Changes in the Federal Reserve's Inflation Target: Causes and Consequences

Peter N. Ireland*
Boston College and NBER

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Abstract

This paper estimates a New Keynesian model to draw inferences about the behavior of the Federal Reserve's unobserved inflation target. The results indicate that the target rose from 1 1/4 percent in 1959 to over 8 percent in the mid-to-late 1970s before falling back below 2 1/2 percent in 2004. The results also provide some support for the hypothesis that over the entire postwar period, Federal Reserve policy has systematically translated short-run price pressures set off by supply-side shocks into more persistent movements in inflation itself, although considerable uncertainty remains about the true source of shifts in the inflation target.

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*Please address correspondence to: Peter N. Ireland, Boston College, Department of Economics, 140 Commonwealth Avenue, Chestnut Hill, MA 02467-3859. Tel: (617) 552-3687. Fax: (617) 552-2308. Email: irelandp@bc.edu. All data and programs used in this research are freely available at http://www2.bc.edu/~irelandp. I would like to thank seminar participants at the Federal Reserve Bank of Boston for extremely helpful comments and suggestions. Some of this work was completed while I was visiting the Research Department at the Federal Reserve Bank of Boston; I would like to thank the Bank and its staff for their hospitality and support. This material is also based upon work supported by the National Science Foundation under Grant No. SES-0213461. Any opinions, findings, and conclusions or recommedations expressed herein are my own and do not reflect those of the Federal Reserve Bank of Boston, the Federal Reserve System, the National Bureau of Economic Research, or the National Science Foundation.

1 Introduction

"Inflation is always and everywhere a monetary phenomenon." Thus spoke Milton Friedman (1968, p.39).

Once controversial, Friedman's words now form part of conventional wisdom for academic economists and central bankers alike, provided they are appropriately qualified as follows: transitory movements in the measured rate of inflation can be driven by shocks of various kinds, but large and persistent movements in inflation cannot occur without the help of monetary policy. Indeed, Friedman himself draws this distinction when defining (p.21) the "inflation" in his statement as a "steady and sustained rise in prices."

An interest rate rule for monetary policy of the type proposed by Taylor (1993) serves to highlight exactly the same principles. Under the simplest such rule, the central bank adjusts the short-term nominal interest rate r around its average or steady-state level r^* in response to deviations of output y and inflation π from their target or steady-state levels y^* and π^* according to

$$r = r^* + \omega_y(y - y^*) + \omega_\pi(\pi - \pi^*),$$

where ω_y and ω_π are both positive coefficients. When it adopts such a rule, the central bank accepts responsibility for choosing the inflation target π^* and for choosing a policy response coefficient ω_π that is large enough to stabilize the actual inflation rate π around its target π^*. In the short run, movements in measured inflation π may occur for many reasons, but in the long run, inflation remains tied down by monetary policy.

Nothing dictates that the central bank's inflation target must remain constant over time, however. In fact, figure 1 shows that even in the relatively stable postwar United States economy, inflation exhibits large and persistent swings, trending upward throughout the 1960s and 1970s before reversing course and falling during the 1980s and 1990s. Friedman's "always and everywhere" dictum strongly suggests that movements of the size and persistence seen in figure 1 could not have taken place without ongoing shifts in the Federal Reserve's inflation target. But the Federal Reserve has never explicitly revealed the setting for its inflation target. Hence, a statistical or econometric model must be used to glean information about the Federal Reserve's inflation target from data on observable variables—that is, to disentangle those movements seen in figure 1 that reflect shifts in the inflation target from those that are attributable to other types of shocks.

This paper develops such a model, drawing on contemporary macroeconomic theory to provide the identifying restrictions needed to shed light on the patterns, causes, and consequences of changes in the Federal Reserve's inflation target. The macroeconomic theory comes from a standard New Keynesian framework like those presented by Clarida, Gali, and Gertler (1999) and Woodford (2003) and used throughout the much of the recent literature on monetary policy and the monetary business cycle. This model offers up a tight description, not just of Federal Reserve policy, but also of the optimizing behavior of the households and firms that populate the American economy. Hence, estimates of the structural parameters of this simultaneous-equation model not only provide a detailed interpretation of historical movements in output, inflation, and interest rates as seen in the US data, but also allow for an equally detailed consideration of counterfactual scenarios such as: what would the behavior of these variables have looked like if, instead, the Federal Reserve had maintained a constant inflation target throughout the postwar period?

Blinder (1982), Hetzel (1998), and Mayer (1998) all attribute the upward secular trend in inflation shown in figure 1 for the period before 1980 to a systematic tendency for Federal Reserve policy to translate the short-run price pressures set off by adverse supply shocks into more persistent changes in the inflation rate itself—part of an effort by policymakers to avoid at least some of the contractionary impact those shocks would otherwise have had on the real economy. Symmetrically, Bomfim and Rudebusch (2000) and Orphanides and Wilcox (2002) suggest that at times during the post-1980 period, the Federal Reserve took advantage of favorable supply-side disturbances to "opportunistically" work the inflation rate back down. To capture these ideas, the model developed here includes a generalized Taylor rule that allows the Federal Reserve's inflation target to respond systematically to shocks hitting the economy from the supply side. The estimation results provide some support for a unified version of these stories that applies to the entire postwar period, although the same results also indicate that considerable uncertainty remains as to exactly why the Federal Reserve allowed inflation to move as much as it did.

Before going on to provide a more detailed description of the model and results, mention should be made of two related sets of contributions to the recent literature. First, Kozicki and Tinsley (2001), Dewachter and Lyrio (2003), Gurkaynak, Sack, and Swanson (2003), and Rudebusch and Wu (2004) argue that the behavior of both short and long-term interest rates in the US data becomes easier to reconcile with the expectations hypothesis of the term structure if one allows for shifts in the long-run inflation rate. Thus, these previous studies help motivate the analysis performed here, which focuses solely on macroeconomic variables in an effort to more sharply estimate exactly when those shifts took place and why.

Second, Favero and Rovelli (2003), Surico (2003), and Dennis (2004) estimate small-scale macroeconomic models and detect evidence of a one-time shift in the Federal Reserve's inflation target occurring coincidentally with the appointment of Paul Volcker as Federal Reserve Chairman in 1979, but these previous studies do not allow for more frequent changes in the inflation target like those considered here. Erceg and Levin (2003), Salemi (2003), Smets and Wouters (2003), Gavin, Keen, and Pakko (2004), and Roberts (2004), on the other hand, develop macroeconomic models that do allow for continual movement in the Federal Reserve's inflation target. However, each of these previous studies focuses on a different set of issues: Erceg and Levin (2003) on private agents' inability to disentangle transitory from persistent movements in the inflation target and the role that this incomplete information plays in accounting for the inflationary dynamics observed during the Volcker disinflation in the US; Salemi (2003) on the relative weights placed by the Federal Reserve on its stabilization objectives for output, inflation, and interest rates over the postwar period; Smets and Wouters (2003) on the ability of their larger-scale New Keynesian model to track the postwar US data on a larger number of variables both in and out of sample; Gavin, Keen, and Pakko (2004) on the ability of their model to account for the persistence of inflation and the relative volatilities of money growth and inflation in the post-1980 US data; and Roberts (2004) on the ability of his model to capture the changing relationships between US unemployment and inflation since 1980. Thus, none of these previous studies focuses as this paper does on obtaining estimates of the Federal Reserves continually-changing inflation target over the postwar period; and none of these previous studies attempts as this paper does to specifically model those target changes as deliberate policy responses to other shocks that have hit the economy in order to tie together the stories told earlier by Blinder (1982), Hetzel (1998), and Mayer (1998) on the one hand and Bomfim and Rudebusch (2000) and Orphanides and Wilcox (2002) on the other.

2 The Model

2.1 Overview and Rationale

The model developed here shares its basic features with many recent New Keynesian formulations, including the benchmark models of Clarida, Gali, and Gertler (1999) and Woodford (2004), but resembles most closely the specification used in Ireland (2004a). As noted above, one extension to previous models that appears for the first time here is a generalized Taylor (1993) rule for monetary policy that allows the central bank's inflation target to adjust in response to other shocks that hit the economy. Indeed, the use of this tightly parameterized structural model, as opposed to a more loosely constrained vector autoregression or unobserved components model, allows for the simultaneous identification not just of movements in the inflation target but also of the exogenous supply-side disturbances that, according to Blinder (1982), Hetzel (1998), and Mayer (1998), prompted the Federal Reserve to accommodate higher and higher rates of inflation throughout the 1960s and 1970s. And, again as noted above, the use of this tightly parameterized structural model responds to the Lucas

(1976) critique, allowing for a detailed consideration of the counterfactual scenario in which, instead, the Federal Reserve held the line on inflation in the face of these shocks.

The model economy consists of a representative household, a representative finished goods-producing firm, a continuum of intermediate goods-producing firms indexed by $i \in [0, 1]$, and a central bank. During each period $t = 0, 1, 2, \ldots$, each intermediate goods-producing firm manufactures a distinct, perishable intermediate good. Hence, intermediate goods may also be indexed by $i \in [0, 1]$, where firm i produces good i. The model retains enough symmetry, however, to allow the analysis to focus on the activities of a representative intermediate goods-producing firm, which produces the generic intermediate good i. Thus, a description of the model boils down to a description of the optimizing behavior of three representative private agents—the household, the finished goods-producing firm, and the intermediate goods-producing firm—together with a description of the generalized Taylor rule adopted by the central bank.

2.2 The Representative Household

The representative household enters each period $t = 0, 1, 2, \ldots$ with money M_{t-1} and bonds B_{t-1}. At the beginning of period t, the household receives a lump-sum nominal transfer T_t from the central bank. Next, the household's bonds mature, throwing off B_{t-1} additional units of money. The household uses some of this money to purchase B_t new bonds at the price of $1/R_t$ units of money per bond, where R_t denotes the gross nominal interest rate between t and $t + 1$.

