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

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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/or 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 DSGE model. The empirical results show that accounting for changes in the volatility of the shocks in a model that allows for real-time learning by policymakers improves the fit of the model to the U.S. data. In fact, the model captures the non-policy related high volatility periods experienced in the 1970s and early 1980s. 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. data, and to understand Federal Reserve behavior during the Great Inflation.

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

JEL Classifications: C11; D83; E31; E50; E52; E58; E32; E44

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1 INTRODUCTION

The evolution of U.S. 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 explains shifts in the monetary policy instruments is an area of research that deserves further attention. Are shifts in the policy instrument due to changes in macroeconomic understanding of the structure of the economy [e.g. Sargent (1999) and Primiceri (2006)] and/or were there changes in policymakers preferences toward output gap vs inflation stabilization at key turning points in the conduction of monetary policy? The combination of both possible explanations has been discussed in Best (2016), and time-varying changes in the latter have been considered in Dennis (2006) and Lakdawala (2016).

On the other hand, Sims and Zha (2006) find evidence of time variation in the disturbance variances of the shocks that hit the economy as the main determinant of U.S. macroeconomic performance. Bianchi (2013) makes an important addition to this literature by considering regime changes not only 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 macroeconomic dynamics in the U.S. post war period. 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.

In this paper we build on the existing literature that combines the bad policy vs bad luck hypotheses. The contribution of this paper is to study if the Fed's evolution of policy decisions is the product of a real time *learning* process about the structure of the economy [Primiceri (2006); Sargent (1999); Orphanides (2005); Lubik and Matthes (2016)] and/or if there were changes in *preferences* toward inflation stabilization by the Fed in the post-1979 period [e.g., Dennis (2006) and Best (2016)], in the presence of possible changes in the *volatility* of the structural monetary and non-monetary shocks [e.g., Bianchi (2013) and Hur (2016)]. We contribute to the literature by combining the three possible hypothesis which allows us to evaluate the relative contribution of each one to the explanations to the Great Inflation—specifically to the disinflation process—and to the Great Moderation.

In regard to the *learning* and change in *preference* hypotheses, we make additional contributions by dissecting their role in the monetary policy instruments as well as the part played by the time varying volatility of the monetary policy shocks—interpreted as deviations from the monetary rule—in the post-war US macroeconomic dynamics. Our findings suggest that i) the interplay between changes in preferences and learning behavior affects the determinacy conditions in the model and consequently the response of the output gap and inflation to a monetary policy shock;[1] ii) monetary and non-monetary policy shocks are tantamount contributors to the Great Inflation. Therefore, monetary policy determinants and non-monetary policy shocks explain the Great Inflation.

We are also able to 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. The literature has looked at three possible sources of the Great Moderation: (i) changes in the structure of the economy, (ii) good luck and (iii) good policy. As Bernanke (2004) noted, each of the three classes of explanation 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 perform a series of counterfactual experiments under alternative learning, monetary preferences, and shock assumptions to assess the role of better policy on the Great Moderation period.[2]

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. We find that learning and a change in policy preference are key to characterize movements in the Fed's monetary policy instrument during the period of study. 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 in the presence of possible time-varying changes in the Fed's understanding about the structure of the economy. Consistent with previous studies, we are able to capture the accommodative response to inflation during parts of the 1960s

[1] Determinacy is deemed the existence and uniqueness of rational expectations equilibrium (REE).

[2] 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.

and 1970s and before the Great Recession.

Lastly, we are also able to disentangle the contribution of the various shocks to the Great Inflation. We find that supply shocks were definitely destabilizing forces driving inflation and output during the 1970s but demand and monetary policy shocks had key contributions to output and inflation dynamics after 1975; especially during Volckers' experiment.

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.[3] 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:

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

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

[3] $\sigma > 0$ 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. 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).[4] Policymakers estimate 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_w, λ_x, and λ_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:

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

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.[5] 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 $\hat{Z} = [\hat{b}_4, \hat{c}_4, \hat{d}_4, \hat{b}_8, \hat{c}_8, \hat{d}_8]'$ 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.

The optimization constraints have the following state-space representation:

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

[4] 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.

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

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.[6] 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.[7] 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 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:

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

The solution to the policy problem is a function of the perceived VAR parameters $\hat{\phi}_t = [\hat{c}_y, \hat{b}_1, \hat{b}_2, \hat{b}_3, \hat{b}_4, \hat{b}_5, \hat{b}_6, \hat{b}_7, \hat{b}_8, \hat{c}_\pi, \hat{c}_1, \hat{c}_2, \hat{c}_3, \hat{c}_4, \hat{c}_5, \hat{c}_6, \hat{c}_7, \hat{c}_8, \hat{c}_w, \hat{d}_1, \hat{d}_2, \hat{d}_3, \hat{d}_4, \hat{d}_5, \hat{d}_6, \hat{d}_7, \hat{d}_8]'$ and the state variables z_t. The value for the optimal monetary policy variable i_t will embed the policymakers' beliefs about the state of the economy. Notice that these beliefs influence the direction of the

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

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

economy through i_t.

The policy rule (14) can be rewritten as

$$i_t = F_{x1}x_t + F_{x2}x_{t-1} + F_{\pi 1}\pi_t + F_{\pi 2}\pi_{t-1}t + F_{w1}\pi_t^w + F_{w2}\pi_{t-1}^w + F_{il}i_{t-1}^f. \quad (15)$$

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)].[8] Agents believe that policymakers will continue to implement policy based on their last estimate of (15).[9] Notice that the private sector in this economy has rational expectations and takes the central bank's optimal policy rule as given, similar to Sargent (1999). Therefore, assuming that estimates $F(\hat{\phi}_t)$ in (14) will remain fixed into the future. Since the parameters in $F(\hat{\phi}_t)$ 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 rational expectations. The next section jointly estimates the model's parameters using Bayesian methods.

4 Estimation Strategy

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

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

[9] 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 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

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. Following Marcet and Nicolini (2003), Milani (2014) and Best (2016), we allow for 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.[10] The preference parameters evolve according to the following: $\lambda_{\varpi,t} = \begin{cases} \mu_1 \quad \lambda_{\varpi,pre-1979} & 1960:Q2 \leq \text{t} \leq 1979:Q2 \\ \qquad \lambda_{\varpi,post-1979} & 1979:Q3 \leq \text{t} \leq 2008:Q1 \end{cases}$ where ϖ=x, w, i. The remaining structural parameters are estimated for the full sample.

The main contribution of this paper is to 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. Best (2016) finds that the model that accounts for a change in the volatility of the SDs in 1984 fits the data better. However, Best (2016) only considers the possibility of a discrete change in volatility in 1984. In the present paper we allow for 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, it allows us to test explicitly the role of changes in the volatility of the shocks during the period, and compare their contribution relative to monetary policy in propagating and ending the Great Inflation. In fact, we can disentangle if "good policy" or "bad policy" were the product of monetary policymakers'

[10]There is a possibility that there were additional monetary policy regime changes during our sample of study, however, accounting for those in the present setting will complicate the estimated algorithm considerably.

preferences toward inflation/output gap stabilization, or if it was due to their real time learning about the structure of the economy.

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 uses 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) *gensys* 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 non-policy and monetary 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 non-policy and monetary 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.

We estimate the set of private sector structural parameters, the policy preference parameters, and the gain coefficient **g** using Bayesian techniques [An and Schorfheide (2007)]. The private sector model parameters include the structural parameters and corresponding standard deviations of the shocks.

The VAR model parameters, estimated using the learning algorithm constitute the policymakers' beliefs about the structure of the economy. The gain coefficient was estimated and not fixed to avoid obtaining results (including preference parameter estimates) dependent on parameters chosen by the researcher. 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). 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

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]
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.

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.[11]

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 (2016).

