THE EVOLUTION OF U.S. MONETARY POLICY:
2000 - 2007

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ABSTRACT

A vector autoregression with time-varying parameters is used to characterize changes in Federal Reserve policy that occurred from 2000 through 2007 and describe how they affected the performance of the U.S. economy. Declining coefficients in the model's estimated policy rule point to a shift in the Fed's emphasis away from stabilizing inflation over this period. More importantly, however, the Fed held the federal funds rate persistently below the values prescribed by this rule. Under this more discretionary policy, inflation overshot its target and the funds rate followed a path reminiscent of the "stop-go" pattern that characterized Fed behavior prior to 1979.

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Introduction

The years from 2000 through 2007 lie between two remarkable, but very different, episodes in United States economic history. The period from the mid-1980s through 2000 exhibited extraordinary macroeconomic stability and came to be known as the "Great Moderation."[1] December 2007, on the other hand, marked the beginning of the "Great Recession," a period of economic and financial turmoil of a kind not seen in the U.S. since the Great Depression. The timing of these events, and the sharp contrast between them, suggest that something fundamental must have changed between 2000 and 2007.

The statistical analysis presented here is directed at assessing the role monetary policy may have played as a possible source of that change. Its focus on monetary policy is motivated by two interrelated sets of considerations. First, a host of studies, including Clarida, Gali, and Gertler (2000), Gali, Lopez-Salido, and Valles (2003), Lubik and Schorfheide (2004), and Boivin and Giannoni (2006), present evidence that links the improved performance of the U.S. economy during the Great Moderation to better monetary policymaking. In particular, these studies find that, in the early 1980s, monetary policy began to place more emphasis on stabilizing inflation and less on stabilizing output and employment. These studies go on to argue that this shift in the Federal Reserve's focus removed monetary policy itself as a source of business cycle

[1] Kim and Nelson (1999), McConnell and Perez-Quiros (2000), and Stock and Watson (2002) establish 1984 as the starting date for this period. Although there is, as yet, no similar consensus as to when the Great Moderation came to a close, it suffices for now to note that over the 16 years that followed, steady growth in aggregate income and employment was interrupted by only one, relatively minor, recession lasting from March through November 1991.

fluctuations and helped the economy respond more efficiently to a range of non-monetary disturbances. If these arguments are correct, a shift in emphasis back towards smoothing fluctuations in the real economy around 2000 may have created conditions conducive to the reemergence since then of monetary disturbances as a source of inefficient fluctuations.

Taylor (2009) offers a different interpretation of events by arguing that the Federal Reserve began to deviate persistently from the prescriptions of his original (1993) rule and, in so doing, set the stage for the financial crisis of 2007 and the Great Recession that followed. His (2009) comparison of the actual trajectory of the federal funds rate from 2000 through 2007 against the values prescribed by his original (1993) rule suggests that monetary policy had been too accommodative over most of this period and fueled a boom-bust cycle in housing and other interest-sensitive sectors of the economy.[2] In short, Taylor's argument is that the Fed abandoned the guidance of a rule and returned to policy actions guided by "discretion" instead.[3]

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[2] Barnett (2012, pp.133-134) also blames the housing boom on overly expansionary monetary policy in the years following 2001, arguing that Federal Reserve officials might have noticed this error had they used appropriate measures of money instead of the federal funds rate to gauge the stance of their policies. That restrictive monetary policy preceded the onset of recession in 2007 is an argument also made by Hetzel (2009, 2012).

[3] The contrast drawn here between "rules" and "discretion" comes closest to the distinction as it is made by Taylor (1993, pp.198-199): The former refers to the policymaker's systematic response to changes in the economy as summarized by a small number of state variables, such as inflation and the output gap, whereas the latter alludes to less predictable actions motivated, perhaps, by the policymaker's own judgment. In contrast, Barro and Gordon's (1983) theoretical framework characterizes a "discretionary" policymaker as one who sets inflation too high in order to exploit a Phillips curve trade-off, but still

This paper attempts to draw distinctions between these alternative interpretations of how the Federal Reserve implemented its policy decisions during the period from 2000 through 2007. To this end, it estimates a vector autoregressive time series model with time-varying parameters and stochastic volatility using Bayesian methods introduced and outlined by Cogley and Sargent (2005) and Primiceri (2005). The equation for the interest rate in this model takes the same general form as the Taylor (1993) rule, but imposes fewer constraints on the dynamics with which the Federal Reserve adjusts its target for the funds rate in response to changes in the economy. Thus, the model is capable of capturing a range of ways in which monetary policy can change and, in particular, distinguishes between whether the central bank adjusted the strength of its systematic responses to inflation versus output (or unemployment) and whether it deviated from that systematic behavior to a greater or lesser extent. Because it embeds this version of the Taylor Rule within a simultaneous-equation system, however, the model can be used to investigate a more general question: How changes in monetary policy during this period affected inflation and output as well the short-term interest rate. The model sheds light, in particular, on whether macroeconomic conditions leading up to the Great Recession might have evolved differently if the Fed had not changed the weights it put on inflation versus output in the estimated rule or if it had not deviated from the behavior prescribed by that rule.

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behaves in a perfectly predictable manner; Ireland (1999) presents a statistical analysis designed to test whether Federal Reserve policy has been discretionary in this alternative sense and offers some support for this perspective.

The results point to both a shift in Federal Reserve policy away from stabilizing inflation between 2000 and 2007 *and* to important departures from rule-like behavior during that time. Moreover, counterfactual simulations conducted with the model indicate that the estimated changes in monetary policy – but especially departures from the policy rule – caused inflation to be higher than it otherwise would have been when the Great Recession began. These results raise the question of whether the United States, after an interlude spanning the mid-1980s through the 1990s, entered a period of renewed monetary instability after 2000. They underscore, as well, the advantages that accrue when central bankers respond systematically to movements in inflation and real economic activity within the context of a monetary policy rule and avoid persistent deviations from that rule.

Some previous studies estimate interest rate rules with time-varying parameters to examine whether the coefficients of a Taylor rule have changed in ways that are more complex than a one-time sample split around 1979 might suggest. Work on this question includes Jalil (2004), Boivin (2006), Kim and Nelson (2006), McCulloch (2007), Trecroci and Vassalli (2001), Li (2012), Jung and Katayama (2014), Lakdawala (2015), and Lee, Morley, and Shields (2015). Other studies, such as Bayoumi and Sgherri (2004), Mandler (2007), Ang, Boivin, Dong, and Loo-Kung (2011), and Doko Tchatoka, Groshenny, Haque, and Weder (2016), go further to consider the effects that time-variation in Taylor rule parameters have had on the persistence of inflation, the predictability of the federal funds rate, the behavior of long-term bond yields,

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and the stability of the economy's rational expectations equilibrium. Canova and Gambetti (2009), Koop, Leon-Gonzalez, and Strachan (2009), and Liu and Morley (2014) use vector autoregressions with time-varying parameters to characterize changes in both monetary policy and the monetary transmission mechanism in the U.S. economy. The analysis here builds on and adds to this literature by focusing, first, on how Federal Reserve policy changed over the more recent period from 2000 through 2007 and, second, on how these changes affected the trajectories of inflation and real activity in the period leading up to the Great Recession.

The Model

The model – a vector autoregression (VAR) with time-varying parameters and stochastic volatility – is based on Primiceri's (2005). Two model variants are considered, each using a different set of variables. Both variants measure the short-term nominal interest rate R_t using the federal funds rate, which the Federal Reserve focuses on most closely in conducting monetary policy. The two model variants differ, however, in the way they measure inflation Π_t and a "gap" variable G_t that tracks the cyclical position of the real economy.

The first model variant measures inflation using year-over-year percentage changes in the price index for core personal consumption expenditures (PCE), reflecting the Federal Reserve's shift in emphasis from the

consumer price index to the PCE price index in 2000.[4] Use of the output gap

to measure G_t then allows this variant of the model to describe monetary policy

in a manner that is closest to that provided by the original Taylor (1993) rule,

but with more flexible dynamics that enter through time-varying coefficients on

the current and lagged values of inflation and the output gap as well as lags of

the federal funds rate itself.[5] These data also reflect the latest estimates of

inflation and the output gap available from the U.S. Department of Commerce

and the Congressional Budget Office, and may thereby provide the most

accurate estimates of how the economy responded to Federal Reserve policy

actions over the period from 2000 through 2007.

Bernanke (2010) argues, however, that in understanding how the Federal

Reserve responded to perceived changes in the economy over this same time

period, it may be important to consider "real-time" data actually available to

policymakers when setting their federal funds rate targets. Thus, the second

model variant uses year-over-year changes in the consumer price index (CPI) to

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[4] See Board of Governors (2000, p.4, footnote 1) for a brief discussion of the rationale for this shift.