During period t, the household supplies a total of h_t units of labor to the various intermediate goods-producing firms and gets paid at the nominal wage rate W_t. Also during period t, the household consumes C_t units of the finished good, purchased at the nominal price P_t from the representative finished goods-producing firm.

At the end of period t, the household receives nominal profits D_t in the form of dividends paid by the intermediate goods-producing firms. The household then carries M_t units of money into period $t+1$; its budget constraint requires that

$$M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t \geq P_t C_t + M_t + B_t/R_t \tag{1}$$

for all $t = 0, 1, 2, ...$

The household's preferences are described by the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t a_t [\ln(C_t - \gamma C_{t-1}) + \ln(M_t/P_t) - h_t],$$

where the discount factor β and the habit formation parameter γ both lie between zero and one: $1 > \beta > 0$ and $1 > \gamma \geq 0$. The preference shock a_t follows the stationary autoregressive process

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \sigma_a \varepsilon_{at} \tag{2}$$

for all $t = 0, 1, 2, ...$, with $1 > \rho_a \geq 0$ and $\sigma_a \geq 0$, where the serially uncorrelated innovation ε_{at} has the standard normal distribution. Utility is additively separable in consumption, real money balances, and hours worked; as shown by Driscoll (2000) and Ireland (2004*b*), this additive separability is needed to derive a conventional specification for the model's IS relationship that, in particular, excludes terms involving money and employment. Given this additive separability, the logarithmic specification for utility from consumption is needed, as shown by King, Plosser, and Rebelo (1988), for the model to remain consistent with balanced growth. Finally, habit formation is introduced into preferences following Fuhrer (2000), who shows that this feature—and the partially backward-looking consumption it implies—helps New Keynesian models like this one replicate the observed effects on real spending of shocks of various kinds.

Thus, the household chooses C_t, h_t, B_t, and M_t for all $t = 0, 1, 2, ...$ to maximize its expected utility subject to the budget constraint (1) for all $t = 0, 1, 2, ...$ The first-order conditions for this problem can be written as

$$\Lambda_t = \frac{a_t}{C_t - \gamma C_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{C_{t+1} - \gamma C_t}\right), \tag{3}$$

$$a_t = \Lambda_t(W_t/P_t), \tag{4}$$

$$\Lambda_t = \beta R_t E_t(\Lambda_{t+1}/\Pi_{t+1}), \tag{5}$$

$$M_t/P_t = (a_t/\Lambda_t)[R_t/(R_t - 1)], \tag{6}$$

and (1) with equality for all $t = 0, 1, 2, ...$, where Λ_t denotes the nonnegative Lagrange multiplier on the budget constraint expressed in real terms for period t and $\Pi_t = P_t/P_{t-1}$ denotes the gross inflation rate between $t-1$ and t. Equation (3) identifies the multiplier Λ_t with the marginal utility of consumption during period t, adjusted to account for the habit-persistence effects that carry over into $t+1$. Since utility is linear in hours worked, (4) equates the marginal rate of substitution between consumption and leisure to the real wage. The Euler equation (5) relates the intertemporal marginal rate of substitution to the real interest rate, while (6) takes the form of a money demand relationship, implying that real balances rise as consumption rises and the nominal interest rate falls.

2.3 The Representative Finished Goods-Producing Firm

During each period $t = 0, 1, 2, ...$, the representative finished goods-producing firm uses $Y_t(i)$ units of each intermediate good $i \in [0, 1]$, purchased at the nominal price $P_t(i)$, to manufacture Y_t units of the finished good according to the constant-returns-to-scale technology described by

$$\left[\int_0^1 Y_t(i)^{(\theta_t - 1)/\theta_t} di\right]^{\theta_t/(\theta_t - 1)} \geq Y_t,$$

where θ_t follows the stationary autoregressive process

$$\ln(\theta_t) = (1 - \rho_\theta)\ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \sigma_\theta \varepsilon_{\theta t} \tag{7}$$

for all $t = 0, 1, 2, ...$, with $1 > \rho_\theta \geq 0$ and $\sigma_\theta \geq 0$, and where the serially uncorrelated innovation $\varepsilon_{\theta t}$ has the standard normal distribution. The firm acts to maximize its profits; the first-order conditions for this problem are

$$Y_t(i) = [P_t(i)/P_t]^{-\theta_t} Y_t$$

for all $i \in [0, 1]$ and $t = 0, 1, 2, ...$

These optimality conditions reveal that $-\theta_t$ measures the time-varying elasticity of demand for each intermediate good $i \in [0, 1]$. Hence, as in Smets and Wouters (2003), Steinsson (2003), and Ireland (2004a), random shocks to θ_t translate into shocks to the intermediate goods-producing firms' desired markups of price over marginal cost; in equilibrium, they act like cost-push shocks of the kind introduced into the New Keynesian model by Clarida, Gali, and Gertler (1999). Competition drives the finished goods-producing firm's profits to zero in equilibrium, determining P_t as

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta_t} di \right]^{1/(1-\theta_t)}$$

for all $t = 0, 1, 2, ...$

2.4 The Representative Intermediate Goods-Producing Firm

During each period $t = 0, 1, 2, ...$, the representative intermediate goods-producing firm hires $h_t(i)$ units of labor from the representative household to manufacture $Y_t(i)$ units of intermediate good i according to the constant-returns-to-scale technology described by

$$Z_t h_t(i) \geq Y_t(i). \tag{8}$$

The aggregate technology shock follows a random walk with drift:

$$\ln(Z_t) = \ln(z) + \ln(Z_{t-1}) + \sigma_z \varepsilon_{zt} \tag{9}$$

for all $t = 0, 1, 2, ...$, with $z > 1$ and $\sigma_z \geq 0$, where the serially uncorrelated innovation ε_{zt} has the standard normal distribution. This random walk assumption for the technology shock serves to distinguish its effects from those of the cost-push shock: as supply-side disturbances, both shocks tend to move output and inflation in opposite directions in the short run, but only the technology shock has permanent effects on the level of output.

Since the intermediate goods substitute imperfectly for one another in producing the finished good, the representative intermediate goods-producing firm sells its output in a monopolistically competitive market: during period t, the firm sets the nominal price $P_t(i)$ for its output, subject to the requirement that it satisfy the representative finished goods-producing firm's demand at that chosen price. And, as in Rotemberg (1982), the intermediate goods-producing firm faces a quadratic cost of adjusting its price between periods, measured in terms of the finished good and given by

$$\frac{\phi}{2}\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}P_{t-1}(i)} - 1\right]^2 Y_t,$$

where $\phi \geq 0$ governs the magnitude of the adjustment cost, Π_t^* denotes the central bank's inflation target for period t, and the parameter α lies between zero and one: $1 \geq \alpha \geq 0$. According to this specification, the extent to which price setting is forward or backward looking depends on whether α is closer to zero or one. At one extreme, when $\alpha = 0$ price setting is purely forward looking, in the sense that firms find it costless to adjust their prices in line with the central bank's inflation target. At the other extreme, when $\alpha = 1$ price setting is purely backward looking, in the sense that firms find it costless to adjust their prices in line with the previous period's inflation rate.

In any case, the cost of price adjustment makes the intermediate goods-producing firm's problem dynamic: it chooses $P_t(i)$ for all $t = 0, 1, 2, ...$ to maximize its real market value, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t [D_t(i)/P_t],$$

where $\beta^t \Lambda_t$ measures the marginal utility value to the representative household of an additional unit of real profits received in the form of dividends during period t and where

$$\frac{D_t(i)}{P_t} = \left[\frac{P_t(i)}{P_t}\right]^{1-\theta_t} Y_t - \left[\frac{P_t(i)}{P_t}\right]^{-\theta_t} \left(\frac{W_t}{P_t}\right)\left(\frac{Y_t}{Z_t}\right) - \frac{\phi}{2}\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1\right]^2 Y_t \quad (10)$$

measures the firm's real profits during period t in light of the requirement that it sell its output on demand at price $P_t(i)$. The first-order conditions for this problem are

$$\begin{aligned} 0 \;=\; & (1-\theta_t)\left[\frac{P_t(i)}{P_t}\right]^{-\theta_t} + \theta_t \left[\frac{P_t(i)}{P_t}\right]^{-\theta_t - 1} \left(\frac{W_t}{P_t}\right)\left(\frac{1}{Z_t}\right) \\ & -\phi \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1\right] \left[\frac{P_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha} P_{t-1}(i)}\right] \\ & +\beta\phi E_t \left\{ \left(\frac{\Lambda_{t+1}}{\Lambda_t}\right) \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha} P_t(i)} - 1\right] \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha} P_t(i)}\right] \left[\frac{P_t}{P_t(i)}\right] \left(\frac{Y_{t+1}}{Y_t}\right) \right\} \end{aligned} \quad (11)$$

and (8) with equality for all $t = 0, 1, 2, ...$ In the absence of price adjustment costs, when $\phi = 0$, (11) simply implies that the firm sets its price $P_t(i)$ as a markup $\theta_t/(\theta_t - 1)$ over marginal cost W_t/Z_t. Hence, as suggested above, $\theta_t/(\theta_t - 1)$ can be interpreted as the firm's desired markup, and random fluctuations in θ_t act like shocks to the firm's desired markup. Costly price adjustment ($\phi > 0$) then implies that actual markups deviate from, but tend to gravitate towards, their desired level as firms respond optimally to the shocks that hit the economy.