5 RESULTS

5.1 POSTERIOR ESTIMATES Table 2 presents posterior probability means for the structural parameters in the DSGE model. 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 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 consistent with 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 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 is consistent with the inflation stabilization goals persistent in the post-Volcker period documented in the literature.

The structural parameters in the DSGE model assume plausible values similar to previous Bayesian estimations of New Keynesian DSGE models for the United States [Lubik and Schorfheide (2004), Milani (2007, 2011), Milani and Treadwell (2012), Smets and Wouters (2007), Slobodyan and Wouters (2014)].

The benchmark model also captures shifts in the volatility of the non-policy and policy shocks

[11] 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: Posterior distributions for the estimated parameters.

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.

motivated by the literature on the Great Moderation. The results presented in Figure 1, 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 are role to "good luck" in the determination of U.S. dynamics.

With reference to the bottom panel, we observe short occurrences of high volatilty in the early, mid, and late 1970s, and a prolonged period that includes "Volcker's experiment," and ends at the

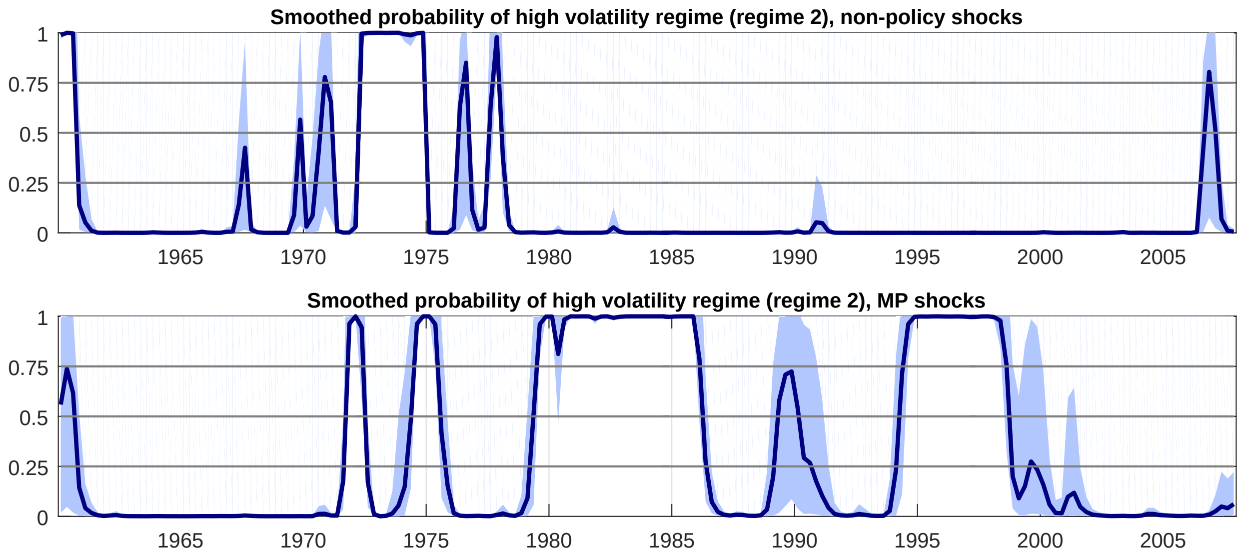

Figure 1: [Upper panel] Posterior smoothed probability estimates of the high non-policy shock volatility regime. [Lower panel] Posterior smoothed probability estimates of the high monetary policy shock volatility regime. In each figure, mean (solid line) and 95% interval (shaded area) are reported.

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.

The data are also informative in the estimation of the gain coefficient **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 economy, supported by the uncertain economic climate, this is entirely consistent with Figure 1. 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

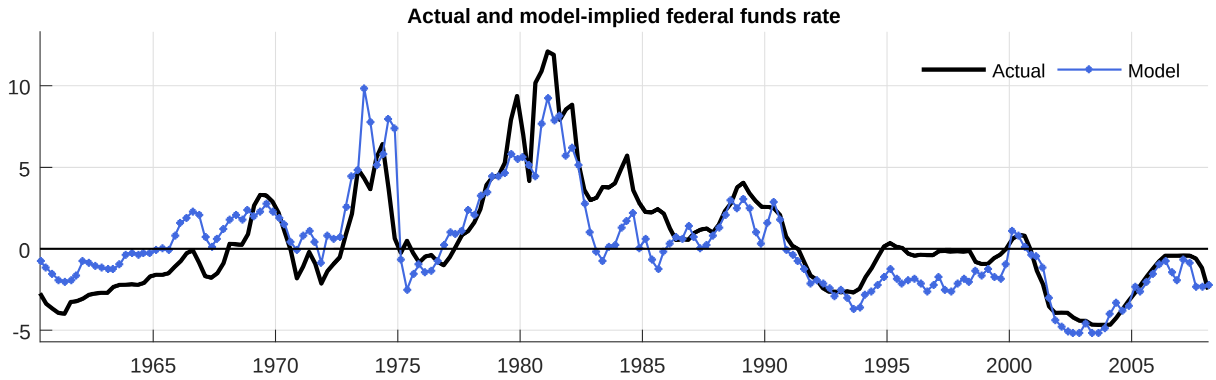

Figure 2: Actual (solid line) and model-implied (solid line with circles) federal funds rate. The model-implied series is evaluated at the mean of posterior parameter estimates.

1980s to revert to a decreased gain later. Thus, policymakers' learning in this paper coincides with agents' speed of learning patterns (see Milani (2014)) over the sample studied.

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

To grasp the monetary policy strategy followed by policymakers in the benchmark model, the bottom panel of Figure 2 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 closely follows the behavior of the federal funds rate in the period of study, 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 taken 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 not growth was occurring or expected. Note that this optimal policy variable is a product of policymakers' learning and the change in the policy preference parameters 1979 estimated in the paper.

5.1.1 HISTORICAL DECOMPOSITIONS

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 an major role in the determination of output before

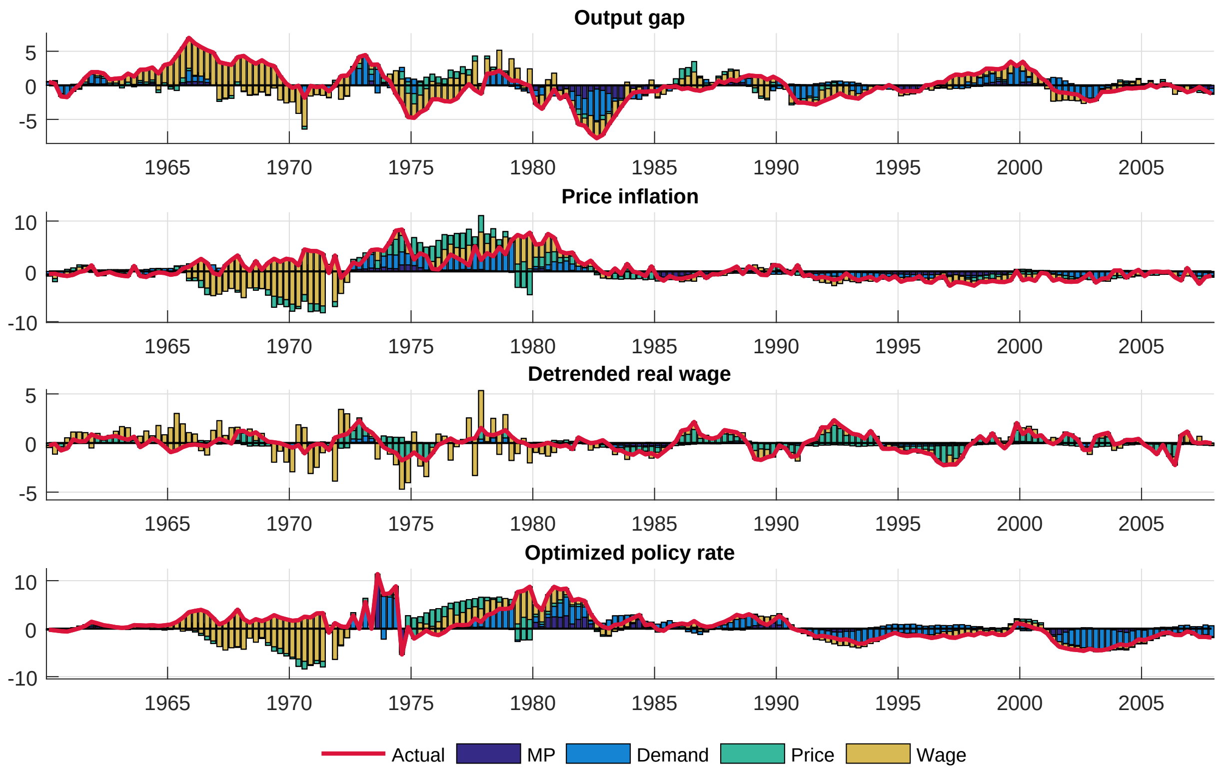

Figure 3: Shock decompositions. Posterior mean estimates are reported.

