers' loss-minimizing problem that yields the policy variable i. We follow most of the adaptive learning literature in that the private sector assumes policymakers are "anticipated utility" decision makers [Kreps (1998)].[7] Agents believe that policymakers will continue to implement policy based on their last estimate of (15). An alternative specification would be to have a "fully rational" private sector that takes into account that policymakers revise their estimates about the model on the basis of future data. However, Primiceri (2006) concludes that having fully rational agents is probably too strong and at odds with the data on the disinflation period. Notice that the private sector is rational except for the fact that it takes the central bank's optimal policy rule as given, similar to Sargent (1999). Therefore, assuming that estimates $F(\hat{\phi}_t, \lambda)$ in (14) will remain fixed into the future. Since the parameters in $F(\hat{\phi}_t, \lambda)$ are estimated and therefore change every period as more information becomes available, the model must be solved every period to find the time-varying data generating process.

3.4 MODEL OVERVIEW

It is useful to provide a brief overview of the economic model before turning to the estimation results. Policymakers use the time-series data on the variables in the economy to estimate the parameters in their model. The policymakers' perceived VAR is estimated over time by CGL. Policymakers solve their optimal control problem using the beliefs derived from their recursively estimated model to formulate a policy rule for i_t. The private sector takes that policy rule and forms expectations. The next section jointly estimates the model's parameters using Bayesian methods.

[7] Policymakers estimate the parameter in their model and treat them as true vales, neglecting the possibility of future updates.

4 ESTIMATION STRATEGY

We estimate the set of private sector structural parameters, the policy preference parameters, the gain coefficient **g** along with the corresponding standard deviations (SDs) of the shocks. The SDs of the shocks are allowed to move across different shock volatility regimes.

The gain coefficient that measures the speed at which the central bank learns the economy's law of motion is estimated and not fixed. It is important to estimate this parameter of the model—and a contribution to Primiceri (2006) and Lubik and Matthes (2016)— because it leaves it to the data to disentangle if learning was an important determinant of the movements in the monetary policy instrument during the period of study.[8] Following Marcet and Nicolini (2003), Milani (2014) and Best (2016), we estimate a potential break in the speed of policymakers' learning. The intuition behind this potential break is that if central bankers were concerned that the economy was subject to structural breaks, then they will assign a larger weight to new information, consistent with a higher gain. Thus, in this setting we contemplate the possibility of a change in the speed of learning in 1979 as in: $\mathbf{g}_t = \begin{cases} \mathbf{g}_{pre-1979} & t < 1979:Q3 \\ \mathbf{g}_{post-1979} & t \geq 1979:Q3. \end{cases}$

The preference parameters λ_w, λ_x, and λ_i are estimated allowing for a (potential) structural break in 1979:Q3 (μ_1) coincident with the appointment of Paul Volcker as chairman of the Federal Reserve. We focus on the 1979 break because of the overwhelming evidence in favor of said regime change and general consensus of its existence. Boivin (2006) using drifting coefficients and real time data, Duffy and Engle-Warnick (2006) using nonparametric methods, and Romer and Romer (1989)—RR henceforth—using the narrative approach, also identify a policy switch in the 1979:Q3, among many others.[9] The preference parameters evolve according to the following: $\lambda_{\varpi,t} = \begin{cases} \mu_1 \quad \lambda_{\varpi,pre-1979} & 1960:Q2 \leq \text{t} \leq 1979:Q2 \\ \quad\;\; \lambda_{\varpi,post-1979} & 1979:Q3 \leq \text{t} \leq 2008:Q1 \end{cases}$ where ϖ=x, w, i. The remaining structural parameters are estimated for the full sample.

We include the possibility of Markov-switching regime changes in the volatility of the shocks that hit the economy during the sample. We propose that the economy experienced a mix of high volatility and low volatility shocks, as in Bianchi (2013), because this could have large implications for the post- world war U.S. macroeconomic dynamics, and could improve the fit of the data to the model. In the present there are multiple regime changes at different points in time with the potential of capturing numerous shocks that hit the U.S. economy during the period of study. Additionally, we explicitly test the role of changes in the volatility of shocks during the period, and compare their contribution relative to monetary policy in propagating and ending the Great Inflation.

[8] To avoid obtaining results (including preference parameter estimates) dependent on parameters chosen by the researcher.

[9] There is a possibility that there were additional monetary policy regime changes during our sample of study, this is addressed in Best and Hur (2017).

4.1 ESTIMATION OF THE MS-DSGE MODEL The article uses U.S. quarterly data on the output gap, price inflation rate, wage inflation rate, and nominal interest rate from 1960:Q2 to 2008:Q1 as observable variables. The output gap is the log difference of the gross domestic product (GDP) and potential GDP estimated by the Congressional Budget Office. Price inflation is measured by the quarterly change of the GDP implicit price deflator at an annualized rate, while wage inflation is calculated by the log difference of the nonfarm business sector real compensation per hour from the Bureau of Labor Statistics. Finally, the nominal interest rate is given by the federal funds rate. The nominal variables (price inflation, wage inflation, and interest rate) are treated as deviations from their sample mean.

As a first step for the estimation procedure, the log-linearized system of the DSGE model in the previous section is solved by Sims's (2002) algorithm. Notice that the solution of the DSGE model associated with regime-dependent heteroskedastic shocks does not hinge upon the stochastic volatility regime. This is due to the usage of the first-order approximation in deriving the equilibrium conditions of the optimizing agents.

In order to detail the solution procedure, let S_t to be the DSGE state vector which contains all the model endogenous variables. Then the log-linearized system can be expressed as

$$\Gamma_0 S_t = \Gamma_1 S_{t-1} + \Psi M(\xi_t^P, \Theta^P, H^P, \xi_t^Q, \Theta^Q, H^Q)\epsilon_t + \Pi\eta_t, \tag{16}$$

where Θ^P and Θ^Q denote the regime-dependent standard deviations of policy and non-policy shocks, respectively. The vector ϵ_t contains all the exogenous shocks of unit variance defined in the previous section, and η_t is the vector of the expectations errors. Existing literature ascribes a significant role in the remarkable stability of the U.S economy since the mid-80s to changes in the volatilities of the *non-policy* shocks [Sims and Zha (2006)]. In contrast, Clarida et al. (2000) and Lubik and Schorfheide (2004) argue that the stabilization of the U.S. economy is largely accounted for by a pivotal switch in the Fed's policy stance. The distinction between the policy and non-policy shock volatility regimes in (16) is guided by the discourse in the previous studies.

If there exists a solution to (16), the output of the solution algorithm is expressed in a regime-switching vector autoregression form:

$$S_t = TS_{t-1} + RM(\xi_t^P, \Theta^P, H^P, \xi_t^Q, \Theta^Q, H^Q)\epsilon_t, \tag{17}$$

where H^P and H^Q are the probabilities of moving across difference policy and non-policy shock volatility regimes, respectively. We posit that H^P and H^Q are governed by two unobserved regimes associated with the shock volatilities. In particular, the state variables, ξ_t^P and ξ_t^Q, follow a first-order Markov chain with the following transition probability matrix:

$$H^P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} \quad \text{and} \quad H^Q = \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix},$$

where $P_{ij} = \text{Prob}(\xi_t^P = j | \xi_{t-1}^P = i)$ and $Q_{ij} = \text{Prob}(\xi_t^Q = j | \xi_{t-1}^Q = i)$.

Let X_t denote the observable data used for the estimation. Then the measurement equation is given by

$$X_t = ZS_t \tag{18}$$

where Z is a matrix that maps the DSGE model's law of motion in (17) into the observable variables.

The next step is to use the Sims's optimization routine *csminwel* to maximize the log posterior function, which combines the priors and the likelihood of the data. In evaluating the likelihood for the model, we use the Kalman filter developed by Kim and Nelson (1999) due to the presence of the unobserved Markov states ξ_t^P and ξ_t^Q. Inferences associated with Kim and Nelson (1999)'s algorithm are conditional both on current and past states ξ's, whereas the standard Kalman filter is based only on information evaluated at the current period. Finally, the random walk Metropolis-Hastings (MH) algorithm simulates 150,000 draws with the first 50,000 used as a burn-in period and every 20th thinned, leaving a sample size of 5,000.

The estimation approach balances the two competing hypotheses, ensuring that neither hypothesis (beliefs or preferences) is favored. The initial beliefs correspond to ordinary least-squares (OLS) estimates of the policymakers' model using data from 1954:Q2 to 1960:Q1; this sample coincides with Slobodyan and Wouters (2014), who conclude that this sample choice for initial beliefs improves the fit of the model.

4.2 PRIORS Table 1 presents prior distributions along with their means and SDs for the parameters estimates. The prior for the parameter φ has a gamma distribution with a mean 1, and an SD of 0.50 that is slightly lower than in Milani (2007). The priors for habit persistence, and price and wage inflation indexation follow a beta distribution with mean of 0.70 and SD of approximately 0.20. This prior aids at estimating parameters because it prevents posterior peaks from being trapped at the upper corner of the interval. The prior for ξ_p, which is a function of price stickiness, follows a normal distribution centered at 0.015, which was the value assigned in Milani (2007). Furthermore, ω_p and ω_w follow a gamma distribution with a mean 0.89 and a large SD of 0.40; a gamma distribution was assigned in this case because the model assumes that these parameters take positive values.

The priors for the weights on the policymakers' loss function are informative. They are centered at the values implied by the microfounded weights derived in Giannoni and Woodford (2003).

Table 1: Prior distributions for the estimated parameters.