2.5 The Central Bank

The central bank conducts monetary policy according to the generalized Taylor (1993) rule

$$\ln(R_t) - \ln(R_{t-1}) = \rho_\pi \ln(\Pi_t/\Pi_t^*) + \rho_{gy} \ln(g_t^y/g^y) + \ln(v_t) \tag{12}$$

for all $t = 0, 1, 2, ...$, where the response coefficients $\rho_\pi > 0$ and $\rho_{gy} \geq 0$ are chosen by the central bank. Here, as in Fuhrer and Moore (1995), the central bank increases the short-term nominal interest rate R_t whenever the inflation rate Π_t rises above its target Π_t^*; a strictly positive value for ρ_π helps provide for the existence of a unique rational expectations equilibrium under an interest rate rule of this type. Since the level of output Y_t inherits a unit root from the random walk process (9) for the technology shock Z_t, (12) dictates that the central bank respond instead to the growth rate of output

$$g_t^y = Y_t/Y_{t-1} \tag{13}$$

as a stationary measure of real economic activity, increasing the short-term nominal interest rate whenever output growth rises about its steady-state level $g^y = z$. The transitory monetary policy shock v_t in (12) follows the stationary autoregressive process

$$\ln(v_t) = \rho_v \ln(v_{t-1}) + \sigma_v \varepsilon_{vt} \tag{14}$$

for all $t = 0, 1, 2, ...$, with $1 > \rho_v \geq 0$ and $\sigma_v \geq 0$, where the serially uncorrelated innovation ε_{vt} has the standard normal distribution.

As noted above, a novel feature of the generalized Taylor rule (12) incorporated into this model is the time-varying inflation target Π_t^*, which evolves according to

$$\ln(\Pi_t^*) = \ln(\Pi_{t-1}^*) - \delta_\theta \varepsilon_{\theta t} - \delta_z \varepsilon_{zt} + \sigma_\pi \varepsilon_{\pi t} \tag{15}$$

for all $t = 0, 1, 2, ...$, where the response coefficients $\delta_\theta \geq 0$ and $\delta_z \geq 0$ are again chosen by the central bank, where $\sigma_\pi \geq 0$, and where the serially uncorrelated innovation $\varepsilon_{\pi t}$ has the standard normal distribution. This addition to the Taylor rule allows the inflation target to vary exogenously when σ_π is strictly positive and also allows the central bank to systematically adjust its inflation target in response to either or both of the two supply shocks: the cost-push shock θ_t and the technology shock Z_t. Since adverse supply shocks (negative realizations of $\varepsilon_{\theta t}$ and ε_{zt}) work to increase goods prices and favorable supply shocks (positive realizations of $\varepsilon_{\theta t}$ and ε_{zt}) work to decrease goods prices, strictly positive values for $\delta_{\theta t}$ and δ_{zt} help the model bring together and formalize the stories told by Blinder (1982), Hetzel (1998), Mayer (1998), Bomfim and Rudebusch (2000), and Orphanides and Wilcox (2002), according to which the Federal Reserve acted systematically over the postwar period to translate the short-run price pressures set off by these shocks into more persistent movements in the inflation rate itself.

Finally, the random walk specification for the inflation target that is built into (15) represents an identifying assumption that, in very much the same spirit as the random walk assumption (9) for technology, helps distinguish the effects of changes in the inflation target from those generated by the model's four other shocks. This identifying assumption, motivated by Friedman's (1968) "always and everywhere" dictum, can be stated more simply as: permanent changes in measured inflation Π_t cannot occur without corresponding changes in the central bank's inflation target Π_t^*.

2.6 Symmetric Equilibrium

In a symmetric equilibrium, all intermediate goods-producing firms make identical decisions, so that $Y_t(i) = Y_t$, $h_t(i) = h_t$, $D_t(i) = D_t$, and $P_t(i) = P_t$ for all $i \in [0, 1]$ and $t = 0, 1, 2, ...$ In addition, the market-clearing conditions for money and bonds, $M_t = M_{t-1} + T_t$ and $B_t = B_{t-1} = 0$ must hold for all $t = 0, 1, 2, ...$ After imposing these equilibrium conditions, and using (4), (6), (8), and (10) to solve out for W_t, M_t, h_t, and D_t, the household's budget constraint (1) can be rewritten as the aggregate resource constraint

$$Y_t = C_t + \frac{\phi}{2}\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} - 1\right]^2 Y_t \tag{16}$$

and the intermediate goods-producing firm's optimal price adjustment rule (11) simplifies to

$$\begin{aligned}\theta_t - 1 &= \theta_t\left(\frac{a_t}{\Lambda_t Z_t}\right) - \phi\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} - 1\right]\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}}\right] \\ &\quad + \beta\phi E_t\left\{\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}} - 1\right]\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}}\right]\left(\frac{Y_{t+1}}{Y_t}\right)\right\}\end{aligned} \tag{17}$$

for all $t = 0, 1, 2, \ldots$. These last two equations, together with (2), (3), (5), (7), (9), and (12)-(15), form a system that completely determines the equilibrium behavior of the eleven variables Y_t, C_t, Π_t, R_t, g_t^y, Λ_t, a_t, θ_t, Z_t, v_t, and Π_t^*.

2.7 The Linearized System

In equilibrium, the real variables Y_t, C_t, and Λ_t all inherit unit roots from the process (9) for technology Z_t; however, the transformed variables $y_t = Y_t/Z_t$, $c_t = C_t/Z_t$, $\lambda_t = Z_t\Lambda_t$, and $z_t = Z_t/Z_{t-1}$ all remain stationary, as does the output growth rate g_t^y. Similarly, the nominal variables Π_t and R_t inherit unit roots from the process (15) for the inflation target Π_t^*; however, the transformed variables $\pi_t = \Pi_t/\Pi_t^*$, $r_t = R_t/\Pi_t^*$, and $\pi_t^* = \Pi_t^*/\Pi_{t-1}^*$ remain stationary, as do the growth rate of inflation

$$g_t^{\pi} = \Pi_t/\Pi_{t-1} \tag{18}$$

and the ratio of the nominal interest rate to the inflation rate

$$r_t^{r\pi} = R_t/\Pi_t. \tag{19}$$

When rewritten in terms of these stationary variables, (2), (3), (5), (7), (9), and (12)-(19) imply that in the absence of shocks, the economy converges to a steady state growth path, along which $y_t = y = [(\theta-1)/\theta][(z-\beta\gamma)/(z-\gamma)]$, $c_t = c = [(\theta-1)/\theta][(z-\beta\gamma)/(z-\gamma)]$, $\pi_t = 1$, $r_t = r = z/\beta$, $g_t^y = g^y = z$, $g_t^\pi = 1$, $r_t^{r\pi} = r^{r\pi} = z/\beta$, $\lambda_t = \lambda = \theta/(\theta-1)$, $a_t = 1$, $\theta_t = \theta$, $z_t = z$, $v_t = 1$, and $\pi_t^* = 1$ for all $t = 0, 1, 2, ...$

The stationary system can therefore be log-linearized around its steady state to describe how the economy responds to shocks. Let $\hat{y}_t = \ln(y_t/y)$, $\hat{c}_t = \ln(c_t/c)$, $\hat{\pi}_t = \ln(\pi_t)$, $\hat{r}_t = \ln(r_t/r)$, $\hat{g}_t^y = \ln(g_t^y/g^y)$, $\hat{g}_t^\pi = \ln(g_t^\pi)$, $\hat{r}_t^{r\pi} = \ln(r_t^{r\pi}/r^{r\pi})$, $\hat{\lambda}_t = \ln(\lambda_t/\lambda)$, $\hat{a}_t = \ln(a_t)$, $\hat{\theta}_t = \ln(\theta_t/\theta)$, $\hat{z}_t = \ln(z_t/z)$, $\hat{v}_t = \ln(v_t)$, and $\hat{\pi}_t^* = \ln(\pi_t^*)$ measure the percentage deviation of each stationary variable from its steady-state level. A first-order Taylor approximation to the aggregate resource constraint (16) implies that $\hat{c}_t = \hat{y}_t$: price adjustment costs are of second-order importance around the steady state growth path. First-order approximations to the remaining twelve equations then imply

$$(z-\gamma)(z-\beta\gamma)\hat{\lambda}_t = \gamma z\hat{y}_{t-1} - (z^2+\beta\gamma^2)\hat{y}_t + \beta\gamma z E_t\hat{y}_{t+1} + (z-\gamma)(z-\beta\gamma\rho_a)\hat{a}_t - \gamma z\hat{z}_t, \tag{20}$$

$$\hat{\lambda}_t = E_t\hat{\lambda}_{t+1} + \hat{r}_t - E_t\hat{\pi}_{t+1}, \tag{21}$$

$$(1+\beta\alpha)\hat{\pi}_t = \alpha\hat{\pi}_{t-1} + \beta E_t\hat{\pi}_{t+1} + \psi(\hat{a}_t - \hat{\lambda}_t) - \hat{e}_t - \alpha\hat{\pi}_t^*, \tag{22}$$

$$\hat{r}_t - \hat{r}_{t-1} = \rho_\pi\hat{\pi}_t + \rho_{gy}\hat{g}_t^y - \hat{\pi}_t^* + \hat{v}_t, \tag{23}$$

$$\hat{\pi}_t^* = \sigma_\pi\varepsilon_{\pi t} - \delta_e\varepsilon_{et} - \delta_z\varepsilon_{zt}, \tag{24}$$

$$\hat{g}_t^y = \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t, \tag{25}$$

$$\hat{g}_t^\pi = \hat{\pi}_t - \hat{\pi}_{t-1} + \hat{\pi}_t^*, \tag{26}$$

$$\hat{r}_t^{r\pi} = \hat{r}_t - \hat{\pi}_t, \tag{27}$$

$$\hat{a}_t = \rho_a\hat{a}_{t-1} + \sigma_a\varepsilon_{at}, \tag{28}$$

$$\hat{e}_t = \rho_e \hat{e}_{t-1} + \sigma_e \varepsilon_{et}, \tag{29}$$

$$\hat{z}_t = \sigma_z \varepsilon_{zt}, \tag{30}$$

and

$$\hat{v}_t = \rho_v \hat{v}_{t-1} + \sigma_v \varepsilon_{vt} \tag{31}$$

for all $t = 0, 1, 2, ...$ where, in (22), (24), and (29), the cost-push shock $\hat{\theta}_t$ has been renormalized as $\hat{e}_t = (1/\phi)\hat{\theta}_t$ and the new parameters ψ, δ_e, ρ_e, and σ_e have been defined as $\psi = (\theta - 1)/\phi$, $\delta_e = \delta_\theta$, $\rho_e = \rho_\theta$, and $\sigma_e = \sigma_\theta/\phi$ so that like $\varepsilon_{\theta t}$, ε_{et} has the standard normal distribution.