[5] The output gap is measured as the percentage-point difference between actual real GDP and the Congressional Budget Office's estimate of potential output. In addition to bringing the variables included in this version of the VAR into close accordance with those appearing in the original Taylor (1993) rule, use of the output gap, instead of the growth rate of real GDP, may help the model control for the effects of technology shocks that affect both real and potential GDP, but not the gap; Giordani (2004) discusses this point in more detail. Consistent with this intuition, results very similar to those reported here obtain when this three-variable version of the model is expanded to include Fernald's (2014) measures of consumption and investment-specific total factor productivity growth.

measure inflation and the unemployment rate as its gap variable. Once released, readings on these variables are never revised; hence, they may reflect more closely the information available to Federal Reserve officials in real time.[6]

Both model variants collect their three variables in a 3x1 vector

$$y_t = \begin{bmatrix} \Pi_t & G_t & R_t \end{bmatrix}',$$

which is assumed to follow a second-order VAR with time-varying coefficients and a time-varying covariance matrix for its innovations. The model's reduced form is

$$y_t = b_t + B_{1,t} y_{t-1} + B_{2,t} y_{t-2} + u_t, \tag{1}$$

where b_t is a 3x1 vector of time-varying intercept terms, $B_{i,t}$, for $i = 1$ and $i = 2$, are 3x3 matrices of time-varying autoregressive coefficients, and u_t is a 3x1 vector of heteroskedastic shocks with time-varying covariance matrix Ω_t. By stacking the intercept and autoregressive coefficients into the 21x1 vector

$$B_t = \text{vec}\left(\begin{bmatrix} b_t' \\ B_{1,t}' \\ B_{2,t}' \end{bmatrix} \right)$$

and decomposing the covariance matrix Ω_t as

$$\Omega_t = A_t^{-1} \Sigma_t \Sigma_t' (A_t')^{-1}, \tag{2}$$

where the 3x3 matrix

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[6] Croushore and Evans (2006) develop an econometric model with constant parameters that simultaneously exploits information in both real-time and revised data sources to understand Federal Reserve policy and its effects on the economy. Extending this model to allow for time-varying parameters presents an interesting but technically challenging exercise for future research.

$$A_t = \begin{bmatrix} 1 & 0 & 0 \\ \alpha_{g\pi,t} & 1 & 0 \\ \alpha_{r\pi,t} & \alpha_{rg,t} & 1 \end{bmatrix}$$

is lower triangular with ones along its diagonal and the 3x3 matrix

$$\Sigma_t = \begin{bmatrix} \sigma_{\pi,t} & 0 & 0 \\ 0 & \sigma_{g,t} & 0 \\ 0 & 0 & \sigma_{r,t} \end{bmatrix}$$

is diagonal, the reduced form (1) can be rewritten more conveniently as

$$y_t = X_t' B_t + A_t^{-1} \Sigma_t \varepsilon_t, \tag{3}$$

where

$$X_t = I_3 \otimes \begin{bmatrix} 1 & \Pi_{t-1} & G_{t-1} & R_{t-1} & \Pi_{t-2} & G_{t-2} & R_{t-2} \end{bmatrix},$$

$E\varepsilon_t \varepsilon_t' = I_3$, and I_3 denotes the 3x3 identity matrix.

Let

$$\alpha_t = \begin{bmatrix} \alpha_{g\pi,t} & \alpha_{r\pi,t} & \alpha_{rg,t} \end{bmatrix}'$$

and

$$\sigma_t = \begin{bmatrix} \sigma_{\pi,t} & \sigma_{g,t} & \sigma_{r,t} \end{bmatrix}'$$

be 3x1 vectors collecting the elements of A_t and Σ_t not equal to zero or one.

The dynamics of the time-varying parameters are governed by

$$B_t = B_{t-1} + v_t, \tag{4}$$

$$\alpha_t = \alpha_{t-1} + \zeta_t, \tag{5}$$

and

$$\log \sigma_t = \log \sigma_{t-1} + \eta_t, \tag{6}$$

where all of the serially uncorrelated innovations are assumed to be jointly normally distributed, with

$$V = \begin{bmatrix} \varepsilon_t \\ v_t \\ \zeta_t \\ \eta_t \end{bmatrix} [\varepsilon'_t \quad v'_t \quad \zeta'_t \quad \eta'_t] = \begin{bmatrix} I_3 & 0_{3\times 21} & 0_{3\times 3} & 0_{3\times 3} \\ 0_{21\times 3} & Q & 0_{21\times 3} & 0_{21\times 3} \\ 0_{3\times 3} & 0_{3\times 21} & S & 0_{3\times 3} \\ 0_{3\times 3} & 0_{3\times 21} & 0_{3\times 3} & W \end{bmatrix}, \tag{7}$$

and $0_{m\times n}$ denotes an $m\times n$ matrix of zeros. In (7), Q is 21x21, S is 3x3, and W is 3x3 and diagonal, so that the standard deviations in σ_t evolve as independent, geometric random walks. Following Primiceri (2005), it is assumed that S is block-diagonal, with one non-zero element in the first column of the first row and three distinct non-zero elements in the second and third columns of the second and third rows. Hence, Q has 231 distinct elements, S has four distinct non-zero elements, and W has three non-zero elements.

Estimation Strategy

Going back to the earliest work by Litterman (1979), Bayesian techniques have proven quite useful in estimating and interpreting vector autoregressions, as these methods offer theoretically coherent and computationally convenient ways of coping with the large numbers of parameters appearing even in VARs with coefficients that do not vary over time. More recently, Cogley and Sargent (2005) and Primiceri (2005) have outlined more powerful Markov Chain Monte Carlo algorithms for simulating the posterior distributions for the still larger number of parameters in systems like that described here by equations (3)-(7).

Following the same approach taken by Cogley and Sargent and Primiceri, prior distributions for these parameters are calibrated with the help of classical estimates obtained by applying a training sample consisting of the first ten years of data to a constant-parameter version of (3):

$$y_t = X_t'B + A^{-1}\Sigma\varepsilon_t.$$

In particular, an estimate $\hat{B}$ of the parameter vector B is obtained by applying ordinary least squares, individually, to each equation in this system, and estimates $\hat{\alpha}$ and $\hat{\sigma}$ of the parameter vectors α and σ are found by applying the same Cholesky factorization shown in (2) to the covariance matrix of least-squares residuals. Standard least-squares formulas provide an estimate of $\hat{V}_B$, the covariance matrix of $\hat{B}$, while Lutkepohl's (2006, Ch.9. p.373) Proposition 9.5 derives an expression for $\hat{V}_\alpha$, the covariance matrix of $\hat{\alpha}$. These magnitudes help fix normal priors for the initial values

$$B_0 \sim N(\hat{B}, 4\hat{V}_B),$$

$$\alpha_0 \sim N(\hat{\alpha}, 4\hat{V}_\alpha),$$

and

$$\log\sigma_0 \sim N(\log\hat{\sigma}, I_3)$$

similar to those used by Primiceri (2005), which then imply, through (4)-(7), normal priors for all three sets of time-varying coefficients.

For Q, the two diagonal blocks S_1 and S_2 of S, and each diagonal element $w_{i,i}$, $i = 1, 2, 3$, of W, inverse Wishart priors are calibrated as

$$Q \sim IW(22k_Q^2 \hat{V}_B, 22),$$

$$S_1 \sim IW(2k_S^2 \hat{V}_{\alpha,1}, 2),$$

$$S_2 \sim IW(3k_S^2 \hat{V}_{\alpha,2}, 3),$$

and

$$w_{i,i} \sim IW(2k_W^2, 2)$$

for $i = 1, 2, 3$, where $\hat{V}_{\alpha,1}$ and $\hat{V}_{\alpha,2}$ are the diagonal blocks of $\hat{V}_\alpha$. The settings

$k_S^2 = 0.01$ and $k_W^2 = 0.0001$ are again taken directly from Primiceri (2005), while

the setting $k_Q^2 = 0.00035$ follows Cogley and Sargent (2005) and Benati (2011) to

allow for additional time-variation in the autoregessive parameters.[7]

Starting from these priors, the remaining sample of quarterly data,

running from 1970:1 through 2007:4, is fed through a "Metropolis-within-

Gibbs" sampling algorithm to draw blocks of parameters from their conditional

posterior distributions. The multi-move algorithm outlined by Carter and Kohn

(1994) and Fruhwirth-Schnatter (1994) generates draws for the sequence of

cofficients in B_t; following Cogley and Sargent (2005), draws implying explosive

VAR dynamics are rejected. Primiceri's (2005) equation-by-equation method

provides draws for the sequence of parameters in α_t. Draws for the volatility

parameters in σ_t are made using Kim, Shephard, and Chib's (1998) algorithm,

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[7] An earlier version of this paper, available as Belongia and Ireland (2015), uses Primiceri's (2005) setting $k_Q^2 = 0.0001$ and obtains results that are, qualitatively, quite similar to those presented here, but with less time-variation in the elements of B_t.

which approximates the true, log-chi-square distribution for each of these coefficients with a mixture of seven normal distributions. Within this algorithm, the state variable indicating which normal distribution each volatility parameter is chosen from gets selected before sampling a value for the volatility parameter itself; the importance of this ordering of steps is discussed by Del Negro and Primiceri (2015). Also as in Del Negro and Primiceri (2015), a Metropolis-Hastings step is added to this part of the algorithm to account for the approximation error between the mixture-of-normals posterior distribution and the true, log-chi-square distribution for the volatility parameters. Finally, updated draws for the parameters in Q, S, and W are taken from their inverse Wishart conditional posterior distributions.

After cycling through this procedure 100,000 times in a burn-in period, all of the results below are based on the 50,000 draws of each parameter that follow. To check that output from the Markov Chain converges and mixes adequately, the algorithm is initialized from different, randomly chosen starting points, to verify that none of the results is affected. In addition, and more formally, table 1 presents summary statistics for inefficiency factors across four blocks of parameters: in the sequences $B^T = \{B_t\}_{t=1}^T$, $A^T = \{\alpha_t\}_{t=1}^T$, and $\Sigma^T = \{\sigma_t\}_{t=1}^T$ of time-varying autoregressive coefficients, shock covariances, and shock volatilities, and in the elements from the matrix V of hyperparameters defined in (7). For each individual parameter θ, the inefficiency statistic, described in more detail by Chib (2001, pp.3579-3580), is defined as the inverse of Geweke's (1992) measure of relative numerical efficiency:

$$IF(\theta) = \frac{2\pi S_\theta(0)}{\int_{-\pi}^{\pi} S_\theta(\omega)d\omega},$$

where $S_\theta(\omega)$ is the spectral density of θ at frequency ω. Thus, $IF(\theta)$ is computed here by multiplying an estimate of the spectral density of θ at frequency zero, obtained using Newey and West's (1987) Bartlett weighting of 24 lagged autocovariances of θ, by 2π and dividing the result by the variance of θ over the 50,000 draws. Primiceri (2005) and Benati (2011) suggest that inefficiency factors at or below 20 are acceptable, and while the statistics for the hyperparameters in V cluster tightly around that upper bound, those for the autoregressive parameters and shock covariances and volatilities come in well below it.