Description	Parameter	Density	Mean	SD	95% Prior Probability Interval
Intertemporal elasticity of substitution	φ	Gamma	1.00	0.50	[0.27,2.19]
Habit formation	η	Beta	0.70	0.20	[0.25,0.98]
Function of price stickiness	ξ_p	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]
Price inflation indexation	γ_p	Beta	0.70	0.17	[0.32,0.96]
Wage inflation indexation	γ_w	Beta	0.70	0.17	[0.32,0.96]
MP weight on output gap	λ_x	Gamma	0.30	0.25	[0.02,0.95]
MP weight on wage inflation	λ_w	Gamma	0.30	0.25	[0.02,0.95]
MP weight on the interest smoothing parameter	λ_i	Beta	0.50	0.25	[0.06,0.94]
Demand shock AR(1)	ρ_r	Beta	0.50	0.20	[0.13,0.87]
Supply shock AR(1)	ρ_p	Beta	0.70	0.10	[0.13,0.87]
Wage shock AR(1)	ρ_w	Beta	0.50	0.20	[0.13,0.87]
MP shock standard deviation	σ_{mp}	Inv. Gamma	0.20	0.20	[0.05,0.63]
Demand shock standard deviation	σ_r	Inv. Gamma	1.00	1.00	[0.28,3.35]
Supply shock standard deviation	σ_p	Inv. Gamma	0.10	2.00	[0.02,0.44]
Wage shock standard deviation	σ_w	Inv. Gamma	0.10	2.00	[0.02,0.44]
Prob. of volatility regime 1, non-policy shocks	P_{11}	Dirichlet	0.909	0.083	[0.751,0.988]
Prob. of volatility regime 2, non-policy shocks	P_{22}	Dirichlet	0.909	0.083	[0.751,0.988]
Constant gain	$\mathbf{g}$	Gamma	0.03	0.02	[0.003,0.08]

Note: H. econ. inc. price, elasticity of the supply wage with respect to the quantity produced, holding fixed households' marginal utility of income; H. econ. inc. wage, elasticity of the marginal cost with respect to the quantity supplied at a given wage.

The implied microfounded weights are functions of the underlying model parameters. The priors of the loss-minimizing rates of wage inflation, deadweight loss, and interest-rate-smoothing parameter follow a gamma distribution. The loss-minimizing rates of wage inflation, as well as the deadweight loss, are centered at 0.30. These means are 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 for the interest-rate-smoothing parameter has its mean approximately at the value at 0.50 and its SD at 0.25. which is consistent with a prior probability interval between 0 and 1.[10]

The priors for the regime switching probability impose two conditions: non-negativity and sum-to-one constraints. The priors used follow Bianchi (2013), and they are Dirichlet prior distributions —for details refer to Hur (2017).

5 RESULTS

[10]We had previously experimented with a prior distribution for the interest rate smoothing weight with a high mean as in Dennis (2006), however, the posterior parameters led to indeterminacy for the entire sample, which is not what has been found in the previous literature. Dennis (2006) estimates the parameters in the Federal Reserve's policy objective function along with the parameters in the optimizing constraints.

Table 2: Model fit: Log marginal density for various specifications.

	M1	M2	M3	M4 (Benchmark)
Gain $\mathbf{g}$	One $\mathbf{g}$	Two $\mathbf{g}_t$	Two $\mathbf{g}_t$	Two $\mathbf{g}_t$
λ_{ϖ}	One set λ_{ϖ}	One sets λ_{ϖ}	Two Sets $\lambda_{\varpi,t}$	Two sets $\lambda_{\varpi,t}$
$\sigma_{mp,r,p,w}$	One set $\sigma_{mp,r,p,w}$	One set $\sigma_{mp,r,p,w}$	One set $\sigma_{mp,r,p,w}$	MS $\sigma_{regime1}$ $\sigma_{regime2}$
Log Marginal Density	-3892.6	-3127.6	-2241.3	-1455.7

5.1 MODEL FIT As described in the introduction, our objective is twofold as we attempt to bridge the gap between two narratives that are at opposite ends of the debate regarding macroeconomic dynamics in the U.S. On one hand we aim at explaining the role played by monetary policy (through changes in policy preferences and beliefs about the structure of the economy) at propagating and ending the Great Inflation, and its contribution to the Great Moderation. On the other hand, responding to the "bad luck" literature we model the structural shocks as a Markov-switching process. The question is, are all these elements necessary? We conducted marginal likelihood analysis of the competing models in which we add each element piece by piece, and the results are summarized in Table 2. We find that the model that best fits the data is the model with all the proposed elements, M4 or benchmark. The break in the gain parameter $\mathbf{g}_t$ and in the λ_{ϖ} parameters are essential to fit and reproduce a policy variable that follows closely the federal funds rate. The following section outlines the contribution of the breaks to the dynamics of the policy variable. These two elements are our contributions relative to Lubik and Matthes (2016) who explain the Great Inflation using a learning model that attributes the excess volatility in macroeconomic aggregates to indeterminacy. Lubik and Matthes (2016) assume that monetary policy preferences for stabilizing objectives remain fixed during the entire period as well as the speed of central bank learning.[11] In addition, we factor in the possibility of regime changes in the volatility of the shocks so as to compare and quantify the historical contributions of "bad luck" and "bad policy" to the dynamics of output and inflation. We will now discuss the results in the context of the benchmark or M4 model.

5.2 POSTERIOR ESTIMATES Table 3 presents posterior probability means for the structural parameters in the DSGE model. The structural parameters in the DSGE model assume plausible values similar to previous Bayesian estimations of New Keynesian DSGE models for the United States [e.g. Lubik and Schorfheide (2004), Milani (2007, 2011), Milani and Treadwell (2012), Smets and Wouters (2007), Slobodyan and Wouters (2014)].

The results show a shift in policymakers' preferences away from output gap stabilization after the appointment of Chairman Volcker. In the pre-Volcker period, the estimated weight on output

[11] Section 4 provides intuition and previous evidence of the importance of a change in gains and preferences as integral parts of the model.

Table 3: Posterior distributions for the estimated parameters Benchmark model.

Description	Parameter	Mean	[2.5%, 97.5%]
Intertemporal elasticity of substitution	φ	3.17	[2.44,3.91]
Habit formation	η	0.13	[0.05,0.22]
Function of price stickiness	ξ_p	0.08	[0.06,0.09]
H. econ. inc. price	ω_p	0.09	[0.03,0.16]
H. econ. inc. wage	ω_w	0.78	[0.25,1.46]
Price inflation indexation	γ_p	0.87	[0.79,0.94]
Wage inflation indexation	γ_w	0.96	[0.91,0.99]
MP weight on output gap, pre-1979	$\lambda_{x,pre-1979}$	0.41	[0.31,0.53]
MP weight on wage inflation, pre-1979	$\lambda_{w,pre-1979}$	0.10	[0.01,0.27]
MP weight on the interest smoothing parameter, pre-1979	$\lambda_{i,pre-1979}$	0.93	[0.82,1.00]
MP weight on output gap, post-1979	$\lambda_{x,post-1979}$	0.03	[0.01,0.07]
MP weight on wage inflation, post-1979	$\lambda_{w,post-1979}$	0.25	[0.02,0.73]
MP weight on the interest smoothing parameter, post-1979	$\lambda_{i,post-1979}$	0.77	[0.46,0.97]
Demand shock AR(1)	ρ_r	0.74	[0.70,0.78]
Supply shock AR(1)	ρ_p	0.37	[0.23,0.50]
Wage shock AR(1)	ρ_w	0.28	[0.08,0.49]
MP shock standard deviation, regime 1 (low vol. regime)	$\sigma_{mp,regime1}$	0.07	[0.05,0.11]
Demand shock standard deviation, regime 1 (low vol. regime)	$\sigma_{r,regime1}$	1.95	[1.40,2.61]
Supply shock standard deviation, regime 1 (low vol. regime)	$\sigma_{p,regime1}$	0.02	[0.01,0.03]
Wage shock standard deviation, regime 1 (low vol. regime)	$\sigma_{w,regime1}$	0.01	[0.01,0.02]
MP shock standard deviation, regime 2 (high vol. regime)	$\sigma_{mp,regime2}$	1.75	[1.14,2.69]
Demand shock standard deviation, regime 2 (high vol. regime)	$\sigma_{r,regime2}$	15.26	[10.90,20.06]
Supply shock standard deviation, regime 2 (high vol. regime)	$\sigma_{p,regime2}$	0.20	[0.10,0.42]
Wage shock standard deviation, regime 2 (high vol. regime)	$\sigma_{w,regime2}$	0.21	[0.10,0.42]
Prob. of volatility regime 1, non-policy shocks	P_{11}	0.95	[0.91,0.99]
Prob. of volatility regime 2, non-policy shocks	P_{22}	0.91	[0.83,0.97]
Prob. of volatility regime 1, MP shock	Q_{11}	0.96	[0.92,0.98]
Prob. of volatility regime 2, MP shock	Q_{22}	0.91	[0.67,0.93]
Constant gain, pre-1979	$\mathbf{g}_{pre-1979}$	0.013	[0.013,0.013]
Constant gain, post-1979	$\mathbf{g}_{post-1979}$	0.009	[0.007,0.012]

Note: H. econ. inc. price, elasticity of the supply wage with respect to the quantity produced, holding fixed households' marginal utility of income; H. econ. inc. wage, elasticity of the marginal cost with respect to the quantity supplied at a given wage.

stabilization $(\lambda_{x,pre-1979})$ was 0.41; this value decreased significantly in the post-Volcker period $(\lambda_{x,post-1979})$ to a value close to zero 0.03. This change in preferences for output gap stabilization relative to inflation is akin to Dennis (2006). He finds that the estimated weight on the output gap is not significantly different from zero in the post-Volcker era. He suggests that the Federal Reserve did 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.