Since (25)-(27) simply restate the definitions of the output growth rate $\hat{g}_t^y$, the inflation growth rate $\hat{g}_t^\pi$, and the ratio of the nominal interest rate to the inflation rate $\hat{r}_t^{r\pi}$ and since (28)-(31) simply describe the processes for the exogenous preference, cost-push, technology, and monetary policy shocks, the model's economic content is concentrated in (20)-(24). In particular, (21) takes the form of a New Keynesian IS curve linking the marginal utility of consumption during period t to its own expected future value and to the value of the ex-ante real interest rate, while (20) measures the marginal utility of consumption and includes both forward and backward-looking terms based on the habit formation specification for preferences. Equation (22) takes the form of a hybrid forward and backward-looking New Keynesian Phillips curve, with the parameter α from the price adjustment cost formulation indexing the degree of backward-looking behavior, the parameter ψ multiplying the real marginal cost term $\hat{a}_t - \hat{\lambda}_t$, and the cost-push shock $\hat{e}_t$ entering additively. Finally, (23) and (24) describe the conduct of monetary policy, including the possibly endogenous evolution of the central bank's inflation target as well as the Taylor-type adjustment of the nominal interest rate taken to stabilize actual inflation around its target.

3 Empirical Strategy and Results

Blanchard and Kahn (1980) and Klein (2000) describe methods for solving systems of linearized expectational difference equations such as (20)-(31). These methods provide solutions that quite conveniently take the same form as a state-space econometric model: in this case, the solution links the behavior of the stationary model's three observable variables—the growth rate of output $\hat{g}_t^y$, the growth rate of inflation $\hat{g}_t^\pi$, and the ratio of the nominal interest rate to the inflation rate $\hat{r}_t^{r\pi}$—to the nine unobservable variables. Hence, the Kalman filtering algorithms outlined by Hamilton (1994, Ch.13) can be applied to obtain maximum likelihood estimates of the model's structural parameters and to optimally exploit information contained in the observable data to draw inferences about the behavior of the unobservables including, most importantly, the unobservable inflation target $\hat{\pi}_t^*$.

Here, this econometric exercise uses quarterly US data running from 1959:1 through 2004:2. In these data, readings on seasonally-adjusted real gross domestic product in chained 2000 dollars, expressed in per-capita terms by dividing by the civilian noninstitutional population, age 16 and over, provide the measure of output Y_t. Readings on the seasonally-adjusted GDP implicit price deflator provide the measure of the nominal price level P_t, and readings on the three-month US Treasury bill rate provide the measure of the short-term nominal interest rate R_t. Prior to their use in the estimation exercise, these raw series get passed through the same stationarity-inducing transformations required to solve the theoretical model. Hence, the empirical model assumes that all three series contain unit roots but that the inflation and interest rates are cointegrated so that, again, the growth rate of output, the growth rate of inflation, and the ratio of the nominal interest rate to the inflation rate are the most relevant stationary variables.

Under the additional assumption that the innovations ε_{at}, ε_{et}, ε_{zt}, ε_{vt}, and $\varepsilon_{\pi t}$ are mutually as well as serially uncorrelated, the model has 17 parameters: z, β, ψ, γ, α, ρ_π, ρ_{gy}, ρ_a, ρ_e, ρ_v, σ_a, σ_e, σ_z, σ_v, σ_π, δ_e, and δ_z. Values $z = 1.0047$ and $\beta = 0.9995$ for the first two parameters on this list are fixed prior to estimation in order to insure that the steady-state rate of output growth $g^y = z$ and the steady-state ratio of the nominal interest rate to the inflation rate $r^{r\pi} = z/\beta$ as implied by the theoretical model match the average values of the same two variables as measured in the data. The model implies that along the steady-state growth path, the rate of growth in inflation is zero and, indeed, in the US data, the sample average of the growth rate of inflation is quite small: figure 1 reveals that, in levels, the inflation rate ends the 45-year sample period at approximately the same point at which it begins, so that the average quarterly rate of change in inflation over four-and-a-half decades is only 0.000016, that is, 0.0016 of one percent or 0.16 basis points. Hence, all variables are accurately demeaned prior to estimation, in a manner consistent with the implications of the theoretical model.

Preliminary attempts to estimate the model's remaining 15 parameters consistently led to very small values of ψ, the coefficient on real marginal cost in the Phillips curve (22); since $\psi = (\theta - 1)/\phi$, these small values for ψ correspond to very large values for the price adjustment cost parameter ϕ. Hence, in deriving the results described below, the same setting $\psi = 0.10$ used in Ireland (2004*a*, 2004*b*) is also imposed prior to estimation. The formulas displayed by Gali and Gertler (1999, p.211) provide a convenient way of interpreting this setting for ψ: in a model in which firms set prices in a staggered fashion according to Calvo's (1983) formulation instead of facing an explicit cost of price adjustment as they do here, a value of $\psi = 0.10$ for the coefficient on the real marginal cost term in a purely forward-looking New Keynesian Phillips curve implies that individual goods prices remain fixed, on average, for 3.7 quarters—or just under one year.

With these three parameter values fixed in advance, table 1 presents maximum likelihood estimates of the model's remaining parameters along with their standard errors, computed by taking the square roots of the diagonal elements of minus one times the inverted matrix of second derivatives of the maximized log-likelihood function. To assist in interpreting many of the results presented below, the table reports two sets of estimates: one obtained from an unconstrained "endogenous target" version of the model in which all 14 parameters, including the inflation target response coefficients δ_e and δ_z, are estimated freely and the other obtained from a constrained "exogenous target" version of the model in which δ_e and δ_z remain fixed at zero while the other 12 parameters are estimated freely.

For both versions of the model, the estimates imply a degree of backward-looking behavior in consumption, as measured by a habit-formation parameter γ around 0.25, that is significant both economically and statistically, but no backward-looking behavior in price setting. For both versions of the model, the estimates reveal that both inflation and output growth enter significantly into the Taylor rule for the nominal interest rate; the policy response to inflation, however, appears considerably more vigorous than the associated response to output growth. And for both versions of the model, the estimates suggest that the preference shock is highly persistent while the cost-push and monetary policy shocks are much less so.

The basic workings of the model are most conveniently illustrated by tracing out impulse response functions generated from the exogenous target variant, since in that case the effects of the cost-push and technology shocks are not distorted by coincident changes in the inflation target. Hence, figure 2 displays these impulse responses. The graphs confirm that the preference shock acts like an exogenous demand-side disturbance, moving output, inflation, and the short-term nominal interest rate in the same direction. The cost-push and technology shocks, by contrast, act like supply-side disturbances, moving output and inflation in opposite directions. As noted above, the random walk specification for technology serves to distinguish between the effects of these two supply-side shocks: a favorable cost-push shock leads to a purely transitory increase in output, whereas a favorable technology shock permanently raises the level of output. In addition, the larger and more persistent increase in output growth that follows the technology shock implies, under the estimated Taylor rule, that the nominal interest rate rises after the technology shock but falls after the cost-push shock.

A one-standard-deviation innovation to the transitory monetary policy shock works to increase the annualized short-term nominal interest rate by about 36 basis points and keeps the interest rate above its steady-state level for two years. This exogenous monetary tightening generates a decline in output of about 30 basis points and a fall in inflation of about 50 basis points; these movements in output and inflation, like that of the interest rate itself, persist over a period of about two years.

Finally, a one-standard-deviation shock to the inflation target leads to a permanent 40-basis-point increase in both the inflation and nominal interest rates. As inflation overshoots in the short run, while the nominal interest rate adjusts only gradually, the real interest rate falls, generating an 11-basis-point rise in output that persists for more than two years. In fact, the cumulative addition to aggregate output over this period amounts to 37.6 basis points. This last figure implies a sacrifice ratio—as measured by the cumulative output loss resulting from a permanent reduction in inflation—of just less slightly less than unity. This value for the sacrifice ratio tends towards the low end, but still lies within, the range of estimates obtained by Cecchetti and Rich (2001) with a set of less highly constrained vector autoregressive models estimated with postwar US data.

For the endogenous target model, the estimates $\delta_e = 0.0010$, $\delta_z = 0.0002$, and $\sigma_\pi = 0.0000$ attribute all movements in the inflation target to the Federal Reserve's deliberate response to the two supply shocks: the exogenous shock to the inflation target no longer plays a role in explaining the data. A clear interpretation of these parameter estimates emerges from figure 3, which plots impulse responses generated from the unconstrained model. In particular, the figure shows that under the estimated policy, the inflation target falls by 41 basis points following a favorable one-standard-deviation cost-push shock and, symmetrically, rises by the same amount following a similarly-sized adverse cost-push disturbance. The figure also reveals that by adjusting the inflation target in this manner, the Federal Reserve's policy works to completely insulate output from the effects of these cost-push shocks: a favorable cost-push shock now causes output to *fall* very slightly, by 4 basis points, before returning to its steady-state level. The smaller estimated value for δ_z implies a correspondingly smaller 6.4-basis-point adjustment of the inflation target following a one-standard-deviation technology shock.