Identification of Structural Shocks

At least two approaches can be used to identify structural disturbances, including monetary policy shocks, from the reduced form described by (1) and (2). One approach, which dates back to Sims (1980), uses assumptions about the timing with which monetary policy disturbances affect inflation and output or unemployment to re-interpret the triangular factorization of the reduced-form covariance matrix shown in (2) as a mapping between the reduced-form and structural models.[8] An alternative, taken here, uses "sign restrictions" on impulse responses to identify an entire set of structural disturbances based on

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[8] The earlier version of this paper, Belongia and Ireland (2015), takes this approach, obtaining results that are qualitatively similar to those presented here.

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the effects each is assumed to have on inflation, the gap variable, and the

interest rate. Faust (1998), Canova and De Nicolo (2002), and Uhlig (2005) first

developed the idea that sign restrictions can serve as a source of identifying

assumptions in VARs, while Benati (2011) implements the particular scheme

used here within a similar VAR framework with time-varying parameters.

The algorithm, based on Rubio-Ramirez, Waggoner, and Zha (2010) and

Arias, Rubio-Ramirez, and Waggoner (2014) and outlined in more detail in the

appendix, works to factor the reduced form covariance matrix as

$$\Omega_t = C_t^{-1} D_t D_t' (C_t')^{-1}, \tag{8}$$

where C_t and D_t are 3x3 matrices of the form

$$C_t = \begin{bmatrix} 1 & -c_{\pi g,t} & -c_{\pi r,t} \\ -c_{g\pi,t} & 1 & -c_{gr,t} \\ -c_{r\pi,t} & -c_{rg,t} & 1 \end{bmatrix} \tag{9}$$

and

$$D_t = \begin{bmatrix} \delta_{\pi,t} & 0 & 0 \\ 0 & \delta_{g,t} & 0 \\ 0 & 0 & \delta_{r,t} \end{bmatrix}, \tag{10}$$

restricted further so that the three structural disturbances – to aggregate

supply, aggregate demand, and monetary policy – affect inflation, the gap

variable, and the federal funds rate as illustrated in table 2. Equations (8)-(10)

provide the mapping between the reduced form (1) and (2) and the structural

model, which now can be written as

$$C_t y_t = \gamma_t + \Gamma_{1,t} y_{t-1} + \Gamma_{2,t} y_{t-2} + D_t \xi_t, \tag{11}$$

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where $\gamma_t = C_t b_t$, $\Gamma_{i,t} = C_t B_{i,t}$ for $i = 1$ and $i = 2$, and

$$\xi_t = \begin{bmatrix} \xi_t^{as} & \xi_t^{ad} & \xi_t^{mp} \end{bmatrix}' \tag{12}$$

is a 3x1 vector of structural disturbances to aggregate supply, aggregate demand, and monetary policy, with $E\xi_t \xi_t' = I_3$.

The third row of the structural model described by (8)-(12) is a monetary policy rule

$$R_t = \gamma_{r,t} + c_{r\pi,t} \Pi_t + \gamma_{1,r\pi,t} \Pi_{t-1} + \gamma_{2,r\pi,t} \Pi_{t-2}$$
$$+ c_{rg,t} G_t + \gamma_{1,rg,t} G_{t-1} + \gamma_{2,rg,t} G_{t-2} + \gamma_{1,rr,t} R_{t-1} + \gamma_{2,rr,t} R_{t-2} + \delta_{r,t} \xi_t^{mp} \tag{13}$$

where the intercept terms and the coefficients on the lagged values of inflation, the gap variable, and the interest rate are those from the third rows of the vector γ_t and matrices $\Gamma_{1,t}$ and $\Gamma_{2,t}$ in (11).[9] This policy rule takes the same general form as Taylor's (1993), in that it prescribes a setting for the federal funds rate with reference to changing values of inflation and the gap variable. However, (13) also allows for considerable flexibility in the dynamic response of the funds rate to changes in inflation and the output gap and, through the inclusion of lagged interest rate terms on the right-hand side, captures as well the central bank's tendency to smooth interest rate movements over time. Deviations in the actual federal funds rate from the value dictated by the current and lagged values of inflation, the gap variable, and the interest rate get picked up as monetary shocks in (13). Finally, (13) allows for time-

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[9] Note that the minus signs in front of the impact coefficients in (9) are just normalizations, which allow the monetary policy rule to be written as (13), after isolating the interest rate on the left-hand side and moving the contemporaneous values of inflation and the gap variable to the right.

variation in all of the response coefficients and in the standard deviation $\delta_{r,t}$ of

the monetary policy shocks.

Therefore, by expanding the time-varying estimation beyond that of a

Taylor rule's coefficients in isolation, this specification becomes ideally suited

for distinguishing between a variety of changes to monetary policy that might

have occurred over the period from 2000 through 2007. In particular, this

more generalized estimation permits drawing distinctions between changes in

the emphasis that the Federal Reserve placed on its stabilizing objectives for

inflation versus the gap variable and the extent to which Federal Reserve

officials became more willing to tolerate deviations from their systematic

behavior. And, because the parameters of (13) are estimated within the

multivariate system (11), the model also can be used to trace out the

implications that these changes in monetary policy had on inflation and real

economic activity over the same period.

Estimation Results

Figures 1 and 2 focus on the time-varying parameters of the monetary

policy rule (13). Figure 1 tracks the evolution of the impact coefficients $c_{r\pi,t}$

and $c_{rg,t}$, which measure the contemporaneous responses of the federal funds

rate to movements in inflation and the gap variable. Figure 2 does the same for

the measure of "interest rate smoothing" given by the sum $\gamma_{1,rr,t} + \gamma_{2,rr,t}$ of the

coefficients on the lagged interest rate terms and the "long-run coefficients"

$$(c_{r\pi,t} + \gamma_{1,r\pi,t} + \gamma_{2,r\pi,t})/(1 - \gamma_{1,rr,t} - \gamma_{2,rr,t})$$

and

$$(c_{rg,t} + \gamma_{1,rg,t} + \gamma_{2,rg,t})/(1 - \gamma_{1,rr,t} - \gamma_{2,rr,t}),$$

which measure the total increase in the funds rate that would, in theory, follow a permanent one-percentage-point increase in inflation or the gap variable.

The graphs show steady declines in the policy response of the funds rate to changes in inflation, both on impact and in the long run, between 2000 and 2007. When inflation is measured with the core PCE price index, the median impact coefficient falls from 1.04 to 0.73 and the median long-run coefficient from 1.94 to 1.64; similarly, when inflation is measured with the core CPI, the impact coefficient falls from 1.10 to 0.54 and the long-run coefficient from 2.26 to 1.85. Meanwhile, the coefficients on the gap variables take their expected signs – positive for the output gap and negative for the unemployment rate – but remain fairly stable over the 2000-2007 period. Thus, the estimates do point to a noticeable shift in the emphasis of monetary policy, responding less to inflation relative to real economic activity.

Figure 3 plots the changing standard deviations of the structural disturbances, measured by the diagonal elements of the matrix D_t shown in (10). In particular, the two panels in the bottom row track the evolution of the identified monetary policy shock: on the left for the model estimated with the core PCE price index and output gap and on the right for the model estimated with the core CPI and unemployment rate. The broad historical patterns are

similar for both model variants, showing that monetary volatility was extremely high during from early-to-mid 1970s and through the period of the Volcker disinflation; compared to those very high levels, the standard deviation of monetary policy shocks has remained low and stable since. Nevertheless, both graphs hint at an increased willingness of Federal Reserve officials to depart from the systematic behavior prescribed by the estimated policy rules during and after the recession of 2001. When estimated with PCE price inflation and the output gap, the median value of $\delta_{r,t}$ rises from 0.34 in 2000:1 to 0.47 in 2001:2 before falling back to 0.32 in 2007:4; and when estimated with CPI inflation and the unemployment rate, the median value of $\delta_{r,t}$ increases from 0.31 in 2000:1 to 0.40 in 2001:2, then declines to 0.21 in 2007:4.

Of course, figures 1-3 also indicate that considerable uncertainty surrounds most of the parameter estimates, with wide bands appearing between the 16th and 84th percentiles of their distributions. Table 3 confirms this by computing, in a manner suggested by Cogley, Primiceri, and Sargent (2010), the posterior probability that the value for each monetary policy parameter in 2000:1 exceeds its value in 2007:4. In only one case – for the impact coefficient on CPI inflation – do the data provide enough information to assign a probability higher than 90 percent to a unidirectional shift.

Thus, figure 4 digs deeper by plotting estimates of the realized monetary policy shocks between 2000 and 2007. Over the entire period, these shocks are most frequently expansionary (negative) in the model based on PCE inflation and the output gap. Most notably, the Federal Reserve appears to

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have held its funds rate target below the value prescribed by the estimated rule for the entire year running from 2003:3 through 2004:2. These patterns appear somewhat muted in the bottom panel, which shows results from the model estimated with CPI inflation and the unemployment rate. These dampened magnitudes offer some support for Bernanke's (2010) arguments that Federal Reserve policy appears to come closer to following a Taylor rule when "real-time" data are considered. Nevertheless, even when the statistical uncertainty summarized by the 16-84 percentile bands is taken into account, both graphs point to potentially important deviations from that rule in the aftermath of the 2001 recession.