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 shocks has a significant importance in the early 1980s during Volcker's disinflation.

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 become important. 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 seem to be driven by supply shocks.

Lastly, supply shocks influenced monetary policy during the Great Inflation, however shortly before the mid 1970s and after 19777 monetary policy appear to be driven by demand shocks and/or exogenously driven.

5.1.2 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, we study their implied optimal interest rate responses. Of note, the interest rate responses are reduced-form representations of policymakers' behavior and their responses

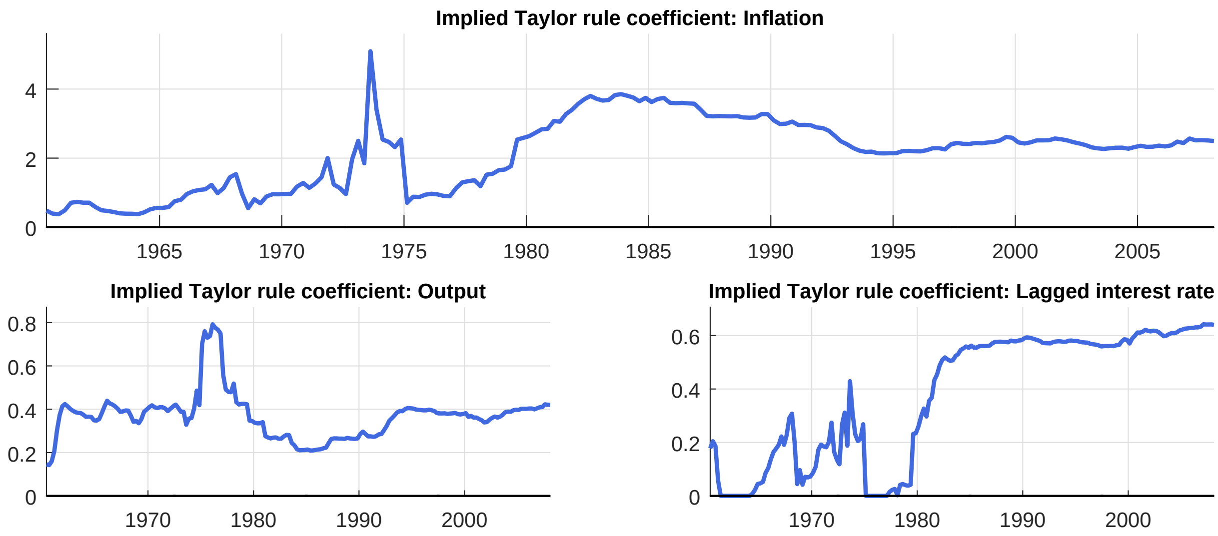

Figure 4: Model-implied Taylor rule coefficients for inflation, output and lagged interest rate. The model-implied series is evaluated at the mean of posterior parameter estimates.

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.

Figure 4 (top) presents the response to inflation (price and wage combined), and (bottom) presents the response to the output gap and interest-rate-smoothing term in the time-varying policy reaction function implied by (15).[12]

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 and the term structure of interest rates. The time-varying coefficient on inflation is also consistent with 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

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

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. This bad policy response could be justified by the Fed's explicit preference for output gap stabilization during the Great Inflation. We find further support to DeLong (1997) that policymakers, during that time, did 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 evidence of perceived changes in the structure of the economy by policymakers in the model that could contribute to the so called bad policy. Figure 5 plots our determinacy indicator evaluated at the mean of the posterior parameter estimates where $2 = determinacy$. Determinacy is prevalent in the post-Volcker period and during the 1974 disinflation policy. Although this is not the main focus of this paper, subsection 5.2 further explains how the determinacy results (i) change with the policy preference parameters and learning assumptions considered, and (ii) have implications for the transmission mechanisms for monetary policy, therefore they are key element to explain macroeconomic dynamics.

Figure 4 (bottom) 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

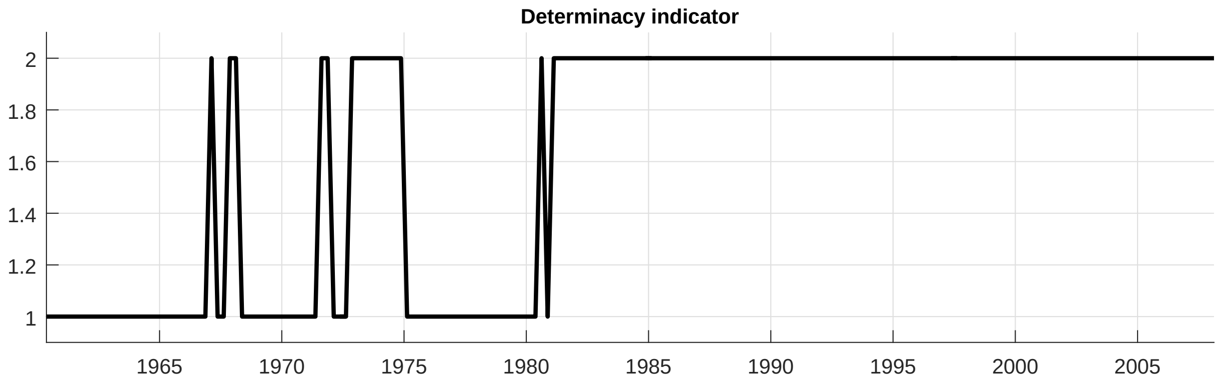

Figure 5: Determinacy of the model, evaluated at the mean of posterior parameter estimates.

to real economic conditions during the 1990s. 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 Figure 4 (bottom). This parameter increases after 1979 consistent with Boivin (2006), Kim and Nelson (2006), and Coibion and Gorodnichenko (2012).