Comparing the point estimates of δ_e to δ_z to their standard errors suggests that the policy response to the cost-push shock is more important, not just economically as shown in figure 3 but statistically as well. However, computation of the standard errors shown in table 1 involves two steps—first, the numerical evaluation of the matrix of second derivatives of the maximized log-likelihood function and second, the numerical evaluation of the inverse of that matrix—both of which can make those figures less than fully reliable. Hence, table 1 also compares the maximized value of the log-likelihood function for both versions of the model: 2310.68 with the endogenous inflation target versus 2309.87 with the exogenous target. Since the exogenous target model is a constrained version of the endogenous target model, the likelihood ratio statistic of 1.62 formed by doubling the difference between these two values suggests that, in fact, the null hypothesis that $\delta_e = 0$ and $\delta_z = 0$ cannot be rejected with any reasonable degree of confidence. Thus, while the estimates from the endogenous target model do provide some support for a combined version of the stories told by Blinder (1982), Hetzel (1998), Mayer (1998), Bomfim and Rudebusch (2000), and Orphanides and Wilcox (2002), according to which the Federal Reserve consistently acted over the postwar period to translate the purely transitory price pressures brought about by supply shocks—particularly cost-push shocks—into more persistent movements in inflation, considerable uncertainty remains about the true source of movements in the Federal Reserve's inflation target, so that one cannot statistically reject the exogenous target model that depicts those movements as purely random.

Tables 2 and 3 present forecast error variance decompositions performed with the exogenous and endogenous target models. According to both model variants, technology shocks represent the dominant source of movements in output, although the preference and monetary policy shocks do play a supporting role in driving short-run output fluctuations. Preference shocks become more important in accounting for movements in the nominal interest rate. And both model variants attribute low-frequency movements in inflation to changes in the inflation target, although the constrained model interprets these movements as purely exogenous whereas the unconstrained model views them instead as reflecting the Federal Reserve's deliberate policy response to cost-push shocks.

Figures 4 and 5 superimpose estimates of the Federal Reserve's inflation target on the graph of actual US inflation shown originally as figure 1. These estimates reflect information contained in the full data sample, that is, they are generated using the smoothing algorithms described by Hamilton (1994, pp.394-397) and generalized by Kohn and Ansley (1983) to handle cases like the one that arises here, where the state covariance matrix turns out to be singular. Consistent with all of the previous results, the two model variants have very similar implications for the evolving path of the inflation target although, again, the sources of the inferred movements differ: those in figure 4 are interpreted as purely exogenous, while those in figure 5 are taken as reflections of the Federal Reserve's deliberate response to supply-side disturbances—mainly cost-push shocks. For the exogenous target model, figure 4 shows that the estimated inflation target rises from 1.18 percent in 1959:1 to twin peaks of 7.98 percent in 1974:4 and 8.02 percent in 1980:4. The estimated target hits its post-1980 low of 1.70 percent in both 1998:2 and 2002:1 before rising slightly to 2.14 percent by the end of the sample period in 2004:2. Meanwhile, for the endogenous target model, figure 5 indicates that the estimated target starts at 1.24 percent in 1959:1, peaks at 8.52 percent in 1974:4 and 8.12 percent in 1980:4, falls to its post-1980 low of 1.80 percent in both 1998:2 and 2002:1, and stands at 2.48 percent in 2004:2.

Finally, the structural model developed and estimated here responds positively to the Lucas (1976) critique by cleanly separating out the parameters describing the central bank's policy rule—parameters that will change when that rule changes—from those describing private tastes and technologies—which ought to remain invariant to shifts in the policy rule. Hence, the estimated model provides a detailed answer to questions such as: how would the US economy have behaved if, instead of allowing inflation to rise and fall, the Federal Reserve had maintained a constant inflation target throughout the postwar period? Along those lines, figures 6 and 7 compare the actual paths for output, inflation, and the short-term nominal interest rate as observed in the historical data to those that, according to the two versions of the model, would have been realized under a constant inflation target, that is, in the counterfactual case where instead of equalling their estimated values, the parameters δ_e, δ_z, and σ_π all equal zero.

The figures reveal that the path for output—expressed either in levels or growth rates—looks much the same under the counterfactual scenario as it does historically. This result echoes those shown previously in tables 2 and 3, which attribute virtually all of the observed movements in output to a combination of preference, technology, and monetary policy shocks in the short run and to technology shocks alone in the long run. Inflation, of course, becomes much more stable under the counterfactual scenario. In particular, estimates from the exogenous target model indicate that without changes in the inflation target, US inflation would have peaked at only 4.56 percent in 1975:1, while estimates from the endogenous target model imply that inflation would have hit a postwar high of just 3.92 percent, also in 1975:1. And, through the Fisher effect, the nominal interest rate follows the inflation rate by becoming lower and more stable under the counterfactual scenario.

4 Conclusions, Interpretations, and Directions for Future Work

The estimates of the Federal Reserve's inflation target shown in figures 4 and 5, together with the counterfactual histories traced out in figures 6 and 7, bring the analysis full circle, back to Friedman's (1968) "always and everywhere" quote from the outset. Those figures, derived from an estimated New Keynesian model, suggest that the Federal Reserve's inflation target rose from about 1 1/4 percent in 1959 to hit twin peaks at or above 8 percent in 1974 and 1980 before falling back below 2 1/2 percent by the end of the sample period in 2004. Those figures also suggest that absent those target changes, US inflation would never have exceeded

4 or 4 1/2 percent. Thus, by attributing the bulk of inflation's rise and fall to Federal Reserve policy, the results confirm that to a large extent indeed, postwar US inflation is a "monetary phenomenon."

What's more, estimates from the best-fitting, "endogenous target" version of the model provide some support for stories told previously by Blinder (1982), Hetzel (1998), and Mayer (1998), which attribute the rise in US inflation during the 1960s and 1970s to a systematic tendency for Federal Reserve policy to translate short-run price pressures set off by adverse supply-side shocks—particularly cost-push shocks—into more persistent movements in the inflation rate itself. And, symmetrically, those same estimates confirm Bomfim and Rudebusch (2000) and Orphanides and Wilcox's (2002) suggestion that since 1980, the Federal Reserve has acted "opportunistically" to bring inflation back down in the aftermath of more favorable supply-side disturbances. But while the results bring together these two sets of stories to provide a unified explanation of inflation's long-run rise and fall, they also indicate that considerable uncertainty remains about the true source of movements in the Federal Reserve's inflation target: the best-fitting version of the model, which interprets those movements as part of a deliberate policy response to exogenous supply-side shocks that hit the economy, turns out to be statistically indistinguishable from the alternative, "exogenous target" variant that depicts movements in the inflation target as purely random.

Stepping back from these literal interpretations of the two model variants and looking more broadly at the results, some links to other recent contributions to the literature on postwar US monetary history begin to appear. The results from the endogenous target model, for instance, also provide some support for Ireland (1999) and Chappell and McGregor's (2004) interpretation of the data, according to which Kydland and Prescott (1977) and Barro and Gordon's (1983) time-consistency problem accounts for the Federal Reserve's unwillingness to prevent inflation from rising in the face of adverse supply-side shocks as well as its ability to bring inflation back down following more favorable supply-side disturbances. Alternatively, to the extent that the adverse supply shocks that hit the US economy during the 1970s can be blamed for inaccuracies in official estimates of the output gap, the results obtained here can be squared with Orphanides' (2002) account of how mismeasurement of the output gap led Federal Reserve officials to mistakenly adopt an overly accommodative monetary policy throughout that decade, fueling the coincident rise in inflation. Finally, the results from the exogenous target model might be reinterpreted in line with Sargent's (1999) hypothesis that Federal Reserve officials actively pushed inflation higher during the 1960s and 1970s in a futile effort to exploit a misperceived Phillips curve trade-off. Clearly, further extensions to and refinements of the empirical New Keynesian model developed here are called for, in an effort to more sharply discriminate between these competing views of the data, to better understand the policy mistakes of the past, and to more reliably guard against similar mistakes in the future.

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Table 1. Maximum Likelihood Estimates and Standard Errors

Parameter	Unconstrained Model with Endogenous Target		Constrained Model with Exogenous Target	
	Estimate	Standard Error	Estimate	Standard Error
γ	0.2553	0.0724	0.2433	0.0682
α	0.0000	$*$	0.0000	$*$
ρ_π	0.9069	0.1605	0.8594	0.1428
ρ_{gy}	0.2347	0.0399	0.2617	0.0416
ρ_a	0.9105	0.0344	0.9097	0.0334
ρ_e	0.0060	0.2661	0.1310	0.2388
ρ_v	0.0546	0.0824	0.0711	0.0830
σ_a	0.0281	0.0084	0.0279	0.0084
σ_e	0.0007	0.0003	0.0015	0.0003
σ_z	0.0134	0.0013	0.0128	0.0013
σ_v	0.0027	0.0003	0.0028	0.0003
σ_π	0.0000	$*$	0.0010	0.0002
δ_e	0.0010	0.0002	0.0000	$**$
δ_z	0.0002	0.0002	0.0000	$**$
	$L^* = 2310.6812$		$L^* = 2309.8728$	

Notes: $*$ indicates that the estimate lies up against the boundary of the parameter space. $**$ indicates that the parameter is constrained to equal zero. L^* denotes the maximized value of the log likelihood function.