The estimated interest-rate-smoothing weights are $\lambda_{i,pre-1979} = 0.93$ and $\lambda_{i,post-1979}= 0.77$, which are similar; their posterior probability intervals overlap between periods. Nevertheless, the time varying interest-rate-smoothing parameter resulting from these weights see an increases in the post-Volcker period consistent with Coibion and Gorodnichenko (2012); they provide evidence that strongly favors the interest smoothing explanation on why are target interest rate changes so

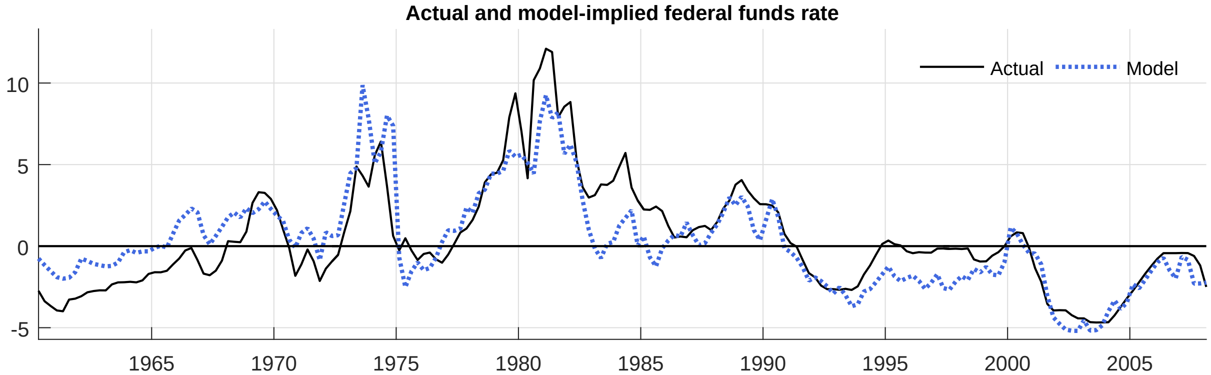

Figure 1: Actual (solid line) and model-implied (dashed line) federal funds rate. The model-implied series is evaluated at the mean of posterior parameter estimates.

persistent in the recent period.

Finally, the weight that central bankers assigned to wage inflation increases from $\lambda_{w,pre-1979} = 0.10$ to $\lambda_{w,post-1979} = 0.25$ in the Volcker-Greenspan period; this explains the inflation stabilization goals persistent in the post-Volcker period documented in the literature. In sum we find a change in policymakers preferences away from output gap stabilization toward inflation stabilization after 1979.[12]

To grasp the monetary policy strategy followed by policymakers in the benchmark model, Figure 1 plots the evolution of the *estimated model's optimal policy variable* over time. The federal funds rate is also plotted for comparison. As shown, the model's optimal policy variable follows closely the behavior of the federal funds rate in the period of study, and this is a contribution relative to Lubik and Matthes (2016).[13] A notable exception is a higher peak in the model implied optimal monetary policy variable in 1974. The 1974 peak has been addressed in paper such as Lubik and Matthes (2016); in fact, they call it "the Volcker disinflation of 1974." Authors find that Volcker's disinflation and the Great Moderation were the product of policy actions that began in 1974. Romer and Romer (1989), following a narrative approach, provide evidence that the Fed was faced with a rate of inflation considered as excessive—following the oil embargo—and responded with an active effort at contraction, even when little or no growth was occurring or expected.

The data are also informative in the estimation of the gain coefficient $\mathbf{g}$. The speed of learning decreased from $\mathbf{g}_{pre-1979} = 0.013$ to $\mathbf{g}_{post-1979} = 0.009$ in the post-Volcker era. Intuitively, before 1979, policymakers were responsive to their suspicion of potential structural breaks in the

[12] It has been widely document that policymakers followed a relatively low inflation stabilization goal before 1979 due to their real-time beliefs—through a continual learning process—regarding the persistence of inflation in the Phillips curve and the slope of the Phillips curve. We choose not to make this the focus of our paper because it mimics closely the analysis and conclusions of Primiceri (2006), Best (2016), Romer and Romer (2002), and Orphanides and Williams (2005).

[13] Lubik and Matthes (2016) focus on a sample that starts in the mid-1970s, however we decide to extend our analysis and start our sample in the 1960s because the beginning of the Great Inflation dates to that decade.

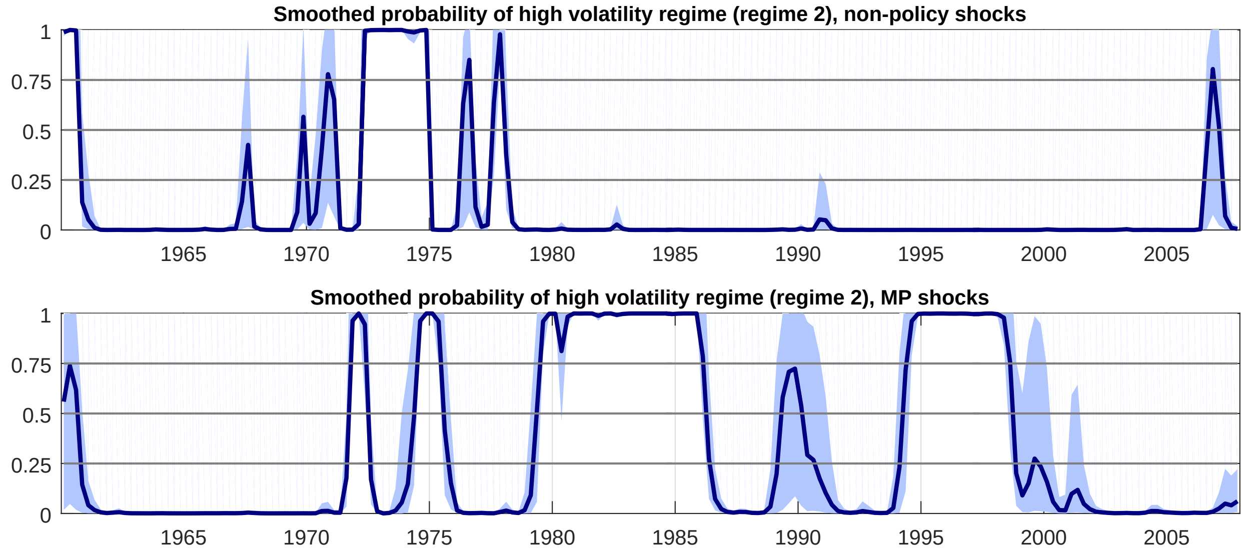

Figure 2: [Upper panel] Posterior smoothed probability estimates of the high non-policy shock volatility regime. [Lower panel] Posterior smoothed probability estimates of the high monetary policy shock volatility regime. In each figure, mean (solid line) and 95% interval (shaded area) are reported.

economy, supported by the uncertain economic climate, this is entirely consistent with Figure 2. Furthermore, after 1979, with the change in preference toward inflation stabilization, but most importantly, with the unfolding of the Great Moderation, central bankers increased their trust in their model of the economy and responded more moderately to new information, resulting in a lower gain. The values estimated for the gain parameter are plausible and are within the range of previous estimations (i.e. Slobodyan and Wouters (2014) find a gain between 0.001 and 0.034). Milani (2014) also estimates the gain coefficients that are allowed to adjust according to past forecast errors in a model that generates time-varying macroeconomic volatility. His estimation results show that private agents switched to a constant gain with high learning during the 1970s into the early 1980s to revert to a decreased gain later. Thus, policymakers' learning in this paper coincides with agents' speed of learning patterns over the sample studied.

We perform a simulation exercise in which we plot the model implied optimal policy variable where we assume (i) pre- and post-Volcker policy preference coefficients, and (ii) pre- and post-1979 gains fixed during the entire sample. We found that (i) has important implications for the Volcker disinflation episode, for example, pre-Volcker weights in the post-Volcker period would have resulted in a significantly lower optimal policy variable during the early 1980s peak confirming post-1979 policy's role at fighting the Great Inflation. Regarding (ii) a post-1979 gain in the pre-1979 sample would have resulted in a much more volatile optimal policy consistently above the federal fund rate even during the second half of the 1970s.[14] Therefore, an optimal policy variable that tracks the federal fund rate is the product of policymakers' learning and the change in

[14]Graphs are available upon request.

the policy preference parameters in 1979 estimated in the paper.

The benchmark model also captures shifts in the volatility of the non-policy and policy shocks motivated by the literature on the Great Moderation. The results presented in Figure 2, show the smoothed probability of high volatility regime for the non-policy shock (top panel) and the smoothed probability of high volatility for the monetary policy shock (bottom panel). We observe periods of high volatility of the non-policy shock clustered around the late 1960s through the 1970s coincident with the energy crisis that increased oil costs, and before the Great Recession. We observe an especially long period of high volatility in the first half of the 1970s; and a long period of low volatility of the non-policy shocks that includes the Great Moderation era. Thus, our model finds a role to "good luck" in the determination of U.S. dynamics.