Before moving on, however, figures 5-8 and tables 4 and 5 look for other possible shifts in monetary policy that may have occurred between 2000 and 2007 and their consequent effects on aggregate activity. Figure 5 plots time-varying "inflation targets" for the core PCE price index and CPI, defined as in Cogley and Sargent (2005) and Cogley, Primiceri, and Sargent (2010) as the stochastic trend towards which inflation would gravitate based on draws of the model's parameters for each period $t = 1, 2, \ldots T$. While both panels show evidence of a long-run decline in the Federal Reserve's objective for inflation over the entire estimation period beginning in 1970, the estimated targets remain stable, just below 2 percent for the PCE price index and 2 1/2 percent for the CPI, from 2000 through the end of the sample in 2007. Likewise, table 3 shows that the data provide no clear evidence of any shift in the inflation targets in either direction between 2000:1 and 2007:4.

Figures 6-8, meanwhile, trace out impulse responses of each observable variable to identified aggregate supply, aggregate demand, and monetary policy shocks. Following Primiceri (2005), these impulse responses are computed for each period based on draws from the posterior distributions of the parameters estimated for that period; thus, they summarize how the Fed and the economy responded to shocks at a particular point in time. The top rows of figures 6 and 7, in particular, show larger responses of inflation to aggregate demand and, especially, aggregate supply shocks in 2007:4 compared to 2000:1, consistent with the decline in the monetary policy response coefficients for inflation appearing previously in figures 1 and 2. Figure 8, however, reveals little change in the effects of monetary policy shocks across the two periods.

Finally, tables 4 and 5 report percentages of forecast error variances in inflation and gap variables attributable to monetary policy shocks for horizons ranging one to ten years ahead. As with the impulse response functions, each of these variance decompositions is based on draws of the model's parameters from their posterior distributions for 2000:1 and 2007:4 in order to summarize changes in monetary policy and the economy taking place between those dates. Particularly when data on the PCE price index and the output gap are used to generate the numbers in table 4, the estimated model attributes sizable fractions of the volatility in inflation to monetary policy shocks. Once again, however, there is little evidence in either table 4 or 5 of dramatic shifts in any of these statistics across the two periods.

Overall, many of the estimation results do suggest that the Federal Reserve shifted its emphasis away from stabilizing inflation between 2000 and 2007. The most striking evidence of a change in monetary policy, however, is provided by the realized shocks shown in figure 4: Rather than indicating a change in emphasis between the two objectives in a standard Taylor Rule, these point to an increased willingness of policymakers to depart from rule-like behavior, especially during 2003 and 2004.

Counterfactual Simulations

To assess how these changes in monetary policy affected U.S. economic performance, figure 9 reports results from two experiments in which the estimated model is used to describe counterfactual scenarios. In the first, the coefficients of the policy rule (13) beginning in 2000:1 and ending in 2007:4 are drawn, not from their own posterior distribution but instead from the posterior distribution from 2000:1. Thus, this experiment is designed to infer what would have happened to inflation, real economic activity, and the federal funds rate if the systematic component of monetary policy from 2000 through 2007 placed consistently higher weight on inflation stabilization. Focusing on the results derived from data on PCE price inflation and the output gap, the graphs in the first column of figure 9 suggest that this shift in emphasis back towards inflation-fighting would have done little to change the course of history: Although the panel in the top row shows that inflation would have been about 10 basis points lower in 2004 and 2005 with the counterfactual policy rule, the

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differences between the actual and counterfactual paths are otherwise so slight that the two lines in each graph can scarcely be distinguished.

The second experiment attempts, instead, to change history by "turning off" the monetary policy shocks that, according to the estimated model, occurred between 2000:1 and 2007:4. In this case, for the model with PCE price inflation and the output gap, the graphs from the second column of figure 9 show more important differences between the actual time series and the median counterfactual paths. Without monetary policy shocks, the funds rate runs higher for virtually all of the five-year period from 2001 through 2005. Most notably, the median counterfactual trajectory for the funds rate between 2003:4 and 2005:2 lies between 40 and 90 basis points above the actual settings.

The graph in the top row of the second column of figure 9, meanwhile, displays the model's implications for how the estimated monetary policy shocks affected inflation. The median path for inflation in the counterfactual without shocks falls below the actual path from 2003:3 onward and runs continuously between 20 and 35 basis points beneath the actual series over the 2004:2 through 2006:4 interval. Moreover, instead of overshooting what has since become the Federal Reserve's official long-run inflation target of two percent, as it did in the actual data by the end of 2004, inflation under the counterfactual converges, and then remains very close to, two percent through the end of the

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sample.[10] The graph in the middle row of the second column suggests that the

negative output gap that persisted in the years following the 2001 recession

would have been as much as 40 basis points larger in absolute value without

the estimated monetary policy shocks. Thus, by deviating from rule-like

behavior, the Fed appears to have successfully "bought" higher output at the

cost of creating more inflation. Note from the bottom graph, however, that the

actual path for the funds rate moves 50 basis points or more *above* the path

without monetary policy shocks beginning in the second half of 2006. At least

in hindsight, deviations from the rule in (13) over this period suggest that

interest rates were kept too low for low long even as the economy continued to

recover and inflation began to rise and then increased too quickly and by too

much when inflation exceeded its target. This pattern bears a troubling

resemblance to the discretionary, "stop-go" dynamics that Hetzel (2012)

associates with Federal Reserve policy before 1979.

Consistent with the estimates of the monetary policy shocks themselves

displayed in figure 5, the last two columns of figure 9 show that the differences

between the actual and counterfactual paths from both experiments are

smaller when the model is estimated with data on CPI inflation and the

unemployment rate. In the figure's third column, virtually no difference

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[10] In Belongia and Ireland (2015), the results of this no-shock counterfactual
appear even more striking when the monetary policy shocks are identified
using a more traditional, Cholesky factorization of the reduced-form covariance
matrix, assuming that inflation and output react to these shocks with a one-
period lag. There, along the counterfactual trajectories, the federal funds rate
rises as much as 150 basis points above the actual setting, and inflation falls
by 45 basis points below its historical path.

appears between the historical data and the counterfactual when the 2000:1

policy rule applies over the entire period running through 2007:4. And in the

fourth column, along the median counterfactual paths without the estimated

monetary policy shocks, inflation never falls more than 20 basis points below

and the federal funds rate never rises more than 45 basis points above their

actual values.

For the purposes of these exercises, however, the choice between the

revised PCE and output gap data and the unrevised CPI and unemployment

data is by no means clear-cut. Even if Bernanke (2010) is correct in stating

that real time data are more useful to understanding why policymakers

behaved as they did, the most recently revised figures provide more accurate

estimates of how the economy responded to their policy actions. Thus, figures

4 and 9 do suggest that, as argued by Bernanke (2010), the Fed's motivation to

keep interest rates low after the 2001 recession was based partly on

preliminary estimates of inflation that, later, were revised substantially

upward. But, even using the unrevised data, both figures point to deviations

from the estimated monetary policy rule that contributed to higher inflation

later on. And the most recently revised data on core PCE inflation and the

output gap indicate that, whether deliberate or inadvertent, monetary policy

actions taken to keep interest rates low played an important role in causing

inflation to overshoot its target in the years leading up to the Great Recession.

Conclusion

Although the Federal Reserve never has announced that it follows a rule to guide monetary policy decisions, Taylor (1993) described a framework the Fed might use to determine its target value for the federal funds rate. Despite its simplicity, this rule appeared to track actual Federal Reserve policy decisions quite well over the period between 1987 and 1992 that was the focus of Taylor's original study. Moreover, the rule's parsimony meant that it could be incorporated easily into even the simplest of New Keynesian models, which focus on the behavior of the same three variables – inflation, the output gap, and the short-term nominal interest rate – that appear in the rule itself. For both of these reasons, the Taylor rule has become a benchmark for assessing and evaluating how Federal Reserve policy has changed over longer periods of time, well beyond the short sample first considered by Taylor.

The models considered here include a version of the Taylor rule that allows for time variation in both the coefficients measuring the Federal Reserve's systematic responses to inflation and real economic activity and in the volatility of an identified monetary policy shock, which may reflect the Fed's willingness to deviate from the interest rate setting prescribed by the rule. Therefore, when estimated, this model works to characterize, more sharply than previous studies have, the changes to Federal Reserve policy that occurred between 2000 and 2007, a period spanning the end of the Great Moderation and the beginning of the Great Recession. Moreover, because the model embeds the time-varying policy rule within a vector autoregressive

framework, it also can be used to investigate how these changes affected the behavior of inflation and real activity.

The results suggest, first, that the Fed did decrease the weight it placed on stabilizing inflation from 2000 to 2007; this finding appears consistently, whether the model is estimated with the most recently-revised data on PCE price inflation and the output gap or with unrevised data on CPI inflation and the unemployment rate. The estimates point more strongly, however, to persistent deviations from the estimated policy rule that had important implications for the behavior of output and, especially, inflation. Counterfactual simulations run with the estimated model suggest that the path for the funds rate under a policy rule would have allowed core PCE price inflation to converge to the Federal Reserve's two percent target without overshooting and also would have avoided the abrupt tightening of monetary policy that occurred just prior to the onset of the Great Recession.

Simulations done with the same CPI and unemployment data that would have been available to the Federal Reserve in approximate real time lend some support to Bernanke's (2010) claim that policymakers may have been misled by initial readings of low inflation that were subsequently revised upward. A persistent series of expansionary policy shocks appears, however, even when the model is estimated with unrevised CPI data. On balance, therefore, the results bolster Taylor's (2009) claim that monetary policy was too expansionary for too long following the earlier recession of 2001. More broadly, the results reinforce a basic message from modern macroeconomics: That economic

performance improves when central banks adopt and adhere closely to a monetary policy rule.

Appendix

Benati (2011, pp.1111-1112) describes how the algorithm developed by Rubio-Ramirez, Waggoner, and Zha (2010) and Arias, Rubio-Ramirez, and Waggoner (2014) can be applied in VARs with time-varying parameters with stochastic volatility. Let the index $i = 1,2,...,N$ keep track of the desired draws from the posterior distribution. For each $i = 1,2,...,N$, the algorithm loops through the following steps.