5.2 COUNTERFACTUALS AND IMPULSE RESPONSE ANALYSES

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

5.2.1 COUNTERFACTUAL ANALYSIS FOR ALTERNATIVE WEIGHTS IN THE CENTRAL BANK LOSS FUNCTION

Figure 6 present the counterfactual series obtained by fixing the policy preference parameters to their pre-1979 values ($\lambda_x = 0.41$), ($\lambda_w = 0.10$), and ($\lambda_i = 0.93$). The relatively higher response to output, and relatively lower response to wage inflation, results in an optimized policy rate that is lower than the fed funds rate, and completely misses the Volcker dis-

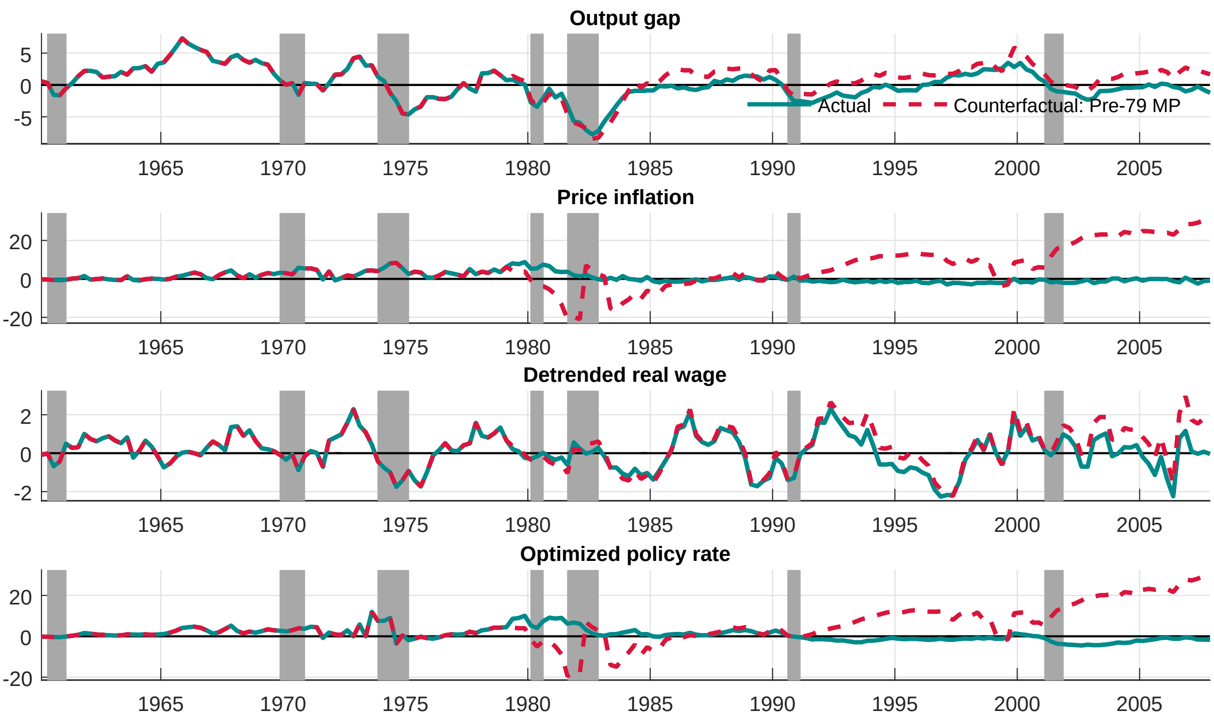

Figure 6: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the pre-79 MP is maintained over the entire sample period. Posterior mean estimates are reported.

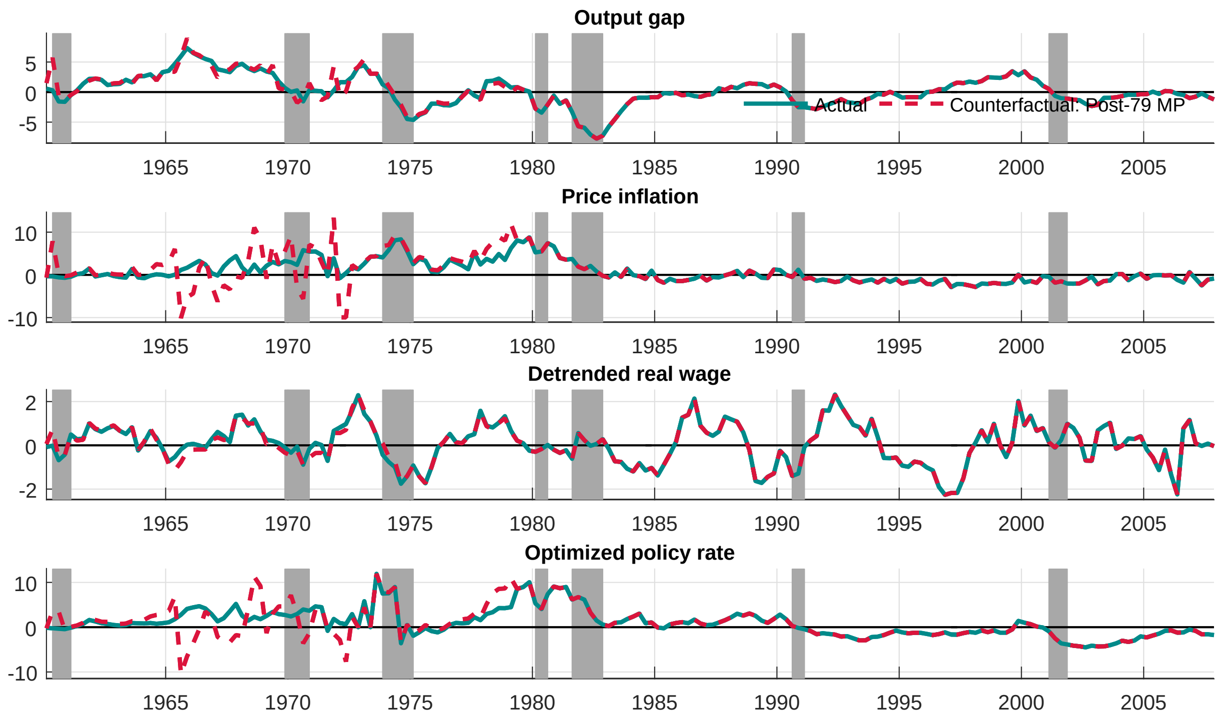

Figure 7: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the post-79 MP is maintained over the entire sample period. Posterior mean estimates are reported.

inflation effort of the late 70s and early 80s. It also implies a higher policy rate in the 1990s and 2000s. The inflation response to this low policy parameter is consistent with the price puzzle and our impulse response analysis further explains this point.

Figure 7 presents the counterfactual model implied series for preference parameters set to their post-1979 level $(\lambda_x = 0.03)$, $(\lambda_w = 0.25)$, and $(\lambda_i = 0.77)$. The relatively higher preference for inflation stabilization as well as the lower interest smoothing parameter result in optimized policy rate that is more volatile and in many occasions higher than the actual federal funds rate from 1965 to the late 1970s. However, even under this post-1979 optimal policy preference parameters in the pre-1979 period indeterminacy is present, leading to the price puzzle.

5.2.2 IMPULSE RESPONSE ANALYSIS FOR ALTERNATIVE WEIGHTS IN THE CENTRAL BANK LOSS FUNCTION

There is an additional result associated with our policy counterfactuals: As previously discussed in Lubik and Matthes (2016),we find indeterminacy prevailing in several periods before Volcker's disinflation as in Clarida et al. (2000), Lubik and Schorfheide (2004), and Ang et al. (2011). Our results also suggest that pre-1979 indeterminacy is associated with the emergence of the price puzzle. This is consistent with Castelnuovo and Surico (2010) where a positive response of prices to a monetary shock is limited to sub-samples (pre 1979:Q3 before the

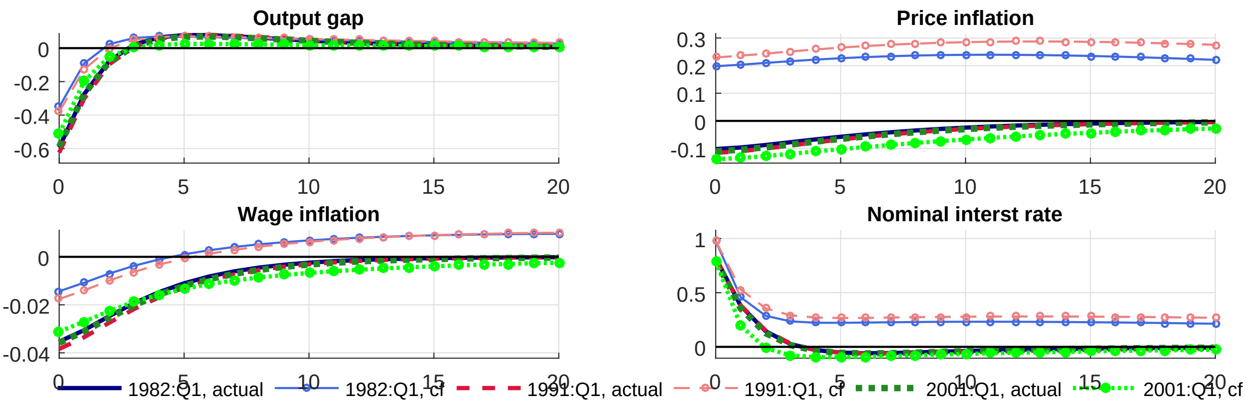

Figure 8: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the pre-1979 monetary policy preference. The x-axis is in quarters.

appointment of Chairman Volcker to the Fed) where a weak interest rate response to inflation has been found.