With reference to the bottom panel, we observe short occurrences of high volatility in the early, mid, and late 1970s, and a prolonged period that includes "Volcker's experiment," and ends at the onset of the Great Moderation. Hakkio (2013) outlines a list of potentially large shocks that hit the U.S. economy during the Great Moderation. He includes the Latin American debt crisis of 1980s, and the failure of Continental Illinois Bank in 1984 possibly leading to monetary policy responses that deviate from the policy rule and increased the volatility in our model. Furthermore, we observe a short period of increased volatility in the early 1990s and a lengthy period from the mid-1990s to the early 2000s that ends with the 2001 recession. The early 1990s peak began around 1988, following the 1987 stock market crash, period where the Fed acted preemptively to prevent inflation.

In sum, we observe a monetary policy regime change from the pre-Volcker era into the Volcker-Greenspan era, even in the presence of policymakers evolving beliefs about the structure of the economy and Markov-switching processes for the volatility of the shocks capturing the Great Moderation.

5.2.1 HISTORICAL DECOMPOSITIONS

Now, we will discuss the relative contribution of each shock to macroeconomic dynamics. In particular, Figure 3 shows the posterior mean estimates for the historical contribution of the exogenous shocks to fluctuations in output, inflation, the model implied policy variable, and wage inflation.

Our analysis yields that supply shocks play a major role in the determination of output before the 1980s, demand shocks seem important after 1980's, while monetary policy shocks played an important role in sporadic episodes in the mid-1960s, and early 1970s, mid-1990s and before the Great Recession. Monetary policy has significant importance in the early 1980s during Volcker's disinflation which confirms our finding of a change in preference for inflation stabilization during this episode.

Inflation is an interesting variable, before approximately 1973 supply shock seemed to be the dominant force driving inflation variability. However, starting from 1974 demand and monetary policy shocks also become important. Possible explanations of the run up of inflation up to this

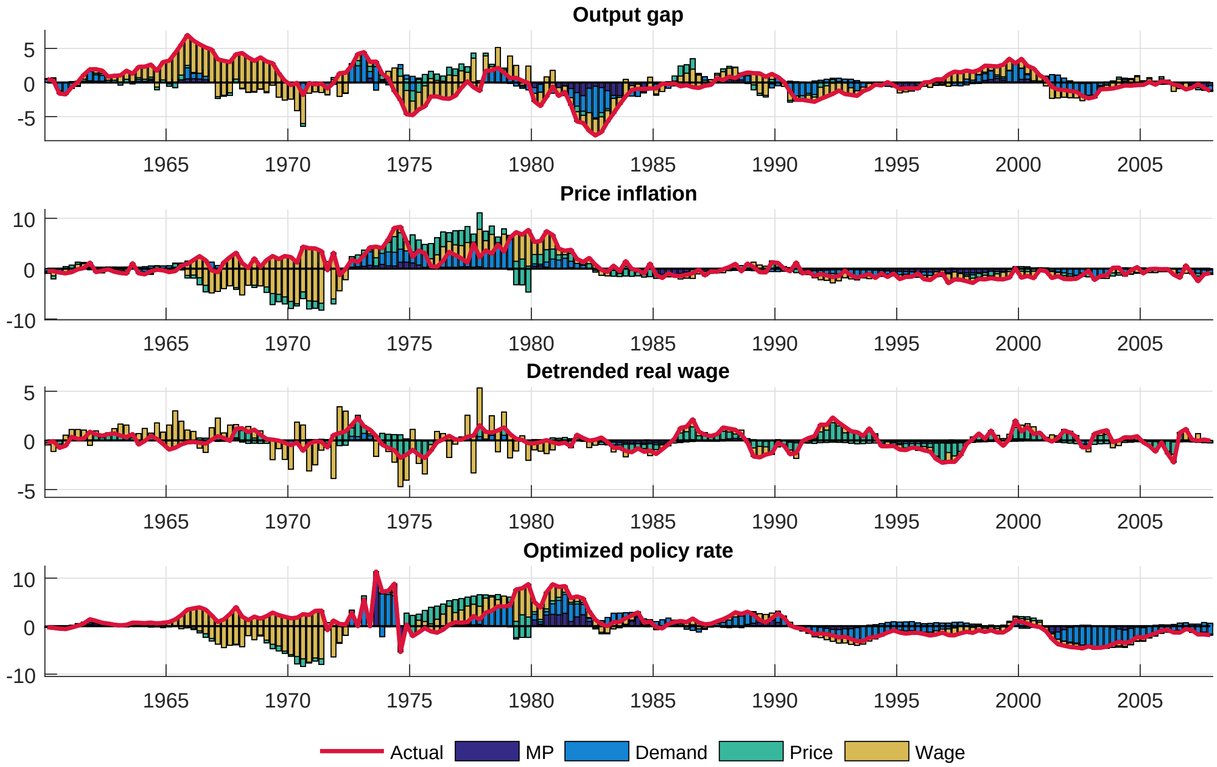

Figure 3: Shock decompositions. Posterior mean estimates are reported.

point could be the end of wage-price controls and the first oil price shock. Monetary policy became the sole driver of inflation during the mid-1980s and as important as supply shocks during the 1990s decade. Moreover, wage inflation seems to be driven by supply shocks.

Lastly, supply shocks influenced monetary policy during the Great Inflation, however shortly before the mid-1970s and after 1977 monetary policy appear to be driven by demand shocks and/or exogenously driven.

5.2.2 CHANGE IN PREFERENCES, LEARNING, AND THE MODEL IMPLIED TAYLOR RULE COEFFICIENTS

To interpret the changes in the stabilizing weights for the inflation rate, output gap, and interest rate change, and central bank learning we study their implied optimal interest rate responses. Of note, the interest rate responses are reduced-form representations of policymakers' behavior and their responses often hide the difference between policymakers' objectives: factors that the central bank can control and those it cannot control. Therefore, the policymakers' preference parameters can better capture the changes in central bank objectives.

The upper panel of Figure 4 presents the long-run response to inflation (price and wage combined), and the bottom panels of the figure presents the long-run response to the output gap, and the interest-rate-smoothing term in the time-varying policy reaction function implied by (15).[15]

[15]The combination of price and wage responses is the simple sum of the price and wage inflation coefficients,

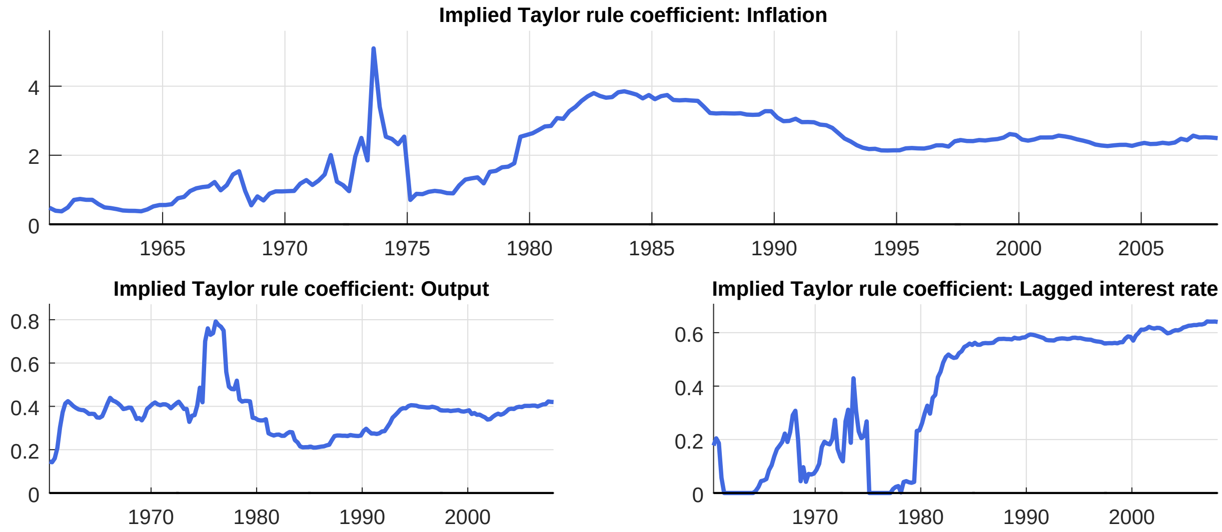

Figure 4: Model-implied Taylor rule coefficients for inflation, output and lagged interest rate. The model-implied series is evaluated at the mean of posterior parameter estimates.

The results obtained from the optimal time-varying policy reaction function implied by the model follow a similar pattern as the Fed's time-varying responses in Ang et al. (2011). These authors estimate a time-varying policy reaction functions that accounts for the term structure of interest rates. The time-varying coefficient on inflation reflects the narrative evidence of the evolution of monetary policy theory and understanding provided in Romer and Romer (2002). The time-varying coefficient for inflation evolves as follows: The Fed pursues a monetary policy easing strategy represented by a low response to inflation during the 1960s and 1970s, until 1979. In this paper, we observe a sharp increase in the response to inflation in 1974, possibly capturing a pronounced but brief increased response in light of the oil price shock. We observe during the earlier part of the sample—before 1979—that the Fed's response to inflation was low (< 1), indicating that the Fed accommodated inflation in several occasions.

The Fed raised its inflation response in the late-1970s, it stayed at a high level during the 1980s, and started a sharp decrease in the early-1990s. There is a further increase in the inflation coefficient starting in the mid-1990s, consistent with the Fed's desire to use pre-emptive measures to fight inflation. Moreover, the 2001 recession is also accompanied by a decreased response to inflation, the dynamics matched what has been described in Ang et al. (2011).