1. Draw sequences (A^T, Σ^T) from their conditional posterior distributions during the Gibbs sampling stage.

2. For each $t = 1,2,...,T$, construct A_t and Σ_t based on the draws for (A^T, Σ^T). Then, let $L_t = A_t^{-1}\Sigma_t$, so that the reduced-form covariance matrix can be recovered as $\Omega_t = L_t L_t'$.

3. Draw $\tilde{X}$, a 3x3 random matrix with each element having an independent standard normal distribution. Then, factor this matrix as $\tilde{X} = Q_X R_X$, where Q_X is an orthogonal matrix and R_X is upper triangular with positive diagonal elements.

4. Let $\tilde{L} = L_t Q_X'$ and note that $\tilde{L}_t \tilde{L}_t' = L_t Q_X' Q_X L_t' = L_t L_t' = \Omega_t$ by virtue of the fact that Q_X is orthogonal. These equalities highlight that multiplying the

structural model (11) through by D_t^{-1} and then Q_X results in an observationally-equivalent rotation of the model's three equations. Suppressing for convenience explicit reference to the constant and lagged terms in (11), the candidate structural model based on the specific draw for Q_X can be written as $y_t = \tilde{L}_t \xi_t$; thus, the matrix $\tilde{L}_t$ contains impact coefficients linking the structural shocks in ξ_t to the observable variables in y_t. The sign restrictions shown in table 2 require the elements of $\tilde{L}_t$ to display similar sign patterns. If these restrictions are not satisfied for any $t = 1, 2, ..., T$, the draws for (A^T, Σ^T) and $\tilde{X}$ are discarded and the algorithm returns to step 1. If the restrictions are satisfied for all $t = 1, 2, ..., T$, then $\tilde{L}_t$ is factored as $\tilde{L}_t = C_t^{-1} D_t$, where C_t and D_t have the forms shown in (9) and (10), these draws are saved, and the Gibbs sampling routine moves on.

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Table 1. Inefficiency Factors

A. Model with PCE Price Inflation and the Output Gap

	median	mean	minimum	maximum	10th percentile	90th percentile
3150 Coefficients B^T	6.7	6.9	2.2	13.6	4.2	9.9
450 Covariances A^T	3.5	3.6	2.2	5.7	2.6	4.7
450 Volatilities Σ^T	7.5	7.8	4.9	12.1	5.8	10.7
238 Hyperparameters V	21.7	21.7	19.1	22.6	21.1	22.2

B. Model with CPI Inflation and the Unemployment Rate

	median	mean	minimum	maximum	10th percentile	90th percentile
3150 Coefficients B^T	7.4	7.6	2.8	15.4	4.4	10.9
450 Covariances A^T	4.0	4.2	2.3	7.7	2.7	6.6
450 Volatilities Σ^T	7.5	8.5	5.1	16.5	5.8	12.3
238 Hyperparameters V	22.7	22.6	18.7	23.5	22.0	23.3

Notes: Inefficiency factors correspond to the inverse of Geweke's (1992) measure of relative numerical efficiency, computed as described in the text using a Bartlett weighting scheme and 24 lagged autocovariances to estimate the spectral density at frequency zero.

Table 2. Sign Restrictions on the Impact Effects of Structural Shocks

A. Model with PCE Price Inflation and the Output Gap

	Structural Shock		
Impact Effect On	Aggregate Supply	Aggregate Demand	Monetary Policy
Inflation	+	+	−
Output Gap	−	+	−
Interest Rate	?	+	+

B. Model with CPI Inflation and the Unemployment Rate

	Structural Shock		
Impact Effect On	Aggregate Supply	Aggregate Demand	Monetary Policy
Inflation	+	+	−
Unemployment Rate	+	−	+
Interest Rate	?	+	+

Notes: Each panel shows the sign restrictions imposed on the impulse response of each indicated variable to each indicated structural shock: a contractionary aggregate supply shock, an expansionary aggregate demand shock, and a contractionary monetary policy shock. The symbol + indicates that the variable must rise, the symbol – indicates that the variable must fall, and the symbol ? indicates that the response is left unconstrained.

Table 3. Monetary Policy Parameters

A. Model with PCE Price Inflation and the Output Gap

	Median 2000:1	Median 2007:4	Pr(2000:1 > 2007:4)
Impact coefficient on inflation	1.04	0.73	0.72
Impact coefficient on the output gap	0.41	0.45	0.40
Interest rate smoothing	0.95	0.94	0.60
Long-run coefficient on inflation	1.94	1.64	0.60
Long-run coefficient on the output gap	0.84	0.90	0.41
Monetary policy shock volatility	0.34	0.32	0.58
Inflation Target	1.92	1.90	0.52

B. Model with CPI Inflation and the Unemployment Rate

	Median 2000:1	Median 2007:4	Pr(2000:1 > 2007:4)
Impact coefficient on inflation	1.10	0.54	0.91
Impact coefficient on unemployment	−1.53	−1.34	0.28
Interest rate smoothing	0.87	0.86	0.62
Long-run coefficient on inflation	2.26	1.85	0.74
Long-run coefficient on unemployment	−1.32	−1.39	0.59
Monetary policy shock volatility	0.31	0.21	0.79
Inflation Target	2.45	2.39	0.58

Table 4. Variance Decompositions: Model with PCE Price Inflation and the Output Gap

A. PCE Price Inflation

	Percentage of Forecast Error Variance Due to Monetary Policy Shocks						
	2000:1 Percentile			2007:4 Percentile			
Quarters Ahead	16	50	84	16	50	84	Pr(2000:1 < 2007:4)
4	2.7	13.1	35.1	1.7	10.2	31.2	0.31
8	7.9	25.5	51.5	4.9	18.8	43.7	0.32
12	13.6	36.5	63.3	8.7	27.7	54.9	0.33
16	17.7	43.2	68.5	11.6	33.4	60.4	0.34
20	20.0	46.1	70.0	13.1	35.8	62.3	0.34
40	21.8	47.5	70.2	14.6	37.5	63.3	0.34

B. Output Gap

	Percentage of Forecast Error Variance Due to Monetary Policy Shocks						
	2000:1 Percentile			2007:4 Percentile			
Quarters Ahead	16	50	84	16	50	84	Pr(2000:1 < 2007:4)
4	1.5	6.7	22.9	1.2	4.9	18.2	0.36
8	2.0	8.0	24.6	2.0	7.4	24.3	0.46
12	2.8	10.0	27.6	2.7	10.2	30.1	0.49
16	3.4	11.3	29.0	3.4	11.9	32.2	0.50
20	4.0	12.5	30.1	4.2	13.4	33.4	0.51
40	5.6	16.0	34.4	6.0	17.3	37.8	0.52

Table 5. Variance Decompositions: Model with PCI Inflation and the Unemployment Rate

A. CPI Inflation

	Percentage of Forecast Error Variance Due to Monetary Policy Shocks						
	2000:1			2007:4			
	Percentile			Percentile			
Quarters Ahead	16	50	84	16	50	84	Pr(2000:1 < 2007:4)
4	1.4	8.7	28.0	1.3	9.1	30.6	0.56
8	1.9	9.8	30.0	2.0	10.7	31.3	0.54
12	2.5	11.3	32.7	2.5	11.4	31.7	0.51
16	2.8	12.0	33.6	2.7	11.6	31.3	0.49
20	3.0	12.4	33.8	2.8	11.6	31.2	0.48
40	3.2	12.7	34.2	2.9	11.7	31.2	0.47