Figure 8 shows that the benchmark parameters, with a relatively lower policy preference for output gap stabilization and a higher preference for inflation stabilization estimated for the post-Volcker sample lead to determinacy, and impulse response functions supportive of the traditional demand channel of monetary policy. In fact, Figures 9 and 10 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 for has non-negative effect on the interest rate and inflation and a non-postive effect on the output gap. However, pre-1979 policy preferences in the post-1979 period would have led to indeterminacy and to the occurrence of the price puzzle.

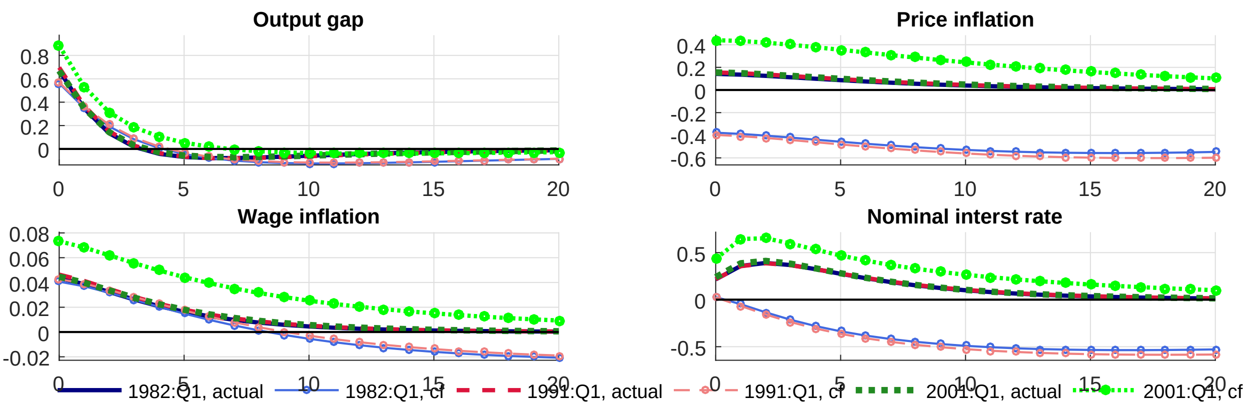

Figure 9: Impulse responses to a demand shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the pre-1979 monetary policy preference. The x-axis is in quarters.

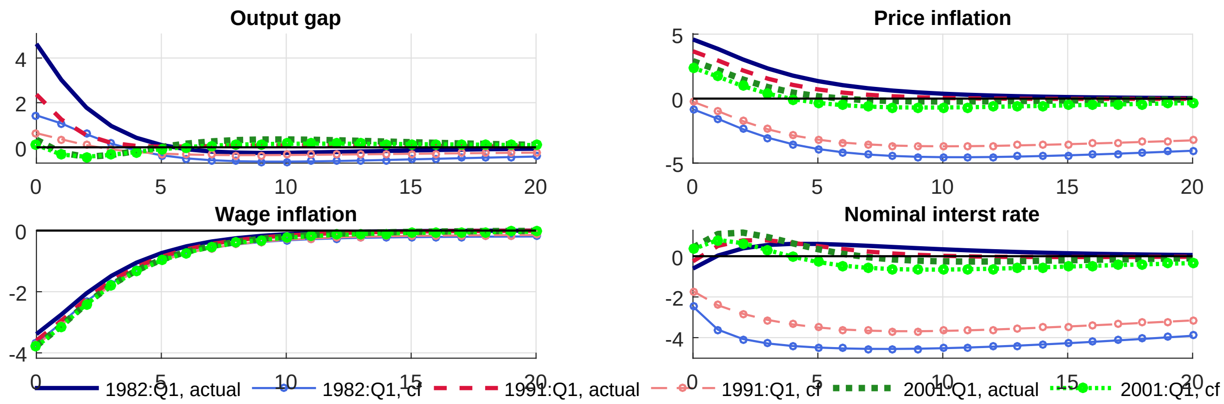

Figure 10: Impulse responses to a price shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the pre-1979 monetary policy preference. The x-axis is in quarters.

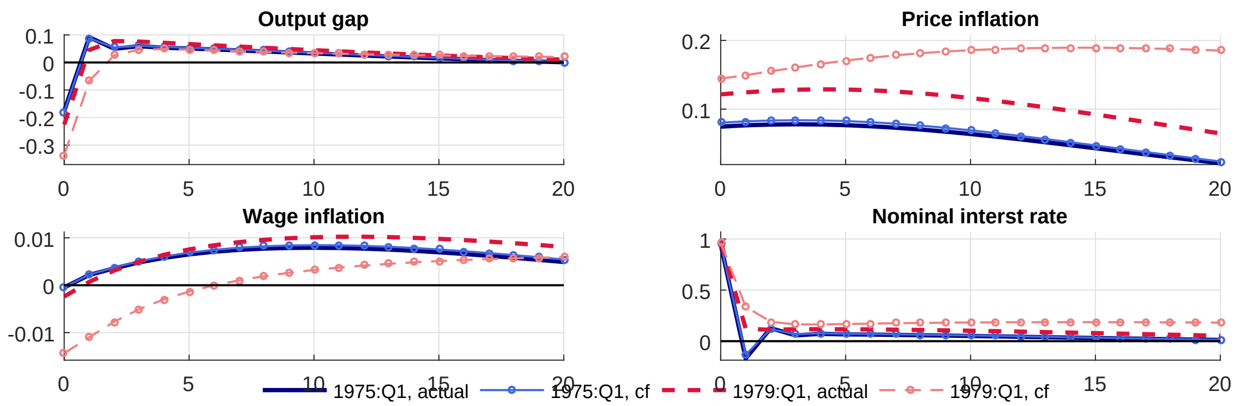

Figure 11: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the post-1979 monetary policy preference. The x-axis is in quarters.

Figure 11 shows the impulse responses to a monetary shock for a counterfactual scenario that assumes post-1979 optimal policy preferences in the pre-Volcker period. The results are somewhat negative but not surprising. Even under a stronger preference for inflation stabilization the picture is still consistent with indetermiacy and the price puzzle.[13] This result gives a pre-amble to our counterfactual section that suggest that learning is essential to our policy understanding and its effect on the post-war economic dynamics.

5.2.3 Counterfactual Analysis for Alternative Learning Assumptions

We will start by describing the effect of alternative learning scenarios on output gap, price and wage inflation, and the optimal policy rate. Figure 12 shows the counterfactual scenario where the pre-1979 gain coefficient of 0.013, that governs the speed of learning, prevails over the entire sample. This

[13]Determinacy indicators for the counterfactual experiments with pre and post-1979 weights in the post and pre-1979 periods respectively are included in the Appendix.