We found evidence of bad policy during the Great Inflation, as Clarida et al. (2000), Lubik and Schorfheide (2004), and Ang et al. (2011) propose. The Fed systematically failed to respond sufficiently strong to inflation, leaving the economy vulnerable to fluctuations driven by self-fulfilling expectations. We find further support to DeLong (1997) that policymakers, during that time, did

Best (2016) shows that the sum of these two coefficients determines the determinacy and learnability properties of the model. Moreover, Erceg et al. (2000) results suggest that the combination of both coefficients have important implications for social welfare.

not make policy decisions that would translate into a sizeable recession to reduce inflation, because they still had the Great Depression fresh in their memories. We also find perceived changes in the structure of the economy by policymakers in the model that could contribute to the so called bad policy.

We find a "low" response to inflation in the mid-1990s and the after the 2001 recession, well into the Great Moderation. Does that imply that the Fed was not "hawkish" enough with respect to inflation in these two episodes? We find that this is not necessarily true. We obtain this low Taylor rule coefficient even under a central bank with a strong preference for inflation stabilization. Therefore this low response to inflation could arise due to the policymakers' continual learning about the structure of the economy.

The bottom left panel of Figure 4 represents the time-varying policy coefficient for the output gap from 1960 to 2008. During most of the 1970s, policymakers used their policy instrument in an attempt to influence the output gap, especially after 1975 but this approach changes after 1979 (see Boivin (2006)). In Volcker's disinflation period, the response of the interest rate to the output gap decreases and was half of its pre-1979 magnitude. Once inflation was stabilized, the Fed increased its reaction to real economic conditions during the 1990s, and positioned itself to respond to the Great Recession as we approach the end of the sample. The time-varying responses of inflation and the output gap generally move in opposite directions; this conclusion follows from the fact that these coefficients are derived using policy preference parameters, and intuitively, reducing the volatility of one variable in the policy frontier would imply increasing the volatility of another variable (see Debortoli and Nunes (2014)).

The time-varying interest-rate-smoothing parameter is shown in the bottom right panel of Figure 4. This parameter increases after 1979 consistent with Boivin (2006), Kim and Nelson (2006), and Coibion and Gorodnichenko (2012). Thus, the model can also capture time-varying responses in a policy reaction function consistent with the literature.

A natural question is what are the implications for equilibrium determinacy in our model? Figure 5 plots our determinacy indicator evaluated at the mean of the posterior parameter estimates where $2 = determinacy$. Determinacy is prevalent in all the post-Volcker period and has episodes during the 1960s and 1970s. We also find short periods of indeterminacy in the pre-Volcker period. Subsection 5.3 further explains how the determinacy results change with the policy preference parameters and learning assumptions estimated. The contribution that we discuss in the next section is that not only learning, as discussed in Lubik and Matthes (2016) but also changes in stabilizing objectives by the Fed can lead to indeterminacy. Most importantly, only when the central bank (1) intends to stabilize inflation (post-1979 λs) and (2) has favorable beliefs regarding the structure of the economy is that "good policy" emerges.

5.3 COUNTERFACTUALS AND IMPULSE RESPONSE ANALYSES

Counterfactual analyses were conducted to investigate the effect of alternative monetary policy regimes, learning assumptions,

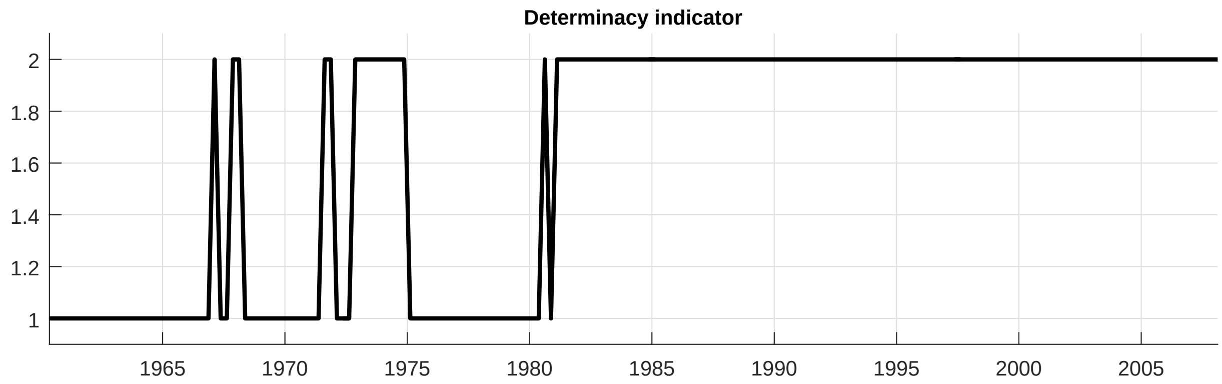

Figure 5: Determinacy of the model, evaluated at the mean of posterior parameter estimates.

and shocks processes on inflation, output gap, and the policy variable.

Notice that the counterfactual exercises in this section are performed conditioning on a particular sequence of structural shocks. More specifically, the counterfactuals are generated by the following steps. The shock sequence is obtained by taking a draw for the parameters and computing the smoothed series for the DSGE states. Then the model is solved with modifications in the structural parameters of interest, while the other parameters remain unaltered. Finally, the model is solved with the alternative parametrization in order to simulate an economy having the same starting point for the DSGE state and facing the same sequence of shocks.

5.3.1 Counterfactual Analysis for Alternative Weights in the Central Bank Loss Function

First we discuss impulse responses that assume post-1979 preferences, or the correct parameters, in the post-1979 period. A priori we know that this is a period associated with "good policy" and should exhibit intuitive policy responses and macroeconomic dynamics. Figure 6 showed that the benchmark parameters (1982:Q1 actual, 1991:Q1 actual, and 2001:Q1 actual) lead to impulse response functions supportive of the traditional demand channel of monetary policy, where no price puzzle is present.

Figures 7 and 8 for our benchmark parameters are capable of producing responses of inflation, output, and interest rate to other shocks that are consistent with economic intuition. We find that a demand shock produces a non-negative effect on the interest rate and price and wage inflation, and a non-negative effect on the output gap. A shock to the Phillips curve has a non-negative effect on the interest rate and inflation and a non-positive effect on the output gap. We find that in the post 1979 era, this model produces intuitive impulse responses.

In our first counterfactual experiment we investigate what kind of equilibrium would have prevailed for the U.S. economy, have we kept 70's type of policy during the post-Volcker period. Figure 9 top panel, shows that "bad policy" or policy consistent with multiple equilibria would have prevailed even during the Great Moderation period. What we can conclude is that Figures 6, 7, and 8 for the pre-1979 preferences in the post 1979 period, specifically 1982:Q1 cf and

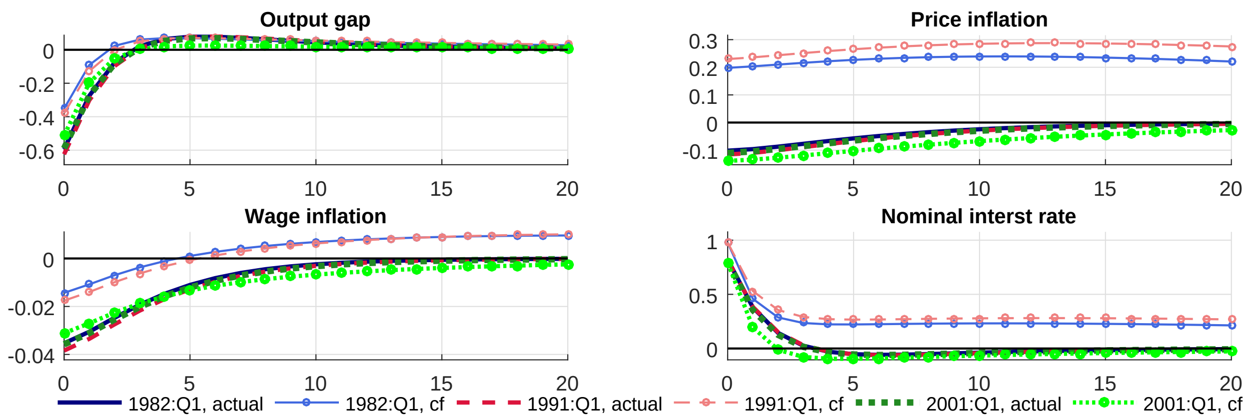

Figure 6: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes that the pre-1979 monetary policy preference is maintained over the entire sample period. The x-axis is in quarters.

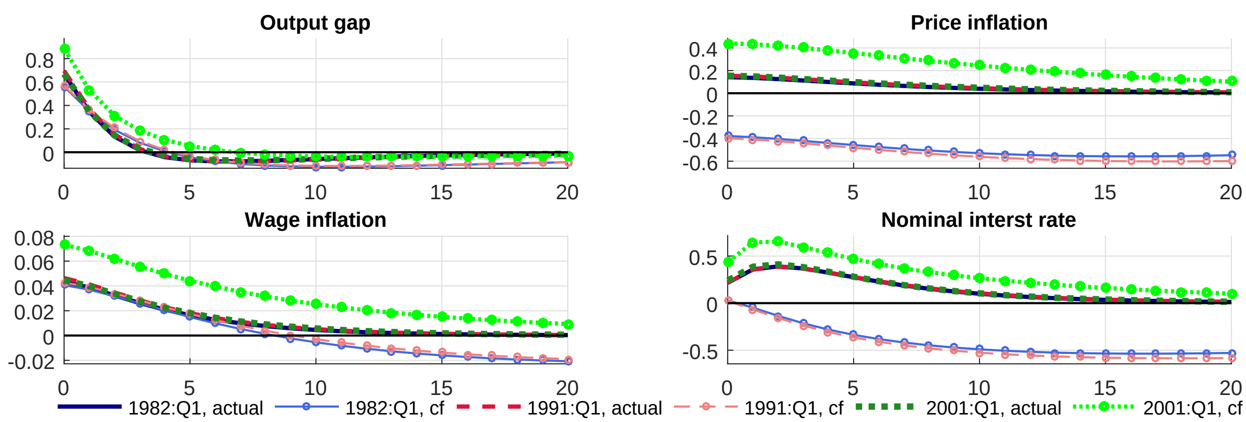

Figure 7: Impulse responses to a demand shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes that the pre-1979 monetary policy preference is maintained over the entire sample period. The x-axis is in quarters.