B. Unemployment Rate

	Percentage of Forecast Error Variance Due to Monetary Policy Shocks						
	2000:1			2007:4			
	Percentile			Percentile			
Quarters Ahead	16	50	84	16	50	84	Pr(2000:1 < 2007:4)
4	0.9	3.3	11.3	0.7	2.9	10.4	0.44
8	1.2	3.9	11.3	1.2	3.8	10.9	0.47
12	1.7	5.3	13.6	1.5	5.1	13.8	0.47
16	2.0	6.2	15.6	1.8	6.0	16.0	0.48
20	2.3	6.9	16.9	2.0	6.6	17.2	0.47
40	2.6	7.6	18.4	2.2	7.2	18.4	0.47
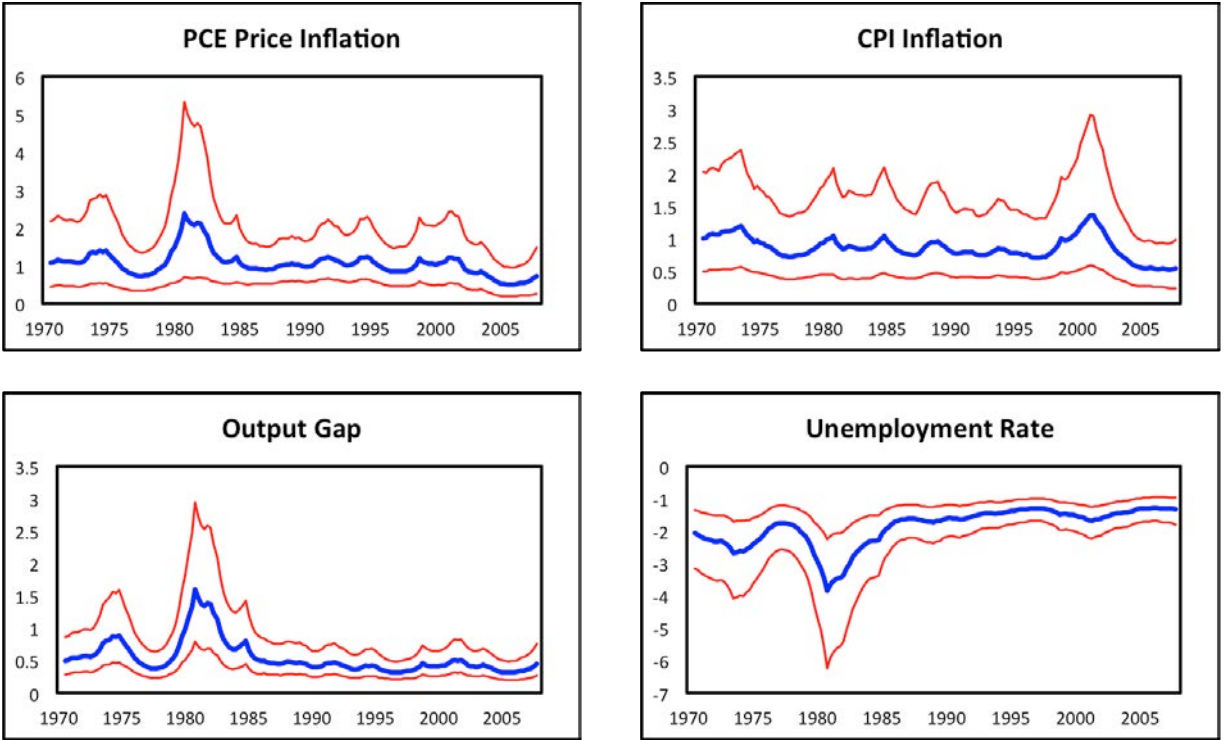
Figure 1. Impact Coefficients from the Estimated Monetary Policy Rules. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the impact coefficient on the indicated variable. Graphs on the left are from the model with core PCE price inflation and the output gap; graphs on the right are from the model with core CPI inflation and the unemployment rate.
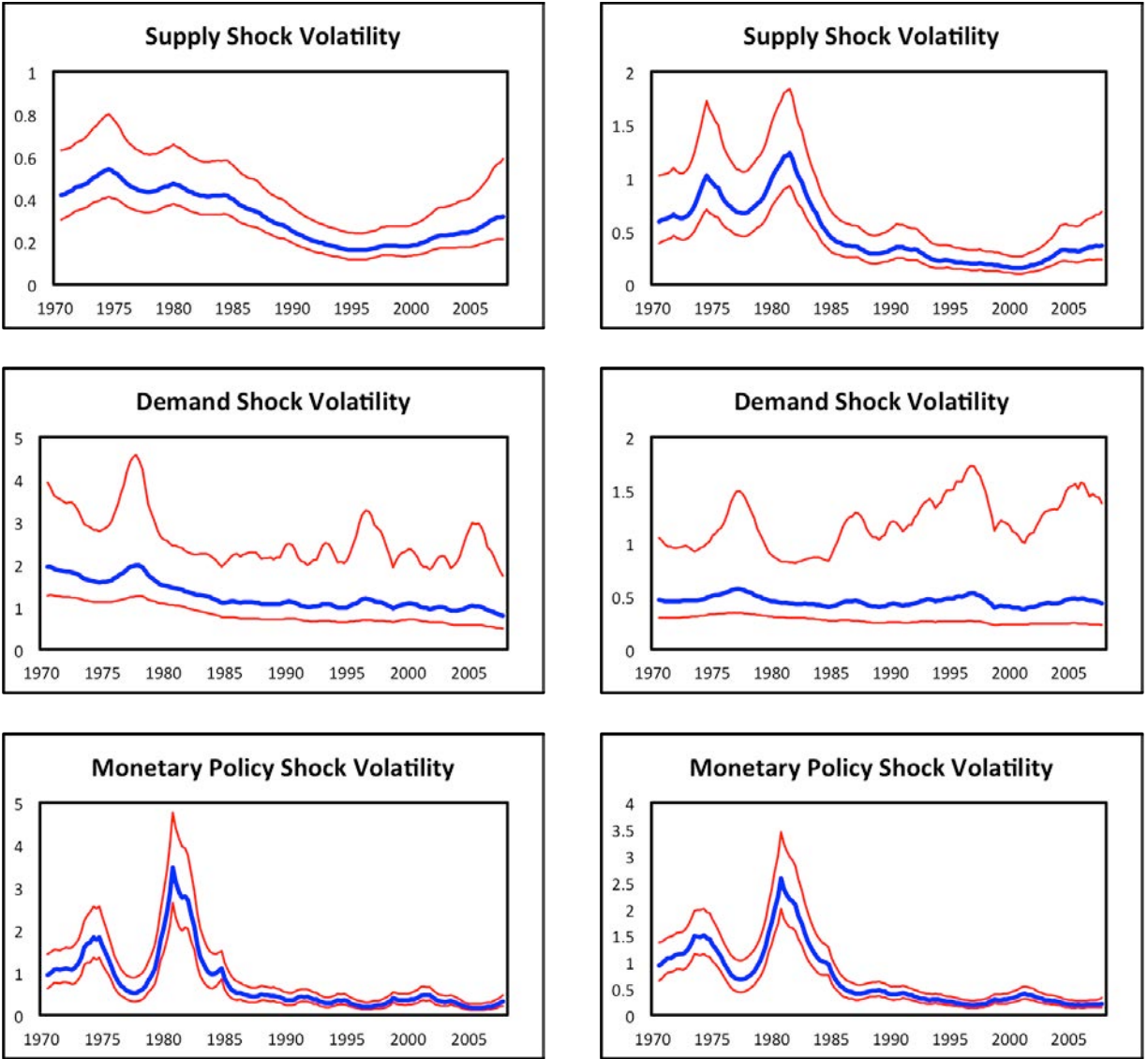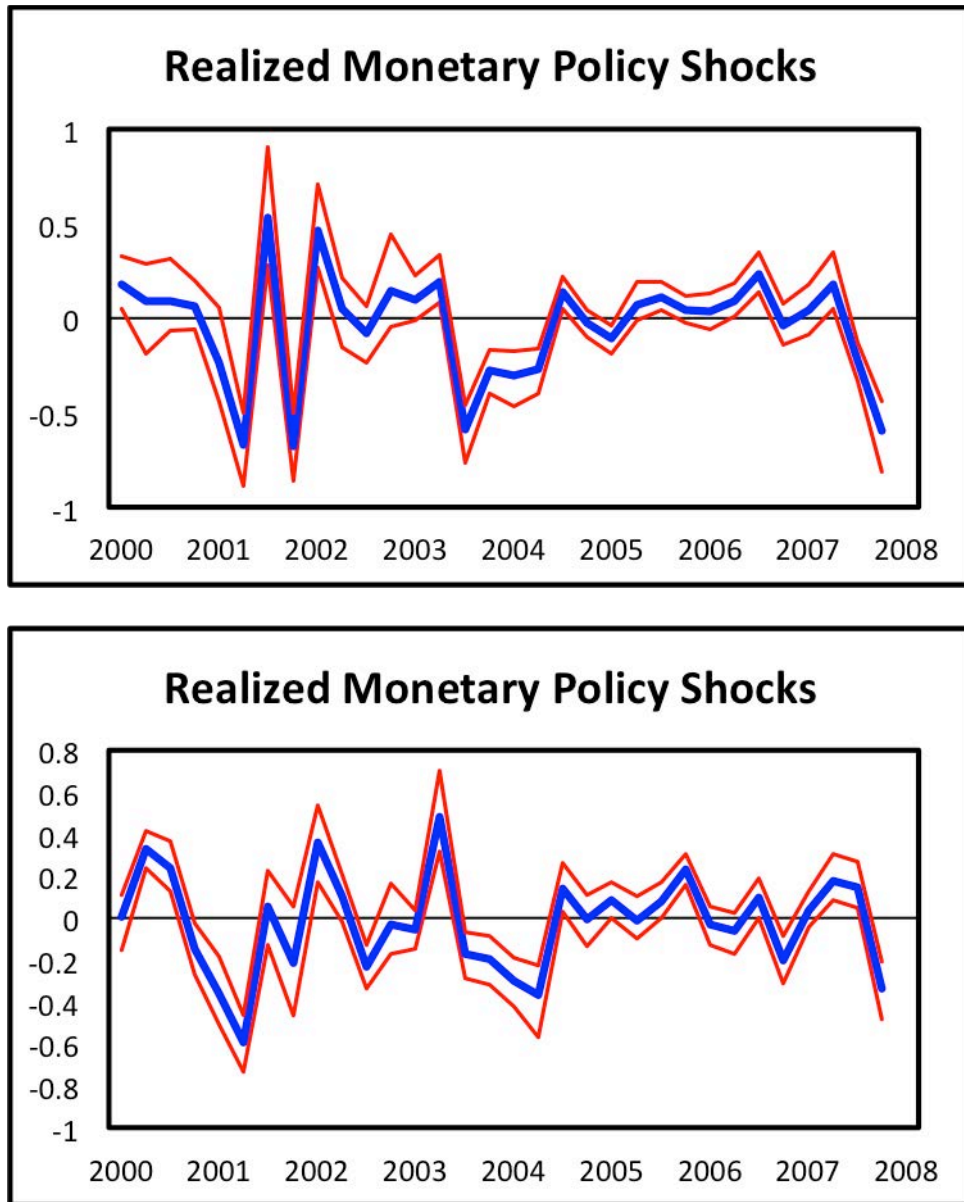
Figure 2. Interest Rate Smoothing and Long-Run Coefficients from the Estimated Monetary Policy Rules. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the interest rate smoothing or long-run coefficient on the indicated variable. Graphs on the left are from the model with core PCE price inflation and the output gap; graphs on the right are from the model with core CPI inflation and the unemployment rate.
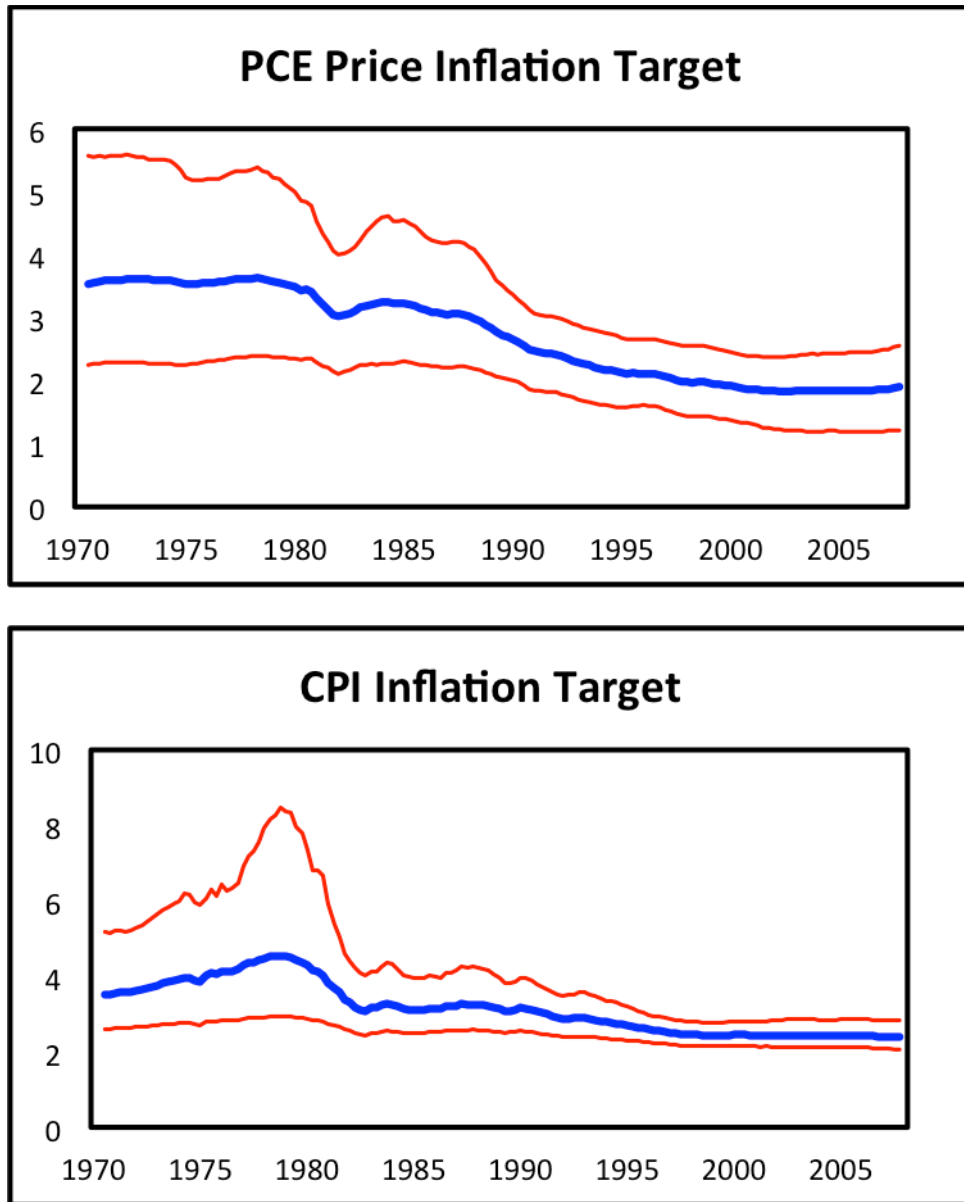
Figure 3. Shock Volatilities. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the standard deviation of the indicated structural shock. Graphs on the left are from the model with core PCE price inflation and the output gap; graphs on the right are from the model with core CPI inflation and the unemployment rate.