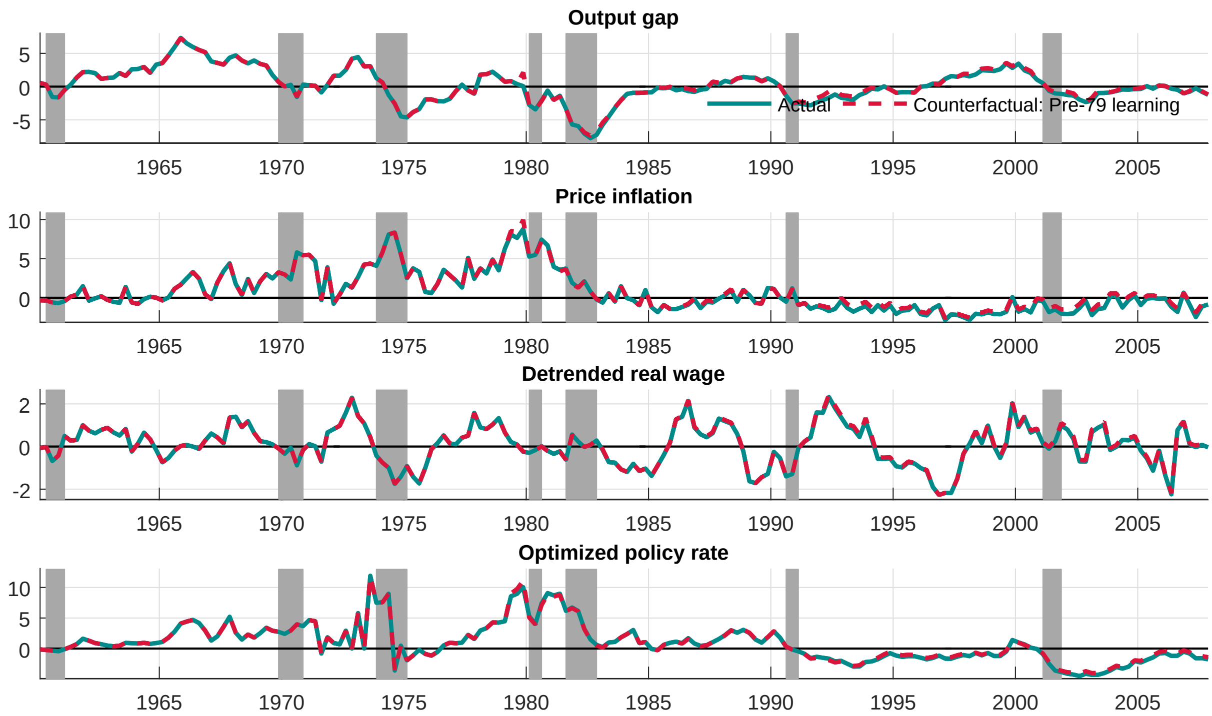

Figure 12: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the pre-79 learning is maintained over the entire sample period. Posterior mean estimates are reported.

gain is relatively higher to the gain estimated for the post-1979 period, and the former implies that policymakers would assign higher weight to more recent observations due to the suspicion of an unstable economic environment; such economic climate can be confirmed by the persistently high volatility shocks present in the pre-1979 period. The effect of a higher gain in the counterfactual post 1979 series is almost negligible; the difference between the actual and counterfactual series are small and oscillate around zero. The most noticeable effect of a higher gain would have been a slightly higher optimal policy variable than the federal funds rate in the late 1970s.

Figure 13 shows the effects of the counterfactual scenario fixing the gain to its post 1979 (0.009) value over the entire sample. We can observe that a lower gain, usually estimated for periods of less economic instability, would have resulted in 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 slightly 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. Our counterfactual model implied series shows that a lower gain in the pre-1979 era would have resulted in a considerably lower policy variable in the 1970s that would have further increased inflation in

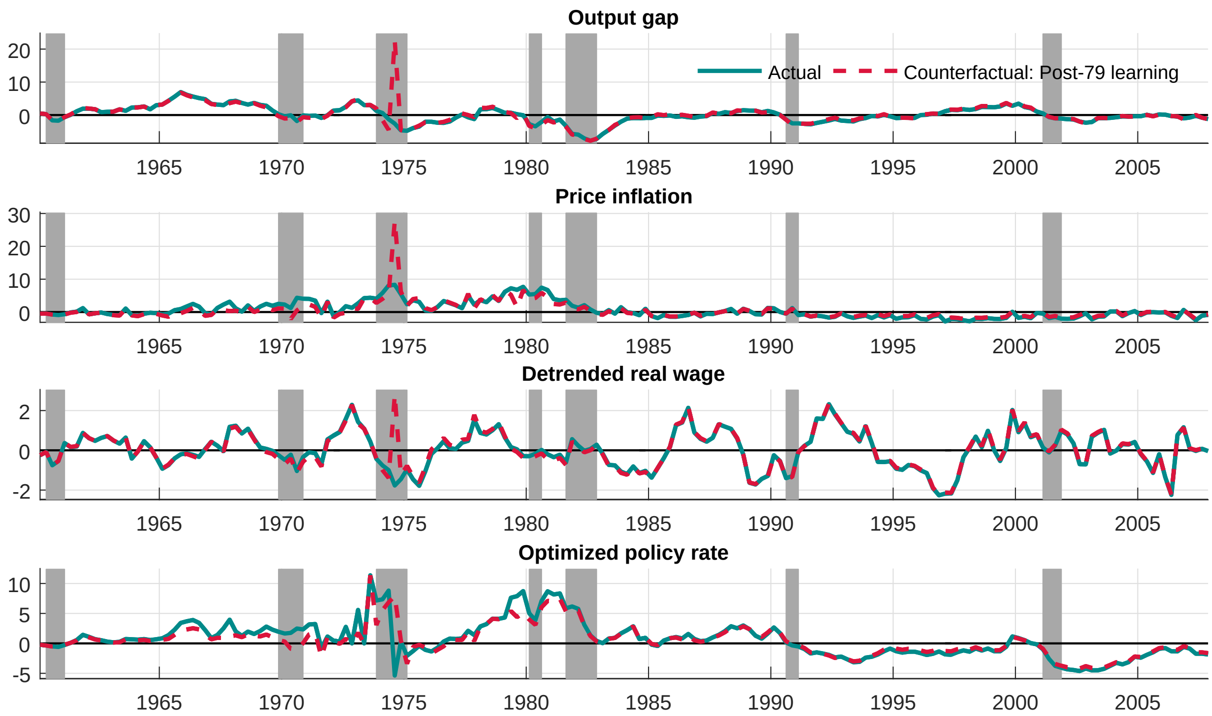

Figure 13: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the post-79 learning is maintained over the entire sample period. Posterior mean estimates are reported.

the mid 1970s; moreover a higher gain of 0.013 early in the Volcker's disinflation period would have resulted in a somewhat higher policy rate. In fact, the response of the output gap, and wage and price inflation to a monetary policy shock varies with the determinacy regime at hand, which is the product of changes in policy preferences **and** changes in beliefs about the structure of the economy.

Figure 14 shows impulse responses to a monetary policy shock under the benchmark model

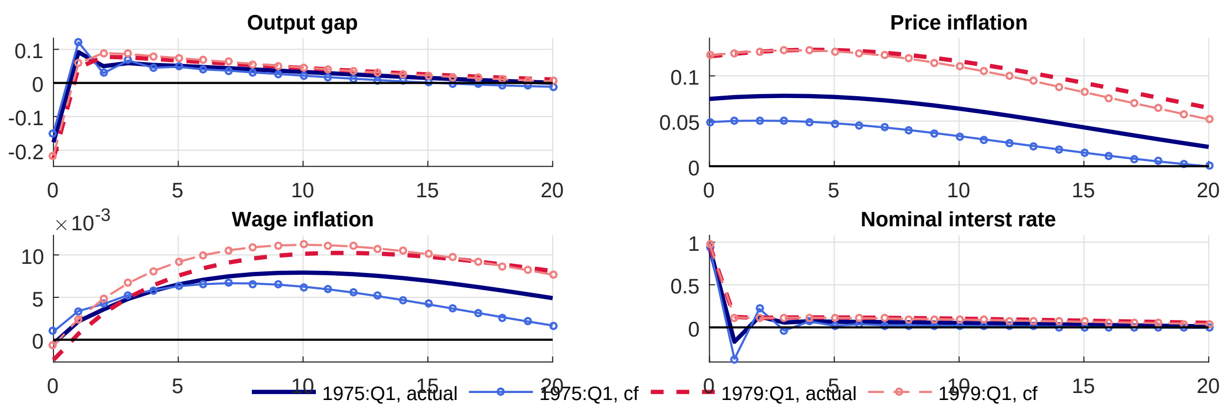

Figure 14: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes post-79 learning over the entire sample period. The x-axis is in quarters.