1991:Q1 cf produce responses to shocks that represent implausible dynamics and could have lead to amplified economic fluctuations.[16] Therefore, this shows that the Great Moderation is also the product of "good policy," or policy directed to stabilize inflation because following 70s type of monetary policy would have led to macroeconomic dynamics of sorts. A notable exception is a short determinacy episode around the 2001 recession.

Our second counterfactual is inspired by the findings in Bianchi (2013) where the appointment of an extremely conservative Chairman in the 1970s would have lowered inflation. We experiment by producing counterfactual model implied series where we assume that a Chairman with post-Volcker type of monetary policy preferences would have been in charge of the Fed in the pre-1979 period. Figure 10 presents series produced with $\lambda_x = 0.03$, $\lambda_w = 0.25$, and $\lambda_i = 0.77$ that

[16]Figure 6 plots impulse responses for the indeterminate equilibria period (1982:Q1 cf and 1991:Q1 cf) that reproduce the price puzzle of interest rates; see Castelnuovo and Surico (2010).

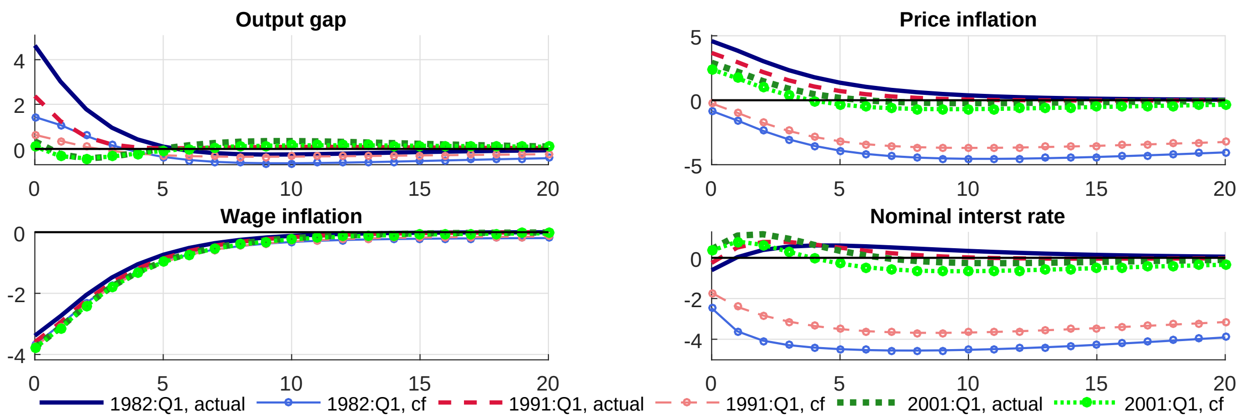

Figure 8: Impulse responses to a price shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes that the pre-1979 monetary policy preference is maintained over the entire sample period. The x-axis is in quarters.

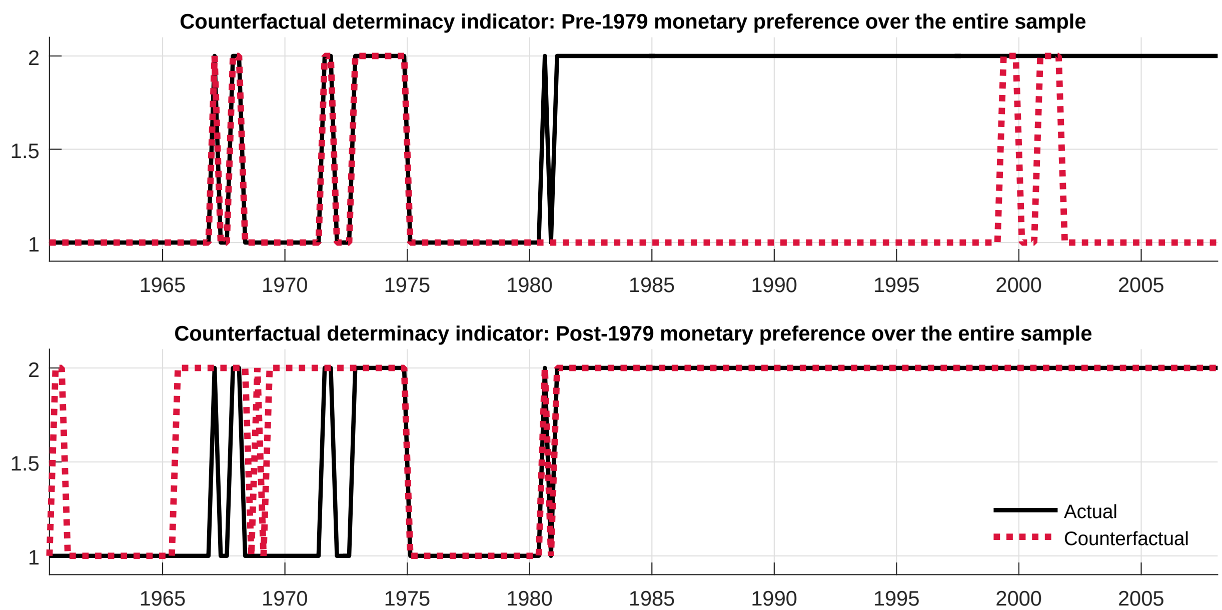

Figure 9: Actual (solid lines) and counterfactual (dashed lines) determinacy indicators, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the pre-79 (upper panel) and post-79 (lower panel) monetary policy preferences, respectively, over the entire sample period.

correspond to our post-1979 estimates through the whole sample. The relatively higher preference for inflation stabilization as well as the lower interest smoothing parameter result in an optimized policy rate that is more volatile and in many occasions higher than the actual federal funds rate from 1965 to the late 1970s. We also see increases in volatility of inflation and slight increases in the volatility of the output gap. Therefore, a post-1979 type of Chairman would have not solved the inflationary problem, at least not under the central bank beliefs about the structure of the economy that prevailed during the Great Inflation; Orphanides and Williams (2005), Primiceri (2006) and Best (2016) among others describe the beliefs mechanism that resulted in rising inflation. In brief

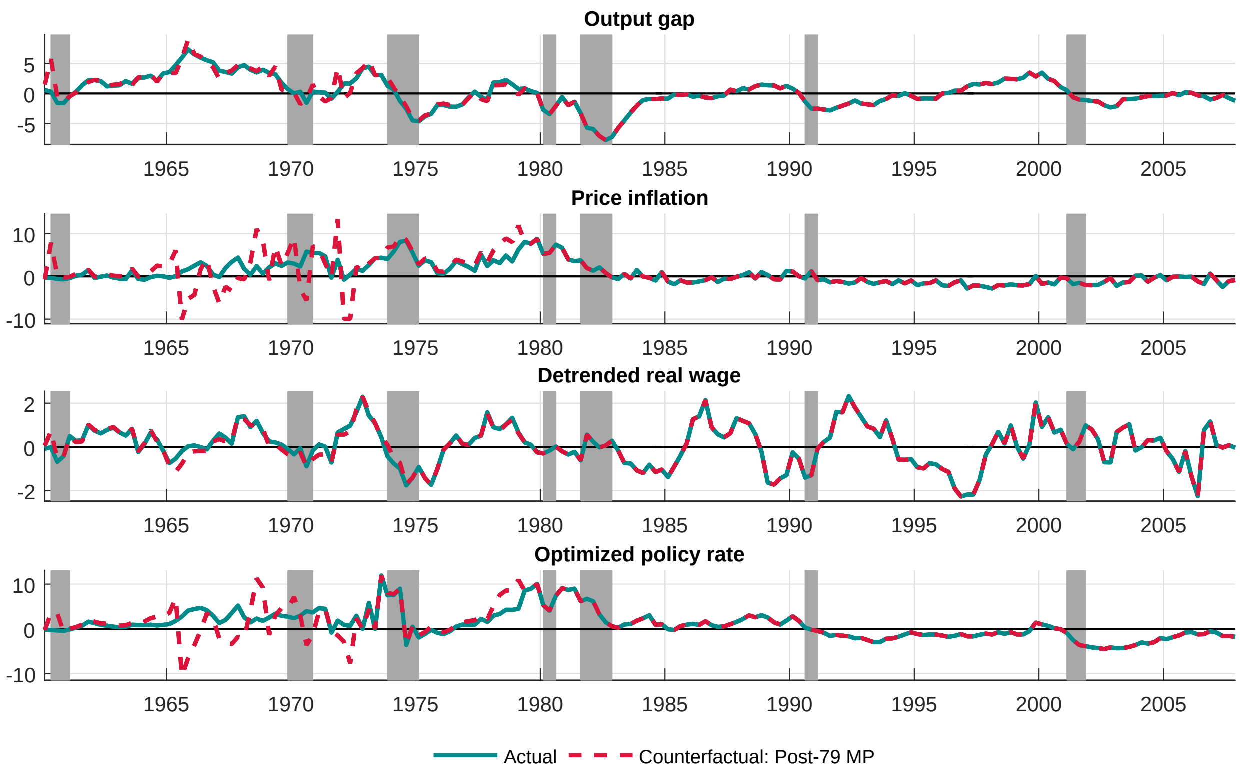

Figure 10: Posterior mean estimates for actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the post-1979 monetary policy preference is maintained over the entire sample period. The shaded areas indicate NBER recession dates.

periods between 1975 and 1980 and in the early 1960s we still observe indeterminacy as shown in the bottom panel of Figure 9.[17] Moreover, increased volatility and higher inflation in the periods consistent with determinacy are the majority.