Figure 4. Monetary Policy Shock Realizations. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the realized monetary policy shock. Top graph is from the model with core PCE price inflation and the output gap; bottom graph is from the model with core CPI inflation and the unemployment rate.
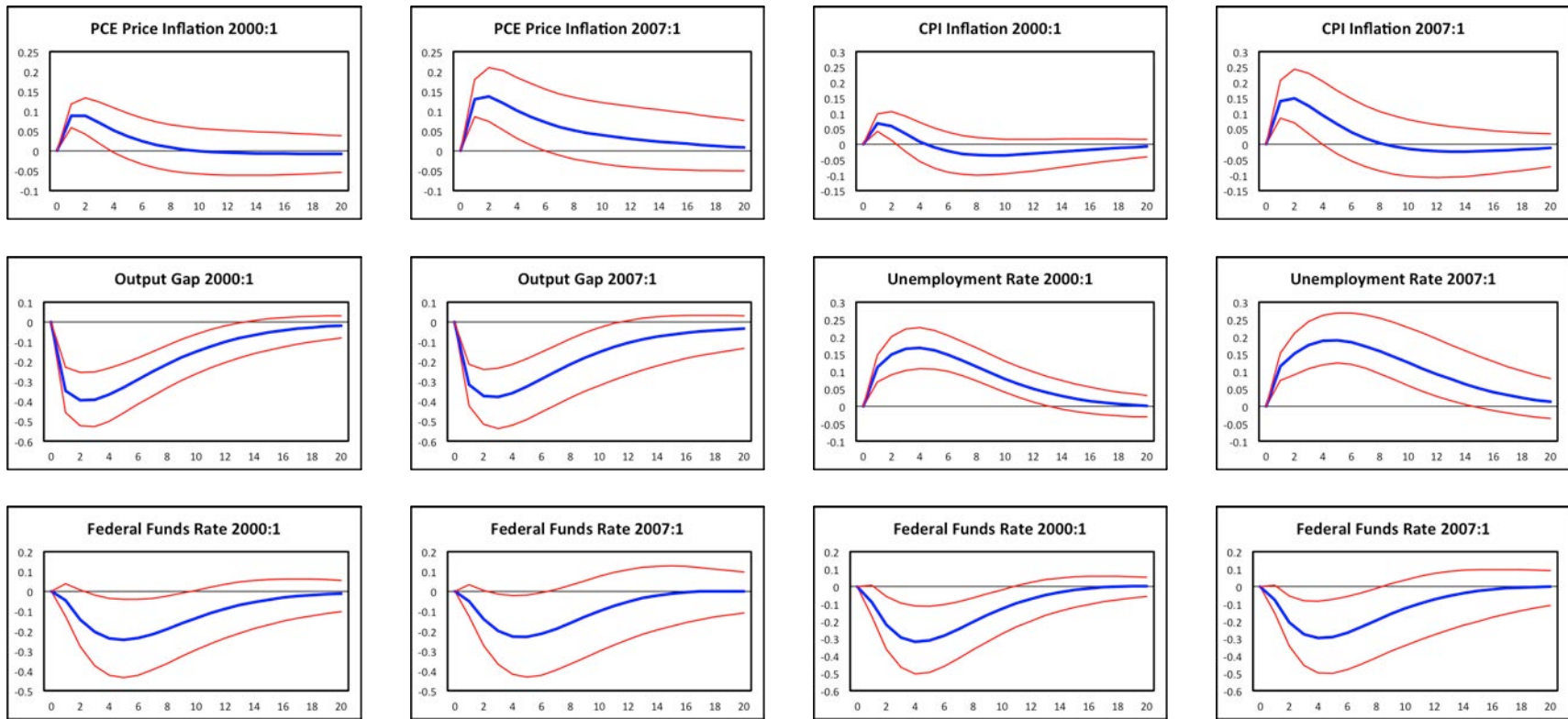
Figure 5. Estimated Inflation Targets. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the inflation target, defined as the time-varying long-run mean for inflation. Top graph is from the model with core PCE price inflation and the output gap; bottom graph is from the model with core CPI inflation and the unemployment rate.