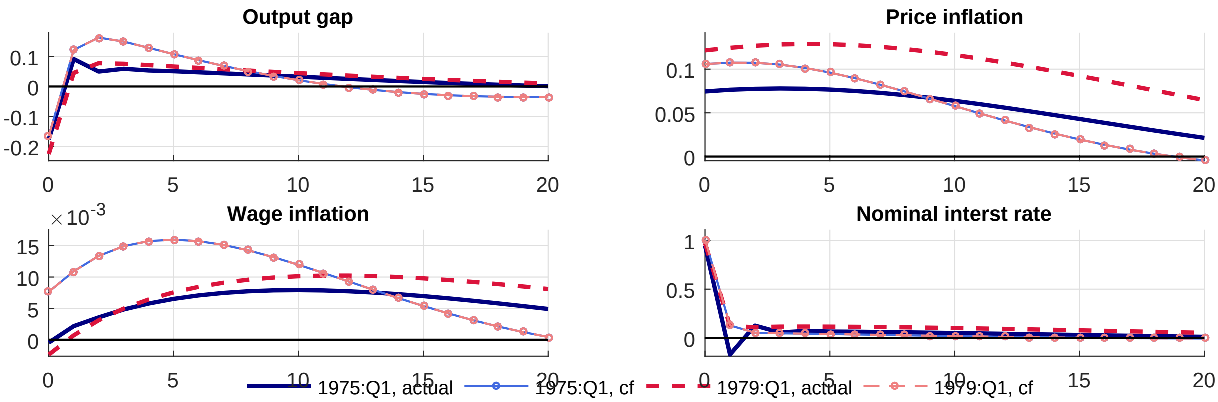

Figure 15: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes no learning over the entire sample period. The x-axis is in quarters.

and the counterfactual scenario that assumes learning under a post-1979 gain coefficient in the pre-1979 period. The price puzzle emerges in here as well and the impulse responses are sensitive to the gain parameter assumed. To further illustrate the previous point, we also conduct impulse response analyses under the counterfactual scenario of no learning, meaning that policymakers' beliefs about the structure of the economy remained static over the sample and the gain coefficient is 0; Figures 15 and 16 show responses to a policy shock pre-1979 and post-1979 respectively. In Figure 15, a period consistent with indeterminacy, we can observe the reappearance of the price puzzle, and that the counterfactual impulse responses are different from the benchmark due to our alternative learning assumption. Figure 16, moreover, illustrates that in the post-Volcker period, no change in beliefs about the structure of the economy would have resulted in indeterminacy and the appearance of the price puzzle, while the benchmark parameters are consistent with determinacy and the traditional response to a monetary shock. Thus changes in the speed of learning, have an effect on determinacy and the response to a monetary shock in the pre- **and** post 1979 periods.

This finding shed light on some important fact emphasized in Lubik and Matthes (2016), Sargent (1999) and Primiceri (2006): learning plays a key role in the determination of policy during the Great Inflation, even when the central bank would have as objective to stabilize inflation relative to output. Learning was essential to the transmission mechanism of monetary policy, because even under post-1979 policy preferences, we would have experienced multiple equilibria and undesirable amplified economic fluctuations.[14]

[14]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).

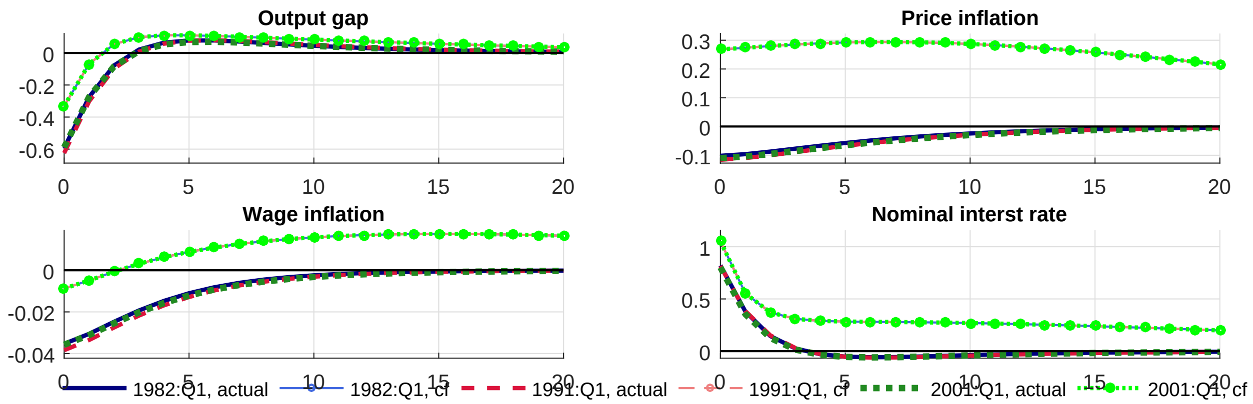

Figure 16: Impulse responses to a monetary policy shock, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes no learning over the entire sample period. The x-axis is in quarters.

5.2.4 COUNTERFACTUA ANALYSIS FOR ALTERNATIVE NON-POLICY SHOCK VOLATILITY REGIME

Figure 17 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 over the entire sample, amplifying the recessions of 1975, early 1980s, and 1991. We also observe a period of higher positive output gap in 1965 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 insignificant.

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 18 presents a counterfactual scenario that assumes the low non-policy shock volatility regime prevailing over the entire 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 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.

5.2.5 STANDARD DEVIATIONS OF ACUTAL AND COUNTERFACTUAL SERIES

In this section, we compute the volatilities of actual and counterfactual output gap and inflation for the scenarios