Therefore, central bank preference parameters and learning play a central role in the determination of the dynamics of the macroeconomy consequently affecting the responses of inflation, output gap, and the policy rate, to shocks. This result gives a pre-amble to our counterfactual section on central bank learning and its contribution to our policy understanding.

5.3.2 COUNTERFACTUAL ANALYSIS FOR ALTERNATIVE LEARNING ASSUMPTIONS

We start by describing the effect of alternative learning scenarios on output gap, price and wage inflation, and the optimal policy rate. The third counterfactual scenario considers having a pre-1979 gain coefficient of 0.013, that governs the speed of learning, over the entire sample. This gain is relatively higher than the post-1979 gain, and implies having policymakers that would assign higher weight to more recent observations due to the suspicion of an unstable economic environment. The effects of a higher gain in the counterfactual post 1979 series are small and the graph has been omitted

[17] Impulse responses during these periods under paint a picture consistent with indeterminacy and are available upon request.

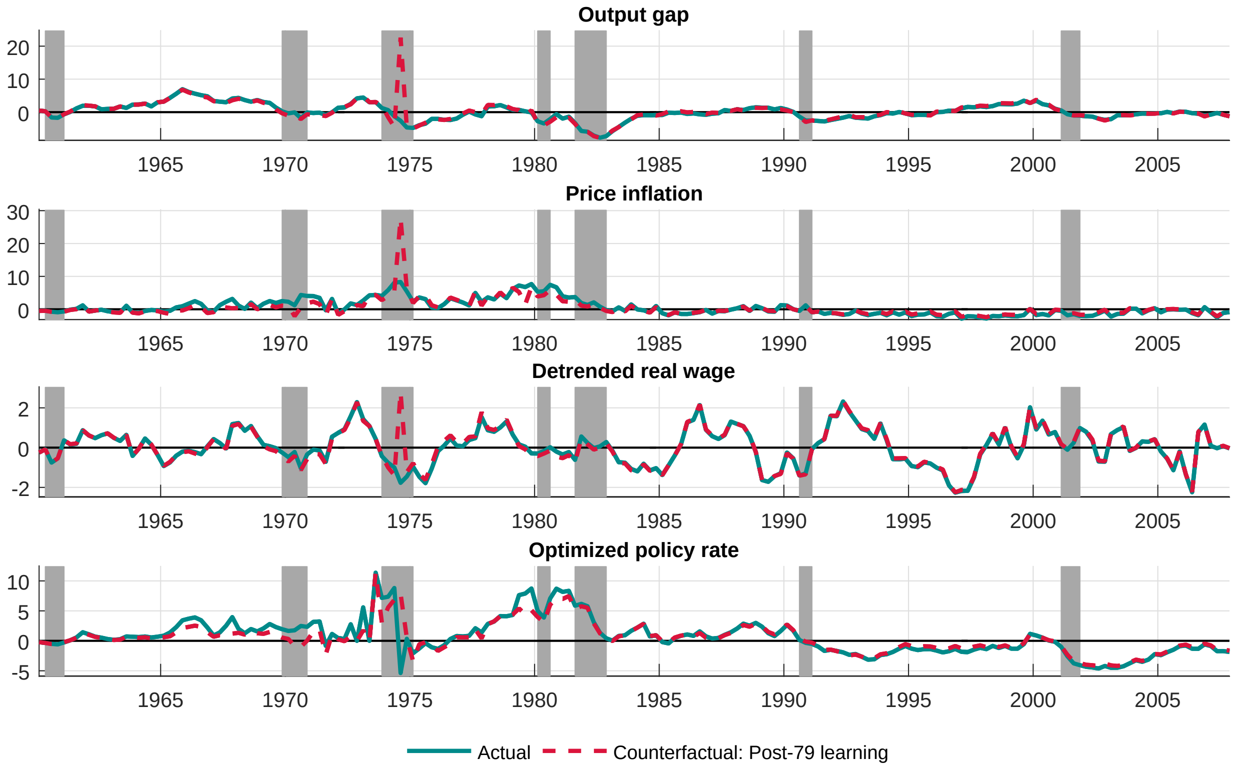

Figure 11: Posterior mean estimates for actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the post-1979 learning is maintained over the entire sample period. The shaded areas indicate NBER recession dates.

for succinctness; the difference between the actual and counterfactual oscillate around zero.[18] The most noticeable effect of a higher gain would have been a higher optimal policy variable than the federal funds rate in the late 1970s.

Figure 11 shows the effects of the counterfactual scenario fixing the gain to its post 1979 (0.009) value over the entire sample. A lower gain, usually estimated for periods of less economic instability, would have yielded a lower policy instrument during the late 1960s, but most importantly during the 1970s. This lower policy response may have increased the output gap but would have also exacerbated the inflationary problem in the mid-1970s. We also note a lower optimal policy rate in the late 1970s.

We conclude that a change in the speed of learning is necessary to reproduce the movements in the policy rate especially during the 1970s and the early disinflation effort of the 1980s. This finding broadens our understanding of an important fact emphasized in Lubik and Matthes (2016), Sargent (1999) and Primiceri (2006) that learning plays a key role in the determination of policy during the Great Inflation and Great Moderation. Our contribution is to evaluate the implications of having a central bank with the potential of shifting stabilizing objectives. We find that the evolution

[18]The figure for this counterfactual is available upon request.

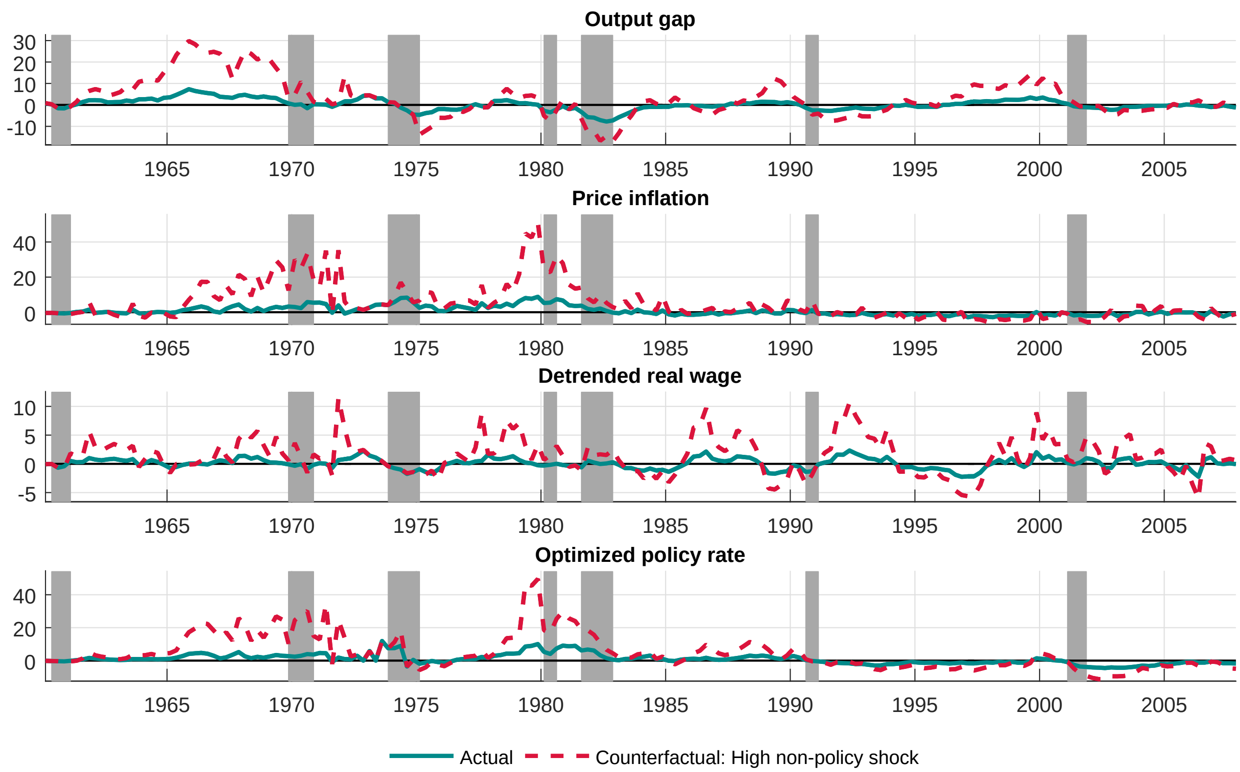

Figure 12: Posterior mean estimates for actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the high non-policy shock volatility regime prevails over the entire sample period. The shaded areas indicate NBER recession dates.

of economic understanding through learning was essential to improve the transmission mechanism of monetary policy and unleash the Great Moderation, because post-1979 policy preferences alone in the pre-1979 period could have still led to undesirable amplified economic fluctuations and in some cases even indeterminacy.[19] Therefore, in the post-1979 period we observe "good policy" because of a shift in policy preferences toward inflation stabilization but also an improvement in the Fed's economic understanding; a recount of the latter has been described in Romer and Romer (2002).