Figure 6. Impulse Responses to Aggregate Supply Shocks. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the impulse response of the indicated variable to an identified contractionary aggregate supply shock at the indicated date. Graphs in the two left columns are from the model with core PCE price inflation and the output gap; graphs in the two right columns are from the model with core CPI inflation and the unemployment rate.
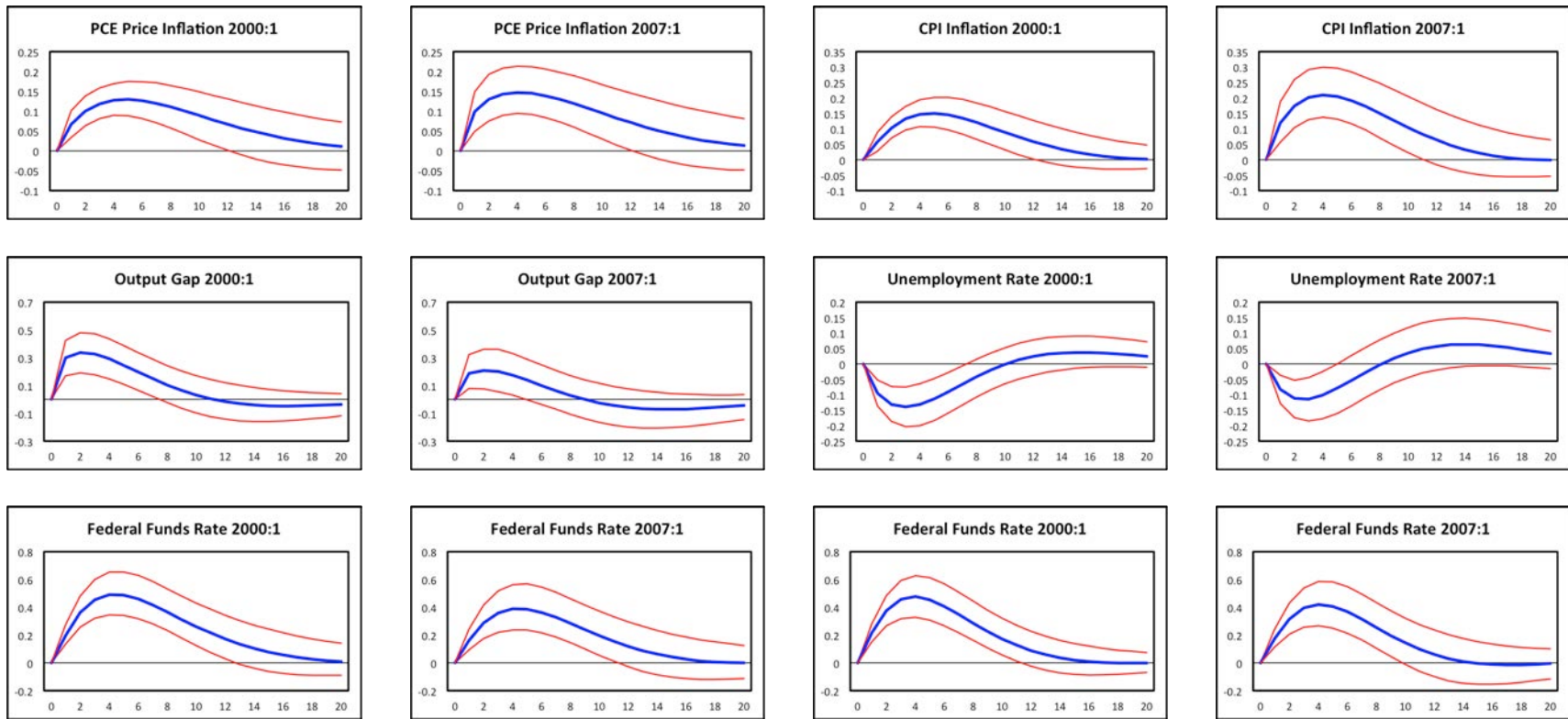
Figure 7. Impulse Responses to Aggregate Demand Shocks. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the impulse response of the indicated variable to an identified expansionary aggregate demand shock at the indicated date. Graphs in the two left columns are from the model with core PCE price inflation and the output gap; graphs in the two right columns are from the model with core CPI inflation and the unemployment rate.
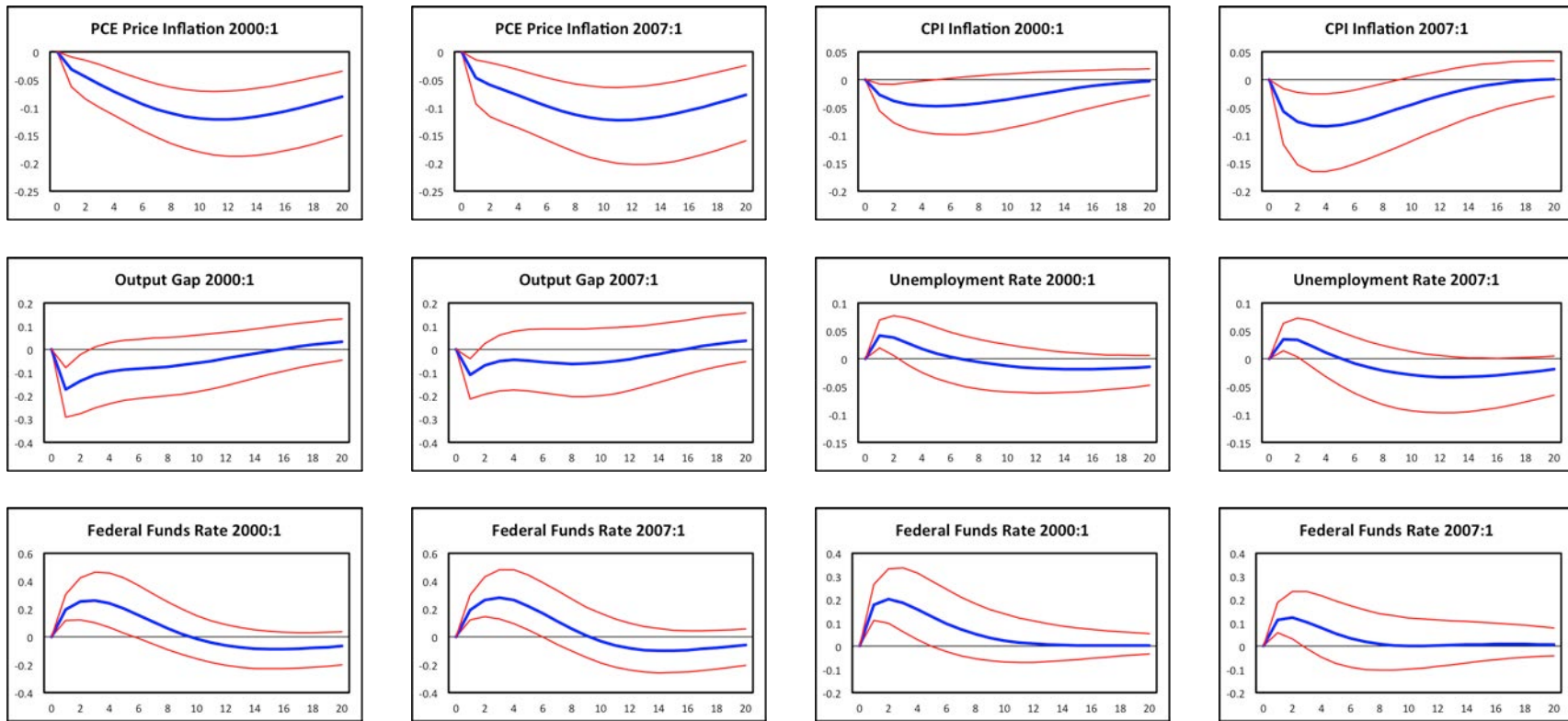
Figure 8. Impulse Responses to Monetary Policy Shocks. Each panel plots the median (thick blue line) and 16th and 84th percentiles (thin red lines) of the posterior distribution of the impulse response of the indicated variable to an identified contractionary monetary policy shock at the indicated date. Graphs in the two left columns are from the model with core PCE price inflation and the output gap; graphs in the two right columns are from the model with core CPI inflation and the unemployment rate.
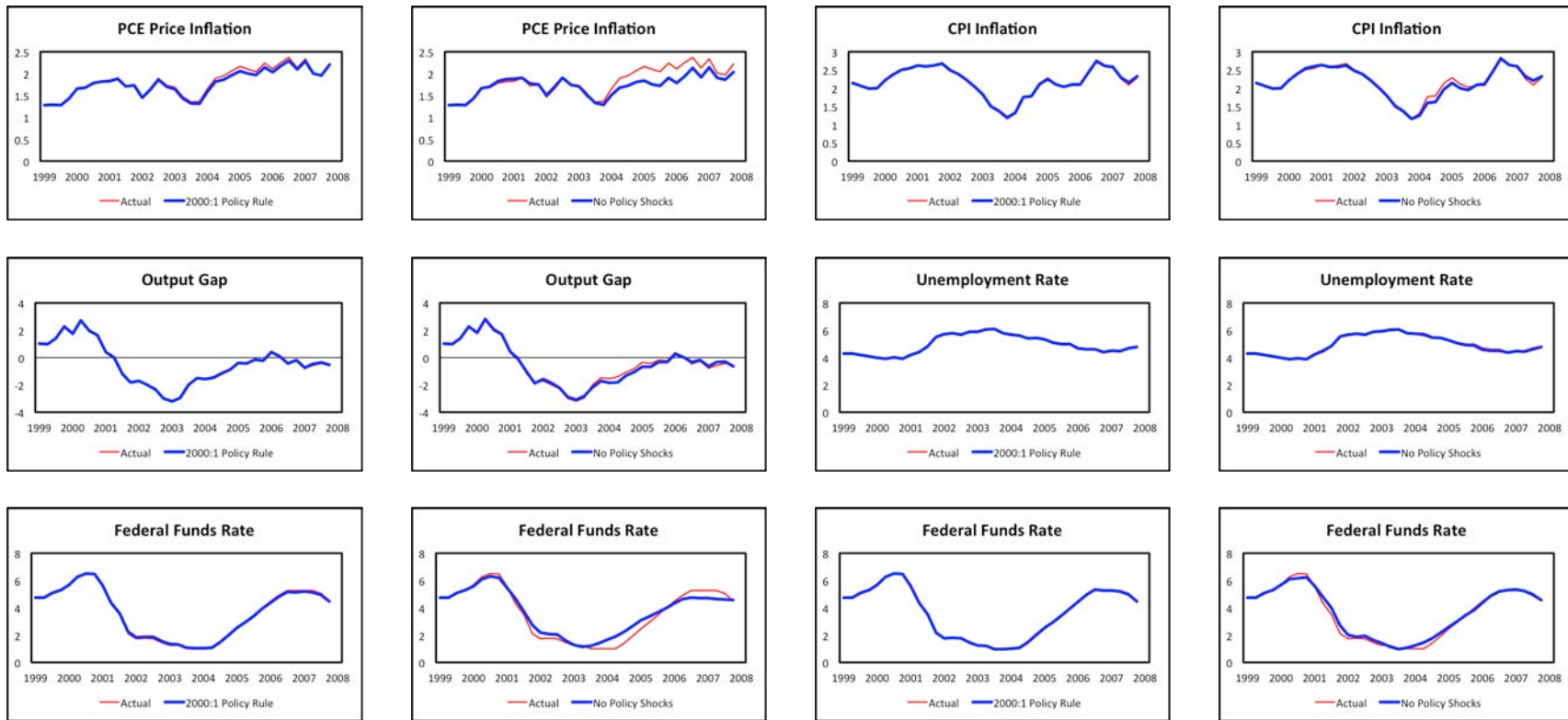
Figure 9. Counterfactual Simulations. Each panel compares the actual behavior of the indicated variable to the median counterfactual path, when either the coefficients of the monetary policy rule are drawn from their 2001:1 posterior distribution or when there are no monetary policy shocks from 2000:1 through 2007:4. Graphs in the two left columns are from the model with core PCE price inflation and the output gap; graphs in the two right columns are from the model with core CPI inflation and the unemployment rate.