Table 2. Forecast Error Variance Decompositions, Constrained Model with Exogenous Inflation Target

Output

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	13.5	3.9	66.7	14.3	1.6
4	5.1	1.5	87.7	5.1	0.6
8	2.3	0.7	94.6	2.2	0.2
12	1.4	0.4	96.7	1.3	0.1
20	0.8	0.2	98.1	0.8	0.1
40	0.4	0.1	99.1	0.4	0.0

Inflation

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	8.2	15.3	26.4	22.2	27.8
4	5.7	9.0	23.0	18.6	43.7
8	4.4	6.9	18.0	14.5	56.2
12	3.7	5.7	14.8	11.9	63.8
20	2.9	4.2	10.9	8.8	73.2
40	1.8	2.6	6.6	5.4	83.7

Interest Rate

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	53.8	5.9	8.5	21.6	10.3
4	67.4	2.4	4.7	8.1	17.4
8	66.8	1.4	2.9	4.8	24.1
12	62.7	1.1	2.2	3.8	30.2
20	53.9	0.8	1.7	2.9	40.7
40	38.1	0.6	1.2	2.0	58.1

Note: Entries decompose the forecast error variance at each horizon into percentages due to each of the model's five shocks.

Table 3. Forecast Error Variance Decompositions, Unconstrained Model with Endogenous Inflation Target

Output

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	13.1	0.2	74.5	12.2	0.0
4	4.7	0.1	91.2	4.0	0.0
8	2.1	0.0	96.1	1.7	0.0
12	1.3	0.0	97.6	1.0	0.0
20	0.7	0.0	98.7	0.6	0.0
40	0.4	0.0	99.4	0.3	0.0

Inflation

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	7.3	47.5	28.0	17.2	0.0
4	5.3	51.4	28.1	15.1	0.0
8	4.1	61.5	22.9	11.6	0.0
12	3.4	68.1	19.1	9.4	0.0
20	2.6	76.0	14.6	6.8	0.0
40	1.5	84.7	9.7	4.1	0.0

Interest Rate

Quarters Ahead	Preference	Cost-Push	Technology	Monetary Policy	Inflation Target
1	49.4	20.6	5.8	24.2	0.0
4	64.6	24.0	2.5	8.8	0.0
8	64.0	29.3	1.6	5.1	0.0
12	59.9	34.7	1.5	4.0	0.0
20	50.9	44.6	1.6	3.0	0.0
40	35.3	60.9	1.8	2.0	0.0

Note: Entries decompose the forecast error variance at each horizon into percentages due to each of the model's five shocks.

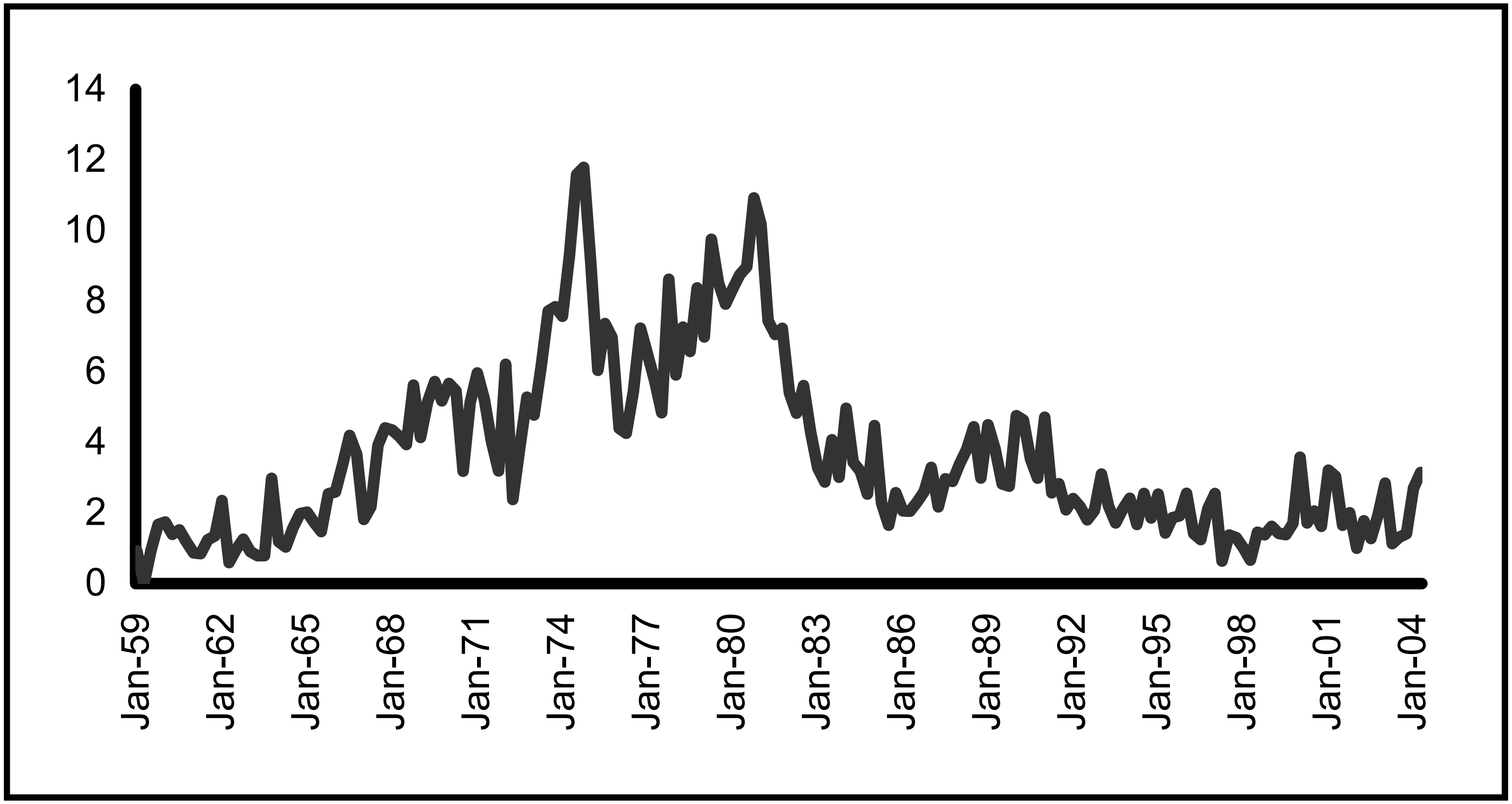

Figure 1. Inflation, United States. Measured by annualized, quarter-to-quarter percentage changes in the GDP implicit price deflator.

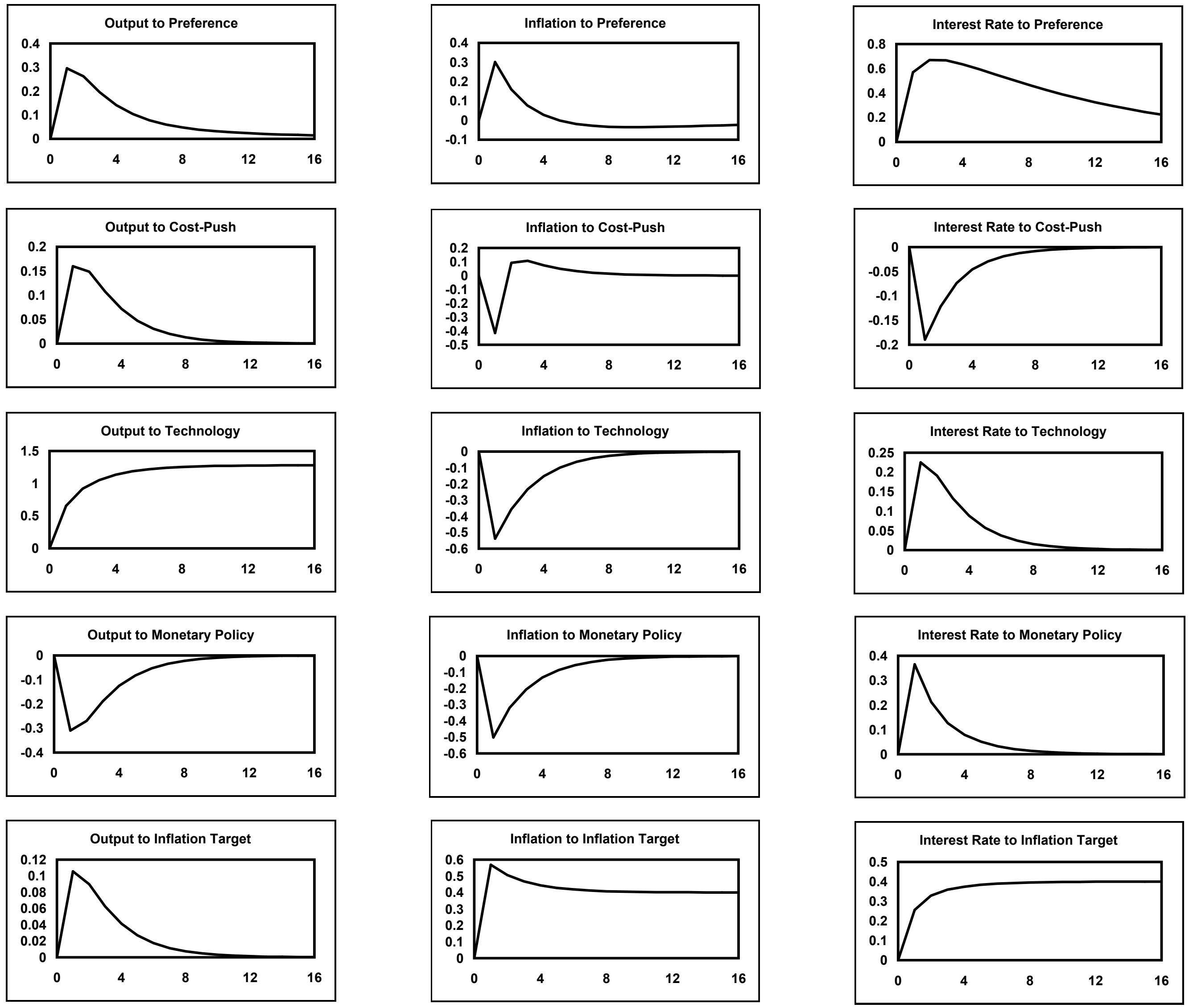

Figure 2. Impulse responses from the constrained/exogenous target model. Each panel shows the percentage-point response of one of the model's variables to a one standard deviation shock. The inflation and interest rates are expressed in annualized terms.