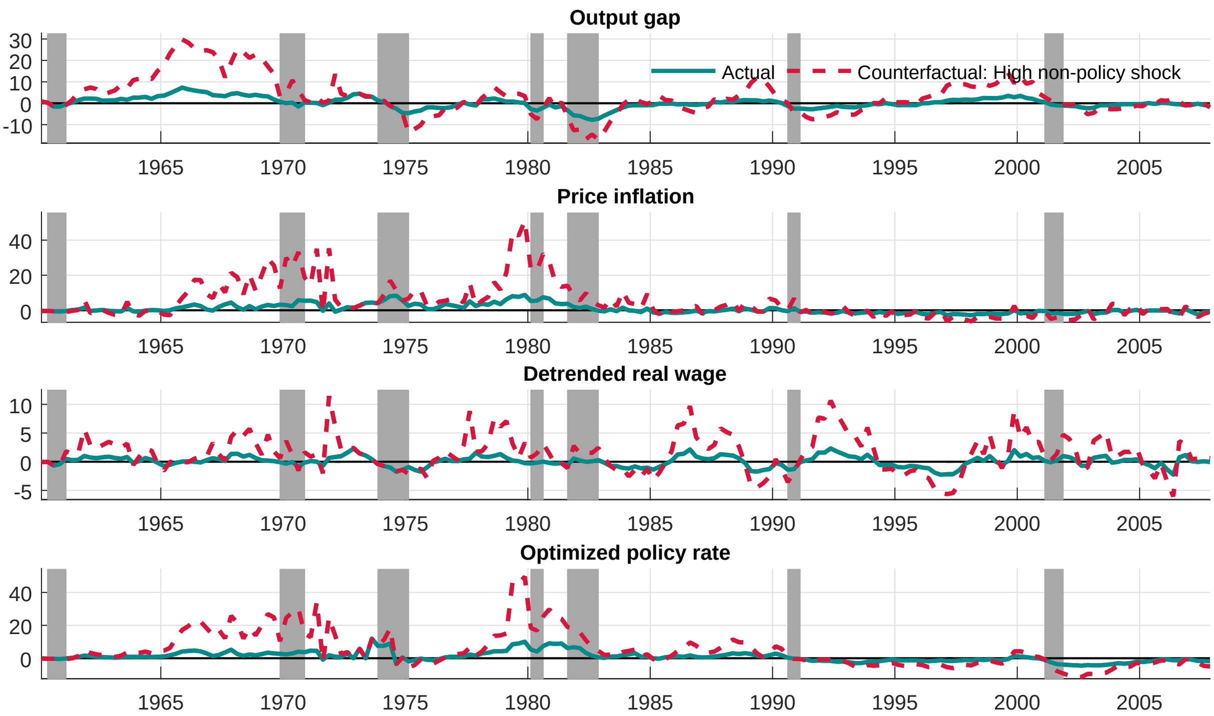

Figure 17: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the high non-policy shock volatility regime prevails over the entire sample period. Posterior mean estimates are reported.

considered in the previous sections. Pre-79 learning, consistent with Figure 12, 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

Table 3: 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.

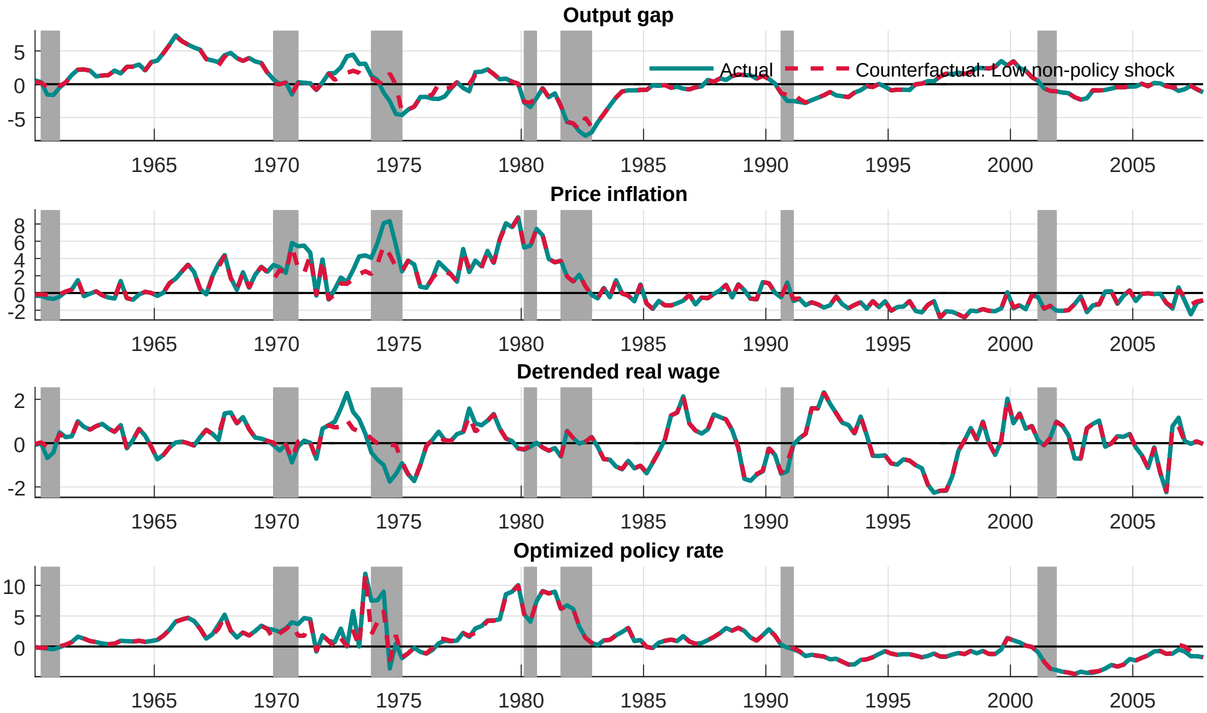

Figure 18: Actual (solid lines) and counterfactual (dashed lines) model-implied series. The counterfactual scenario assumes that the low non-policy shock volatility regime prevails over the entire sample period. Posterior mean estimates are reported.

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 non-policy shock would have cut output gap's volaitlity 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 played an integral role at 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 found evidence of a marked 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 also find supporting evidence of having rational policy-makers 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, however, its effect on inflation and output depend on its potential to induce indeterminacy. Regarding Sims (2012) kitchen fire analogy, our results suggest that good monetary policy may limit the adverse effect of even a major shock, as our counterfactual analysis shows. Pre-1979 policy in the post-1979 period would have left the economy vulnerable to amplified economic fluctuations in the presence of multiple equilibria. This could have also occurred if our economic understanding would have not improved over time as described in Romer and Romer (2002) and illustrated with our learning counterfactuals.

In regards 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. 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. The effect of the high non-policy volatility shocks on inflation and the output gap during the Great Moderation would have been less pronounced.

A Counterfactual Determinacy

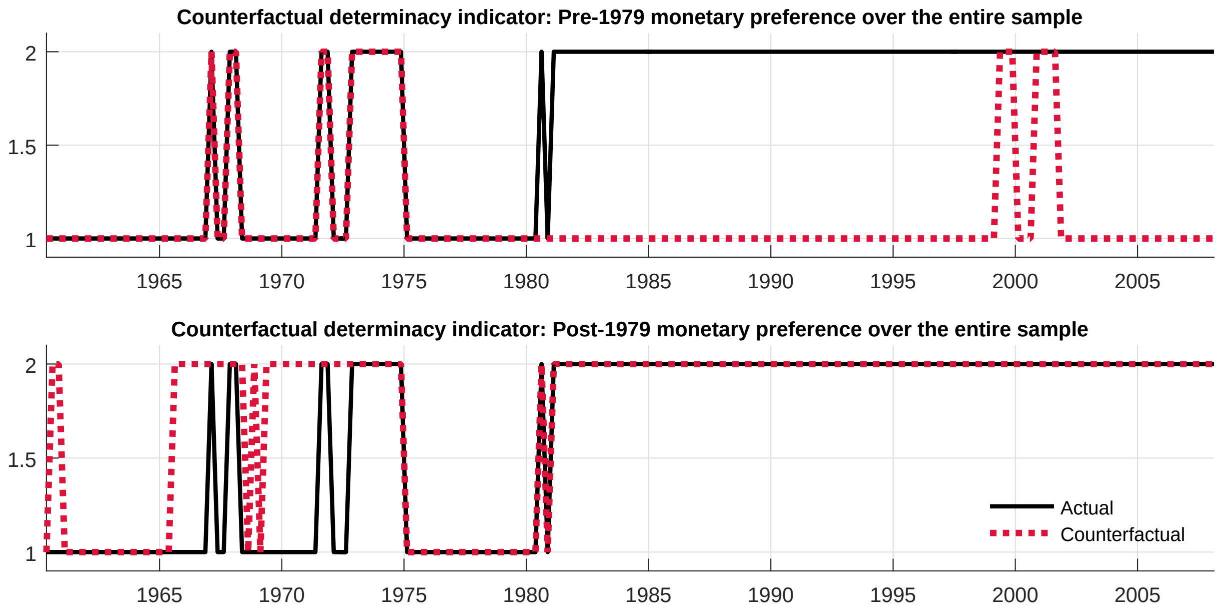

Figure 19: Actual (solid lines) and counterfactual (dashed lines) determinacy indicators, evaluated at the mean of posterior parameter estimates. The counterfactual scenario assumes the pre-79 (upper panel) and post-79 (lower panel) monetary policy preferences, respectively, over the entire sample period.

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