5.3.3 Counterfactual Analysis for Alternative Non-policy Shock Volatility Regime

We have previously described the effect of policy, we proceed with the evaluation of the effect of a **non-policy shock** in the U.S. macroeconomy. Figure 12 explores the counterfactual scenario that assumes that a high-non policy shock volatility regime prevails over the entire sample period. The results show that output gap would have been more volatile, amplifying the recessions of 1975, early 1980s, and 1991. We also observe a period of higher positive output gap in 1965

[19] The large multiplicity of solutions and its harmful implications including equilibrium responses to shocks to fundamentals and sunspot states that could lead to arbitrarily large fluctuations in endogenous variables, have been widely discussed in Bullard and Mitra (2002) and Woodford (2003).

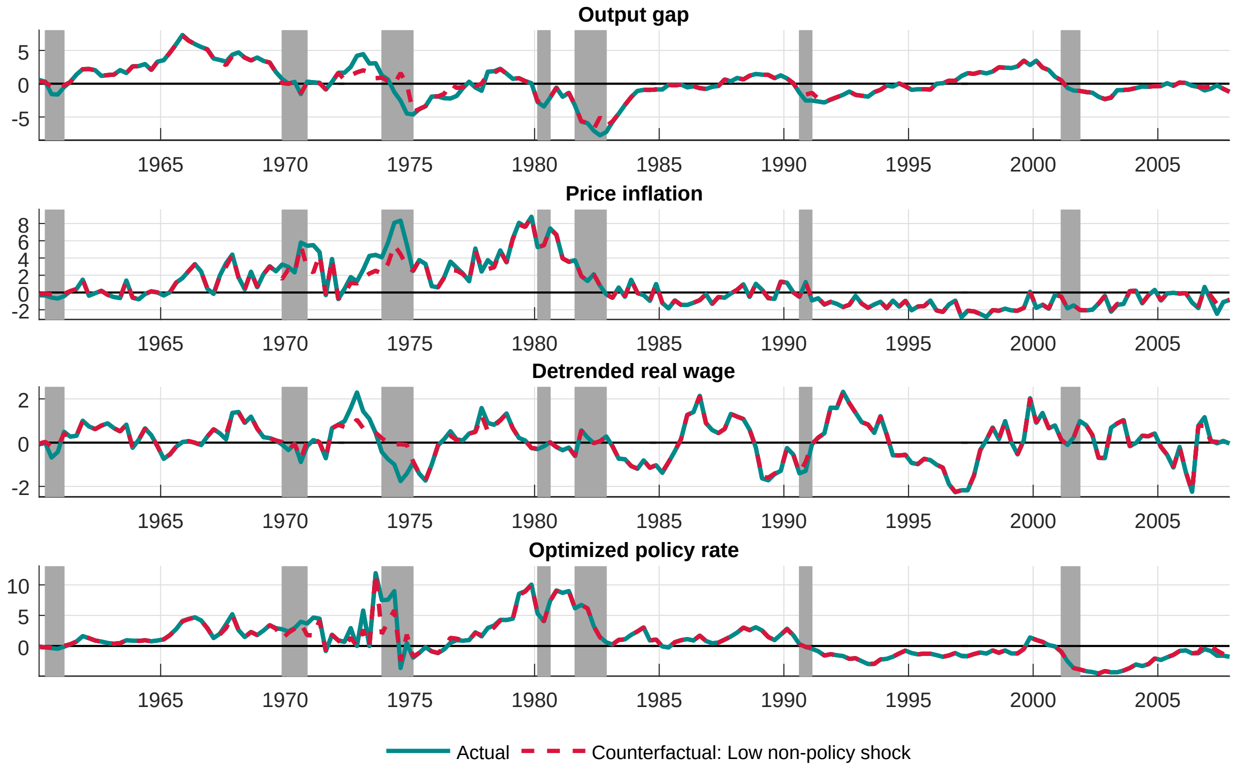

Figure 13: Posterior mean estimates for actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the low non-policy shock volatility regime prevails over the entire sample period. The shaded areas indicate NBER recession dates.

and in the second half of the 1990s.

The price inflation counterfactual is interesting in the sense that a higher shock would have led to a more pronounced Great Inflation episode from the mid-1960s to the early 1970s and in the second half of the 1970s and early 1980s. Conversely, during the Great Moderation, the effect of a higher volatility shock would have been less significant.

Regarding the wage counterfactual series, we observe a more volatile series during the entire period, with a positive bias. Lastly, the policy rate, consistent with a positive response to economic conditions, have been higher during the Great Inflation, but very stable during the Great Moderation.

Figure 13 presents a counterfactual scenario that assumes the low non-policy shock volatility regime over the whole sample. The effect on the counterfactual series is zero after the Great Inflation and during the Great Moderation period, except for a less pronounced output gap and slightly lower inflation during the early 1990s recession. However, during the late 1960s and the 1970s the effect is clear and considerable—especially important during the mid-1970s inflationary period—confirming that non-policy shock also played an essential role at explaining output and inflation dynamics during the Great Inflation.

Table 4: Conditional standard deviations of actual and counterfactual series.

	Actual	Pre-79 learning	Post-79 learning	No learning	Pre-79 MP	Post-79 MP	High shock non-policy	Low shock non-policy
x	2.42	2.42	3.17	3.18	2.92	2.45	7.58	2.26
	[2.37, 2.50]	[2.36, 2.50]	[2.49, 23.61]	[2.67, 4.10]	[2.62, 3.51]	[2.41, 2.53]	[5.92, 10.25]	[2.17, 2.35]
π	2.39	2.32	2.07	9.67	13.29	3.71	7.39	2.09
	[2.35, 2.48]	[2.25, 2.43]	[1.83, 16.59]	[6.06, 19.48]	[9.58, 16.93]	[3.42, 4.23]	[5.66, 10.73]	[2.02, 2.18]

Note: Posterior median and [2.5%, 97.5%] intervals are reported.

5.3.4 Standard Deviations of Acutal and Counterfactual Series

The qualitative effect of learning, preferences, and non-policy shocks have been assessed, now we attempt to quantify the potential effect of the alternative scenarios previously described. In this section, we compute the volatilities of actual and counterfactual output gap and inflation and report them in Table 4. Pre-79 learning does not increase the SD of output gap and inflation, however post-1979 learning increases the volatility of the output gap. Of note is that post-1979 learning increases the 95% confidence bands considerably, leaving the economy subject to potentially large volatility. Furthermore, no improvement on our macroeconomic understanding (no learning) would have led to a higher standard deviation of output gap and inflation.

Pre-79 policy in the post-79 period, and post-79 policy in the pre-1979 period would have primarily increased the volatility of inflation. It is essential to point out that pre-79 monetary policy present through the whole period would have resulted in 5.5 times the volatility of inflation. Lastly, a high non-policy shock present during the whole sample would have tripled the volatility of inflation and output. While a low volatility of non-policy shock would have cut output gap's volatility by 7% and inflation volatility by 12%. Therefore, 1979 policy preferences during the whole sample would have had the most pronounced effect on inflation volatility, while a high volatility shock would have had the strongest impact on output's standard deviation.

6 Conclusion

Learning, monetary policy preferences, and volatility changes play integral roles of explaining macroeconomic dynamics for the United States from the 1960s to 2008. In particular, we find evidence of the three sources as important contributors to the Great Inflation and the Great Moderation. We encounter a preference for output gap stabilization during the 1970s, and a shift in policy in 1979 with the appointment of Chairman Volcker to the Federal Reserve captured by a change in the stabilizing weights in the central bank loss function. We present evidence of having policymakers that are learning about the economy in real time, and subject to their beliefs, set policy optimally.

Policy preferences and learning are essential in the determination of the policy instrument; and shifts in both are necessary to match the movements of the Federal Funds Rate in the period of study. These elements, along with time varying volatility changes improve the fit of the model to the data. Regarding Sims (2012) kitchen fire analogy, our results suggest that good monetary policy may limit the adverse effect of even a major shock. As shown otherwise by our counterfactual analysis, pre-1979 policy in the post-1979 period would have left the economy vulnerable to amplified economic fluctuations. Therefore, we conclude that the Great Moderation is also the product of good policy associated with the Fed's inflation stabilization goal. Improved understanding about the structure of the economy would have fallen short at reproducing the decrease in volatility of the Great Moderation. Consequently, we explore the possibility of having appointed a central banker with hawkish preferences during the Great Inflation period. We find that this period of exacerbated volatility could have not been averted solely by having a central banker with stronger preference for inflation stabilization; at least not under the prevailing economic understanding at the time described in Romer and Romer (2002) and illustrated by the central bank learning dynamics in our model.

In regard to the effect of the volatility of the shocks, our results show that supply shocks were definitely a destabilizing force during the 1970s but demand and monetary policy shocks were main drivers of output and inflation after 1975; especially during Volckers' experiment. We believe that not accounting for time variation in the volatility of the non-policy shocks would yield an incomplete analysis because of their historical contribution to the dynamics of our macroeconomic variables. To be precise, the most pronounced effect on the volatility of output would come from a non-policy shock with high volatility present in the economy. Moreover, a lower volatility non-policy shock through the whole sample would have resulted in lower inflation during 1970s, providing evidence of the contribution of the "good luck" hypothesis to the Great Inflation. We believe that a natural extension of this model is not only to have policymakers learning, but agents that are learning about the structure of the model and forming expectations accordingly which is in our future plans.

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