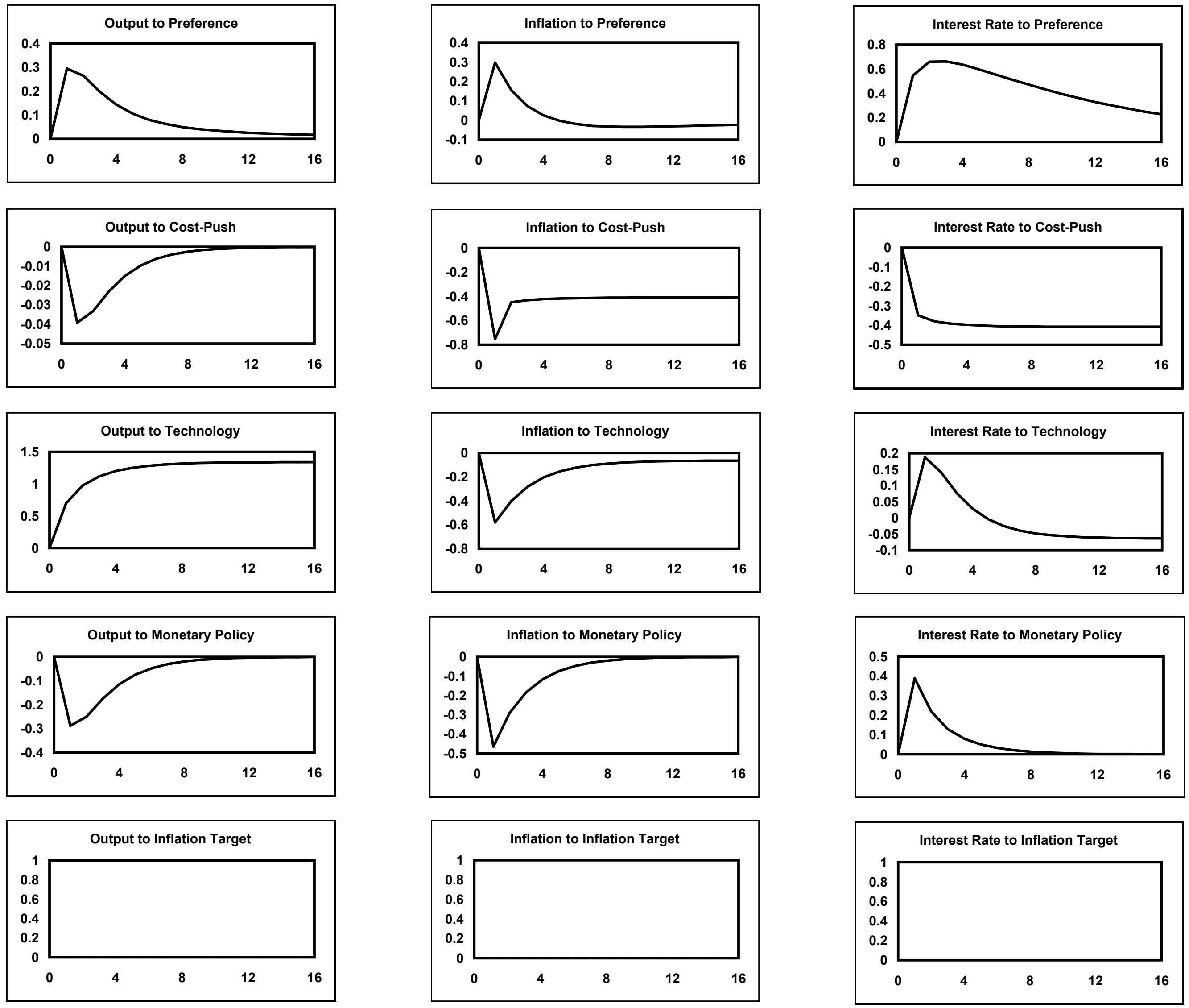

Figure 3. Impulse responses from the unconstrained/endogenous target model. Each panel shows the percentage-point response of one of the model's variables to a one standard deviation shock. The inflation and interest rates are expressed in annualized terms.

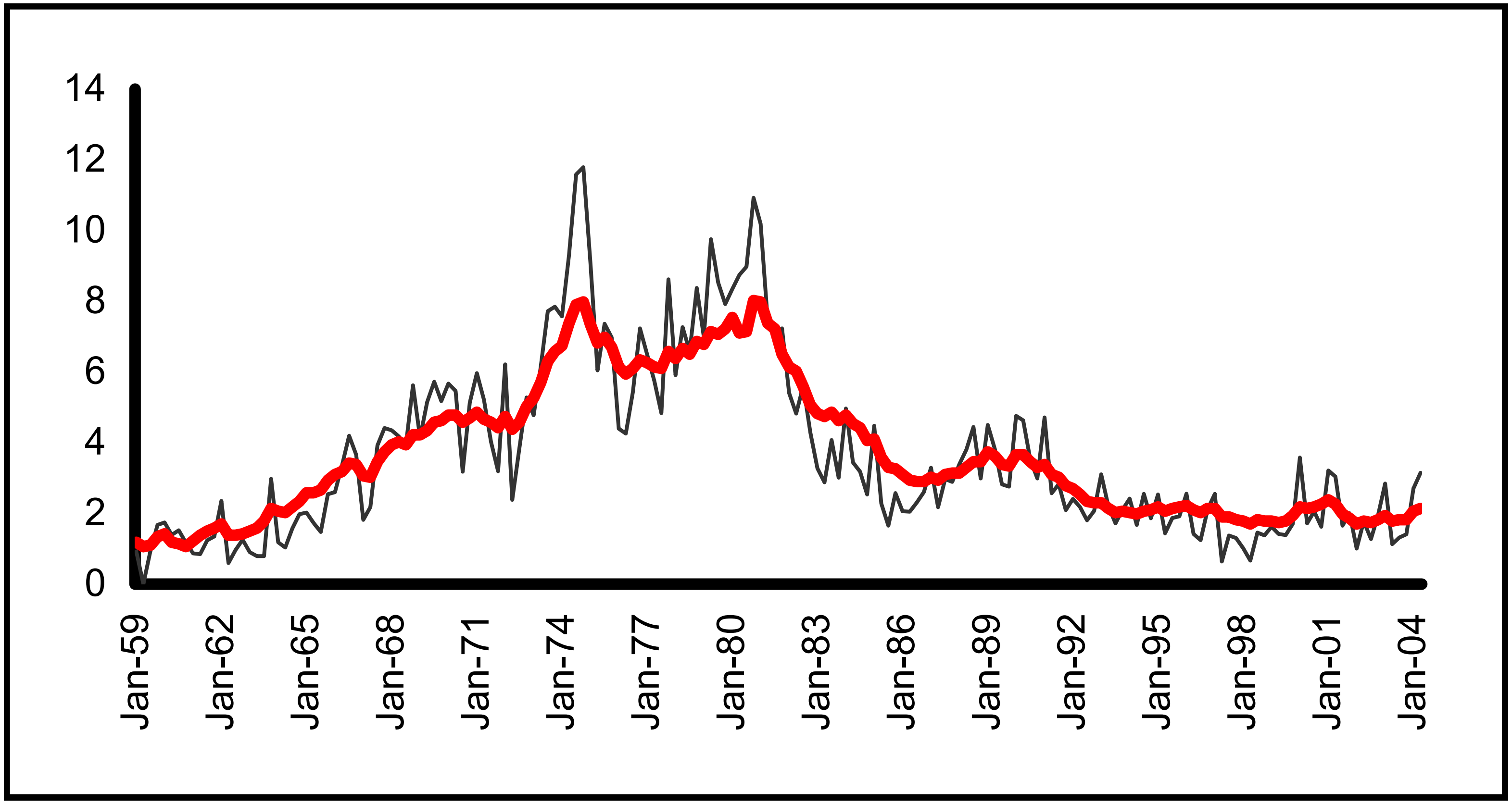

Figure 4. Actual inflation (thin black line) and the Federal Reserve's target (thick red line), as implied by the constrained/exogenous target model.

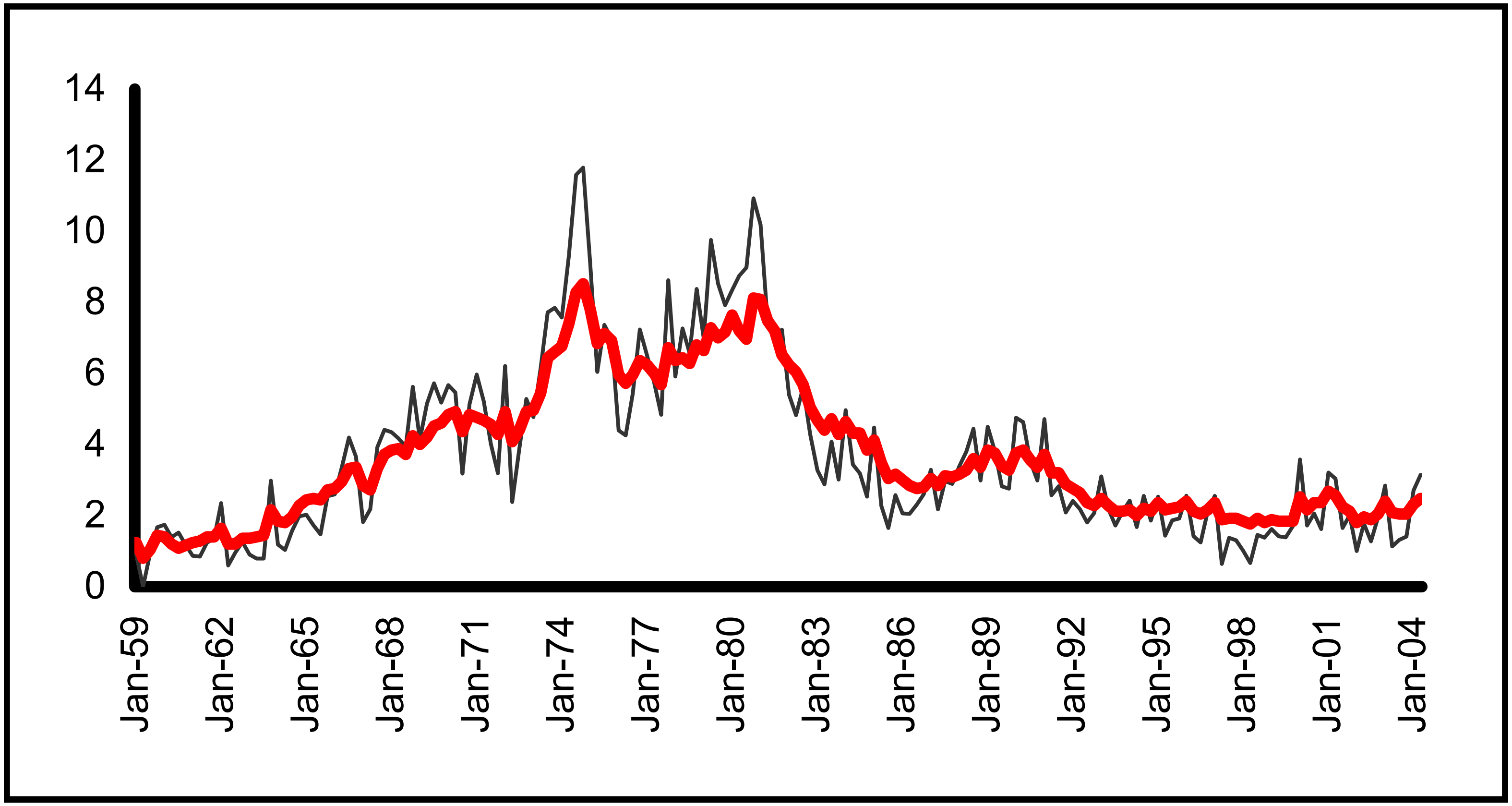

Figure 5. Actual inflation (thin black line) and the Federal Reserve's target (thick red line), as implied by the unconstrained/endogenous target model.

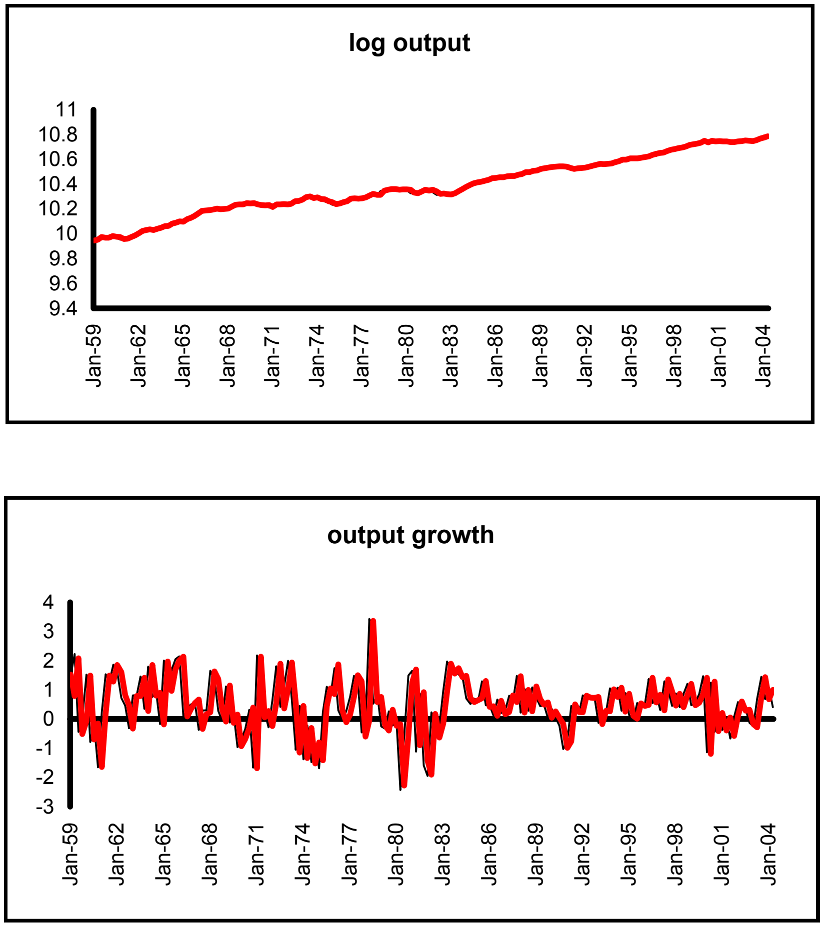

Figure 6. Actual US data (thin black lines) and counterfactual paths (thick red lines) generated under a constant inflation target using the constrained/exogenous target model.

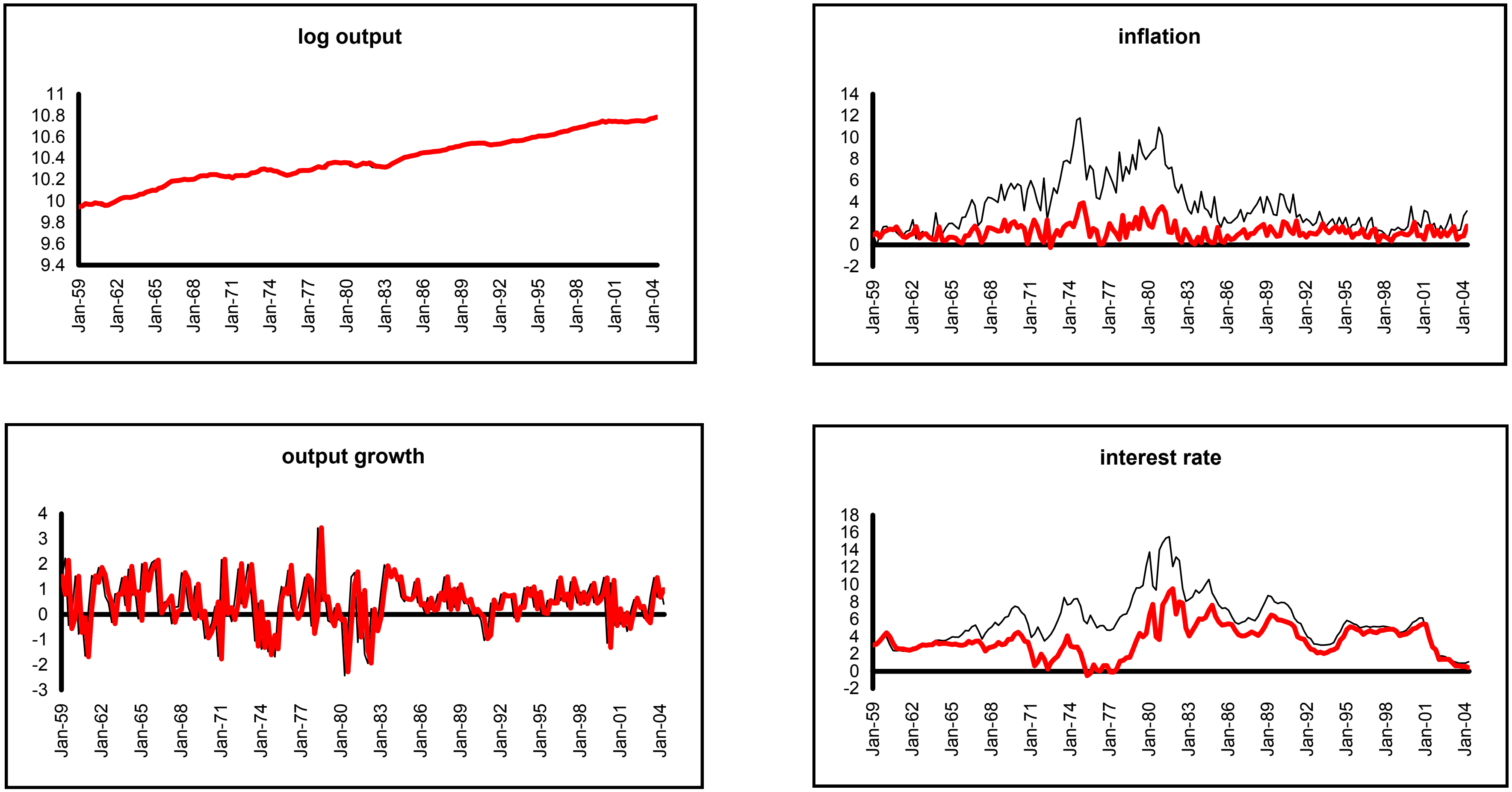

Figure 7. Actual US data (thin black lines) and counterfactual paths (thick red lines) generated under a constant inflation target using the unconstrained/endogenous target model.